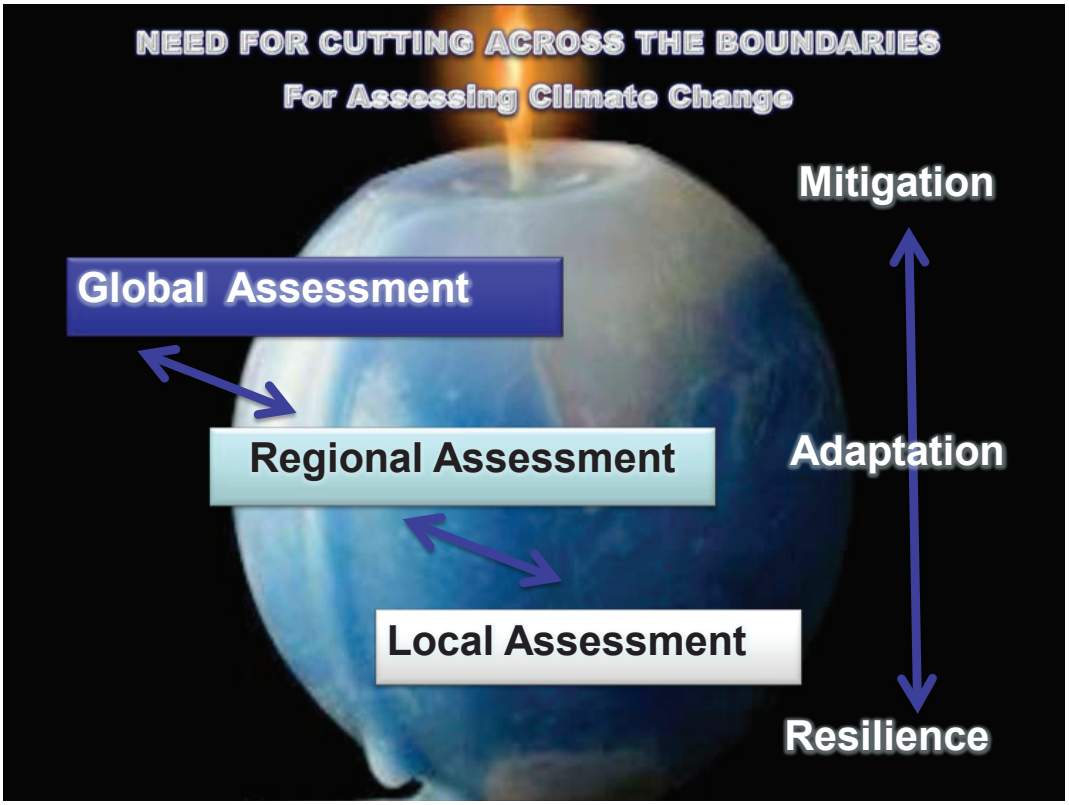
Tenth International Conference on Development of Drylands

Meeting the Challenge of Sustainable Development in Drylands under Changing Climate – Moving from Global to Local

12-15 December 2010, Cairo, Egypt

Proceedings



INTERNATIONAL DRYLAND DEVELOPMENT COMMISSION

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Editors

Adel El-Beltagy and Mohan C. Saxena

International Dryland Development Commission

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Dedicated

To

Professor Iwao Kobori

Former Professor, Department of Geography, Tokyo University; Professor (Mediterranean & European Studies), Mie University; Professor, School of Political Science & Economics, Meiji University; and Senior Program Advisor (Desertification and Dryland Issues), United Nations University (UNU); Expert on Traditional Archaeology & Qanats, UNESCO-Expert on Desertification,

(***1924 -2010***)

A friend and an admirer of the Desert and Dryland Communities, a promoter of their traditional knowledge on water management and a member of the executive of the International Commission on Dryland Agriculture

Tenth International Conference on Development of Drylands
Meeting the Challenge of Sustainable Development in Drylands under Changing Climate – Moving from Global to Local
12-15 December 2010, Cairo, Egypt

The International Dryland Development Commission (IDDC) is an autonomous nongovernmental nonprofit organization established in 1987 by the individuals and institutions interested in and concerned about the sustainable development of dry areas. It is promoting all aspects of dryland studies by fostering cooperation, collaboration and networking between various international, regional and national organizations. One of the important modus operandi of the networking of IDDC has been to hold a major scientific conference every three to four years to provide opportunity to participants from around the world to exchange research results and experiences in dryland development and combating desertification. In pursuance of this objective the IDDC has organized in the past nine international conferences.

The Tenth International Conference on Dryland Development (ICDD) on **"Meeting the Challenge of Sustainable Development in the Dry Lands under Changing Climate – Moving from Global to Local"** was held on 12-15 December 2010 in Cairo, Egypt. It was organized under the auspices of the International Dry Lands Development Commission (IDDC) and sponsored by the Agriculture Research and Development Council of the Ministry of Agriculture and Land Reclamation of Egypt and other national and international organizations.

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- International Fund for Agricultural Development (IFAD)
- International Development Research Center (IDRC-Canada)
- Japanese International Research Center for Agricultural Sciences (JIRCAS)
- Japanese International Cooperation Agency (JICA)
- United Nations University-Institute for Water, Environment and Health (UNU-INWEH)
- World Meteorological Organization (WMO)

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Note from the Editors

Dry areas are home to a large number of highly marginalized people that depend on the limited natural resources of land, water and biodiversity, under a very fragile environment, for their livelihoods. The predictions by the Intergovernmental Panel on Climate Change indicate that the climate change would have serious impact on the agriculture and the natural resources in the dry areas, which would exacerbate the suffering of the dryland communities by adversely affecting their livelihoods. Hence, urgent action is needed to develop effective coping mechanism and risk aversion and management strategies for these vulnerable communities in the dry areas. However, the first prerequisite for successfully developing the adaptation and mitigation strategies is to have a very precise assessment of the impacts of climate change at the local level because the current global and regional assessments mask the local differences. The developing countries with large dry areas have therefore got to undertake precise local assessment of the climate change in different agro-ecological regions. National capacity building and establishing the scientific linkages with regional and international organization dealing with climate sciences are needed as much as the policy and institutional support that would make this possible. The Tenth International Conference on Development of Drylands (ICDD), with the theme "Meeting the Challenge of *Sustainable Development in Drylands under Changing Climate – Moving from Global to Local",* was organized to underpin this need and to start ball rolling for more precise local assessment of the impacts of climate change and identification of strategies for adaptation and mitigation in dry areas.

In the 24 plenary presentations, 51 voluntary oral presentations in the concurrent sessions, and 27 posters, the leading experts and young scientists highlighted the impact of global climate change on the natural resources and communities in the dry areas, methodologies to assess these changes and for scenario building, indicators for assessing changes, and integrated measures to enhance adaptive and mitigation capabilities of the communities in the dry areas to cope with the climate change and achieve sustainable development. In view of the increasing frequency of disastrous events because of climate change, measures to improve risk-bearing capability of the affected communities and development of safety nets was emphasized and case studies were presented. In the Concluding Session of the Conference the key recommendations that emerged from the scientific deliberations during the Conference. These were debated by the participants and a Cairo 10th ICDD Declaration was developed for wide dissemination amongst all the stakeholders.

This volume contains the text of most of the presentations and the Cairo Declaration. It is hoped that it will serve as an important source of information on catalysing the local/regional assessment of impact of climate change and development of adaptive and mitigation strategies in the dry areas for their sustainable development under changing climates.

Adel El-Beltagy
Mohan C. Saxena
Editors

Opening Address

Importance of local assessment of climate change for dryland development

Adel El-Beltagy[1]

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Abstract

Climate change is occurring at the rate faster than anticipated as revealed by the studies done by the Intergovernmental Panel on Climate Change (IPCC). The adverse impact of unfolding changes are nowhere as great as in the dry areas of the world with highly fragile natural resource base and predominately inhabited by poor. With a highly vulnerable system in which the dry area communities live, the sustainability of their livelihood would depend on developing appropriate coping strategies, particularly those related to agriculture. They may require developing new crops and crop cultivars, cropping systems and management practices and integration of cropping with livestock production and fish culture.

A prerequisite for developing the coping strategies is sufficient knowledge to understand the system that is characterized by great spatial and temporal variations. Global assessment of the impact of climate change fails to reveal the actual changes occurring at regional and local levels and how they affect the production system and livelihoods of the people there. Thus, there is a need for more precise local assessment. To enable this, models and methodologies will have to be developed that can help in better understanding the impact under different ecological conditions so that targeted adaptation strategies could be developed. This subject has received great attention in the preparation of the fifth report of IPCC. Developing countries having large dryland populations will have to start preparing themselves now and establish linkages with the international scientific community working on climatology to get appropriate assessment, on which will depend the development of coping mechanisms to enhance the resilience and reduce vulnerability of their people.

Introduction

The world today is facing a complex problem from the unholy alliance of climate change, food crisis, financial crisis and rising population. This presentation will highlight the impact of climate change on sustainable development of drylands by affecting biodiversity and other natural resources, livelihoods of the people and inter-related activities including out migration of people. It will also deal with possible solutions of the problems associated with climate change and briefly present the global efforts underway to put cap on further climate change and develop coping mechanisms for the situation that would prevail in the short and medium term.

The world is facing major a major challenge of deterioration of the health of planet Earth. Over 2000 million hectares of land has already degraded. There is rampant loss of biodiversity, increase in water scarcity, loss of water quality, and increasing pressure of rising population that

is causing destruction of natural resources. The global temperature is rising as has been evident from various IPCC reports, at a rate faster than earlier predicted. Sea level is also going to rise, perhaps by 80 cm by 2100 or even earlier, because melting of ice caps and glaciers. The other key components of the climate change are more extremes of heat, more precipitation in some parts, more severe storms, more frequent and severe floods and more severe and frequent droughts. All these developments are going to adversely impact human health (weather related mortality – infectious diseases, air-quality related respiratory diseases), agriculture (crop yields, water demands for irrigation), forests (composition, geographic range, health and productivity), water resources (supply, quality and composition), coastal areas (erosion of beaches, inundation of lands, livelihoods of coastal communities), and ecotourism and natural areas (loss of habitat and species, diminishing glaciers) as reported by United States Environmental Protection Agency (EPA).

There is compelling evidence that climate change is not just an environmental issue but a serious sustainable development challenge that is going to affect all the countries in the world. Developing countries and the poor will bear disproportionately higher negative impacts. Consequently, climate change may undermine the ability of developing countries to achieve the Millennium Development Goals.

Effects of climate change on agriculture, forestry and ecosystems in different regions

As mentioned before rise in temperature is going to affect food production, water resources, ecosystems, extreme weather events, risk of abrupt and major irreversible changes. The magnitude of adverse effect will depend on the magnitude of global climate change (1 to 5 degree C) as predicted by different climate models under different scenarios. This is illustrated in Figure 1.

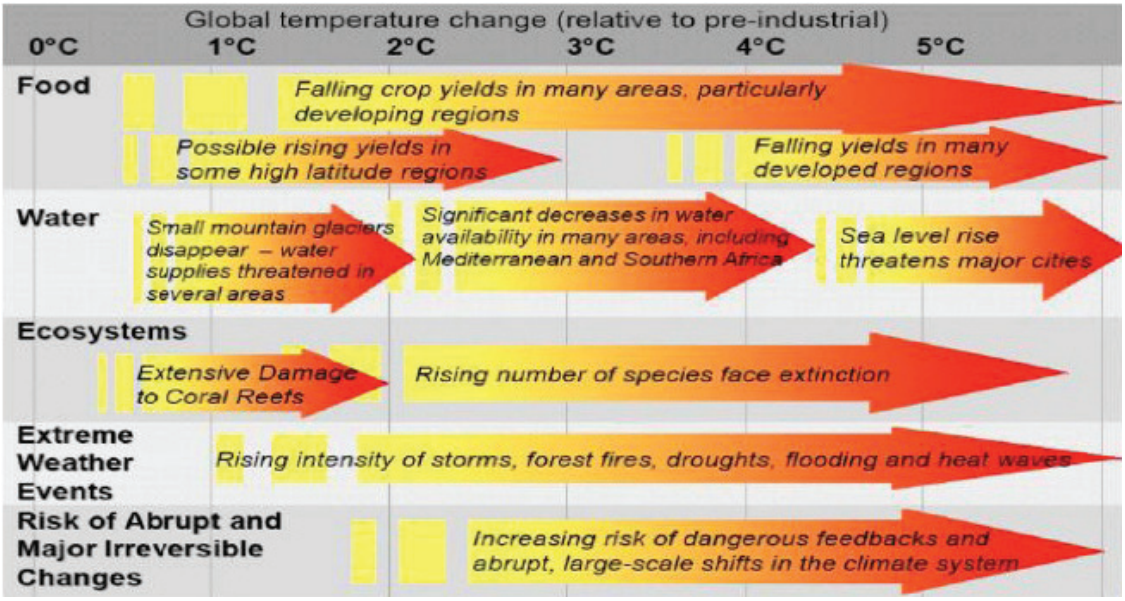

Figure 1. Major impact of climate change (different degrees of rise in global temperature)

According to the World Resources Institute, the output potential of agriculture due to climate change is going to decrease by varying degree in different regions of the world in 2080 as compared to 2000. The change is going to be the largest in Africa (Figure 2), where more than 15% reduction is predicted. Latin America, Middle East and North Africa and Asia will be the

next in order to face reduction. In contrast, the industrialized countries are likely to see a small increase in the production potential.

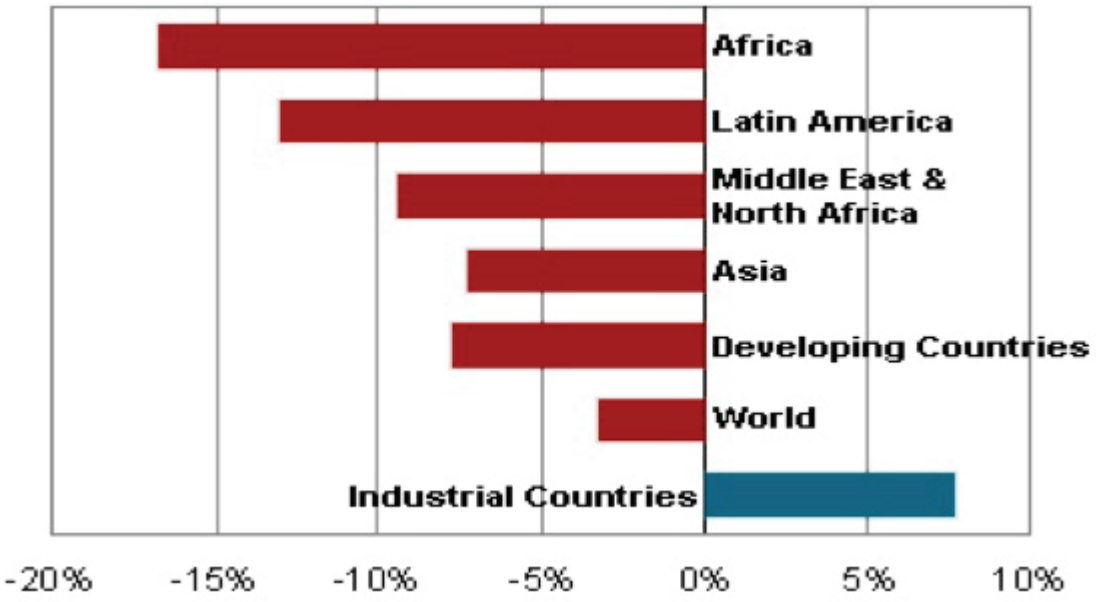

Figure 2. Change in agriculture output potential due to the climate change, 2000-2080.

By 2020, in some countries in Africa, yields in rainfed agriculture might get reduced by 50%. This will severely compromise access to food and accentuate food shortage and malnutrition. In Central, South, East and Southeast Asia, freshwater availability by 2050s in large riverbasins is projected to decrease. In Latin America, by mid century, increases in temperature and associated decrease in soil water are projected to lead to gradual replacement of tropical forest by savanna in Eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation. Productivity of most crops and livestock are projected to decrease with adverse consequences for food security. At the same time, the food production needs will be increasing as there will be additional 3 billion people in the next 30 years in the world.

Climate change and drylands

Drylands are home to over 2 billion people, nearly 35% of the world population. Some 54% of the dryland population lives in rural areas. More than 90% of the dryland inhabitants are found in developing countries. Approximately half of all the poor in the world live in drylands. At the same time, the dryland communities have the highest population growth rate. It is clear therefore that the dry areas will be most disadvantaged by climate change. There will be increased pressure on the natural resources of land, water and biodiversity because of increased population, further accentuated by climate change. The process of desertification would therefore accelerate, with all its negative impacts on natural resources and human welfare. Genetic resources will be lost soil will deteriorate in its physical, chemical and biological attributes, quality of water will deteriorate, salinity effects will increase.

The climate change will also lead to mass migration in the developing world. It is estimated, according to the Stern Report (Stern 2007) that some 150 million people will be displaced. Christian Aid (2007) gives an even higher estimate of nearly one billion people. This should naturally be leading to great socio-political upheavals. Business as usual, will lead to catastrophe.

Hence action would be needed to develop effective coping strategies and put them to operation.

Coping with the challenges of climate change

The challenge can of course be effectively faced through the use of new tools of science and technology and develop adptive and mitigation measures for climate change. Technologies such as remote sensing, GIS/GPS; biotechnology/genetic engineering; genomics and proteomics (gene mining); simulation modelling; information technology/expert systems/advanced artificial intelligence; renewable energy, solar and wind power; new energy saving techniques for water desalination and transport; nanotechnology (biosensors, bio-processing, nano-materials) etc. are going to enhance the human capacity to develop innovative ways for minimizing the risks associated with climate change in-so-far-as the sustainable development is concerned. An integrated approach is needed to use the land, water and human resources through appropriate legislations and political will. For a 'Climate-smart' agriculture in the future, there is a need for developing the human resources that has knowledge base to develop strategies and course of operation to cope with the adverse impacts of climate change. There is a major resilience knowledge gap between the OEDC countries and the developing countries, which will have to be bridged. The technologies will have to be transferred from the OEDC to the developing countries for effective adaptation and mitigation strategies to be implemented. Also support of funds will be needed for making this possible.

There is strong relationship between adaptation to and mitigation of climate change and action will have to be taken on both fronts simultaneously. Any delay will lead to increase in costs (Figure 3).

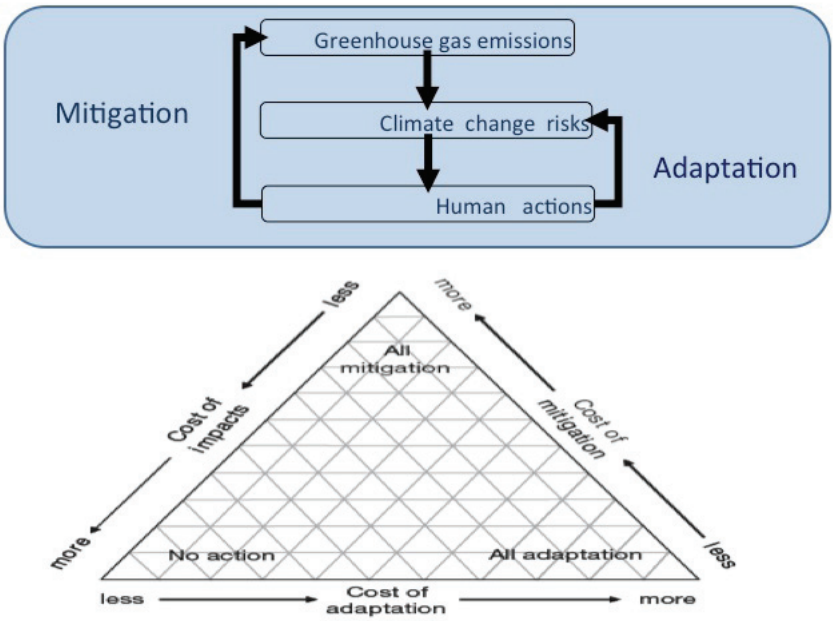

Figure 3. Relationships between adaptation and mitigation actions to meet the threat of climate change.

As mentioned before, agriculture will be severely affected by climate change. Adapting to climate change would need increased investment in agricultural science and technology with emphasis on crop breeding including biotechnology that targets abiotic and biotic stresses and provides biological resilience. Increased investments in water storage and management would be needed.

There will be need for improving rural infrastructure both in terms of physical facilities (roads, market buildings and storage facilities) as well as institutional support (extension programs, credit and input markets, and reduced barriers to trade). And finally policy improvements will be needed to internalize externalities associated with environmental services (e.g. innovative approaches to property rights). Knowledge base for adaptation has to increase for developing new genetic makeup (cultivars with tolerance to heat and drought as well as to new biotic stresses associated with climate change) and for new agro-management techniques (irrigation, fertility management, etc.). This will require massive human resource development and capacity building efforts.

While agriculture is affected by climate change, it is also a contributor to the change through emission of greenhouse gases. However, the contribution is rather small as compared to other anthropogenic factors, being only around 14% of all emissions. Climate-smart agriculture could indeed be a solution to the problem of climate change.

International efforts to assess impact and develop strategies for adaptation and mitigation

The Intergovernmental Panel on Climate Change (IPCC), under the auspices of WMO and UNEP, has so far produced four assessment reports (1990, 1995, 2001 and 2007). The fifth report (AR5) is expected to be out in 2014. The Panel operates through three working groups (WGs). WG I assesses the physical scientific aspects of climate systems and climate change. WG II assesses the vulnerability of socioeconomic and natural systems to climate change, negative and positive consequences of climate change and options for adapting. WG III assesses options for mitigating climate change through limiting or preventiong greenhouse gas emissions and enhancing activities that remove them. Many of the predictions made by IPCC reports have proved correct and several have come well before the time predicted.

The Conference of Parties (COP) started in 1995, with COP 1 in Germany resulting in Berlin Mandate dealing with agreements on capping the emissions of green house gases. COP 3 in 1997 in Japan came out with Kyoto Protocol on climate change, which has been ratified by most of the countries, USA being the most conspicuous exception. It recommended targets for cutting greenhouse gas emissions for Annex 1 and Non Annex 1 countries with high (12.8 to 67.8 t CO_2 eq. per person emission), medium (5.0 to 12.8 t CO_2 eq. per person emission) and low (0 to 5.0 t CO_2 eq. per person) emissions. Since then 12 more COPs have been held, the 16th being this year in Cancun, Mexico.

Unfortunately, agriculture did not figure in the deliberations of any of these COPs. The Dutch Government therefore took the initiative of organizing a Global Conference on Agriculture, Food Security, and Climate Change in The Hague, 30 October to 6 November 2010. Some 120 countries participated. The focus was on positioning agriculture in a positive way in the context of climate change. The Conference deliberated on understanding the challenges and solutions. With respect to the challenges, it concluded that (a) Growth in agriculture sector remains fundamental for poverty alleviation, economic growth and environmental sustainability; (b) Agriculture, forestry and fisheries are under threat from climate change; and (c) The challenge of producing more in a changing climate, while reducing greenhouse gas emission overall is immense. Regarding the solutions, the Conference concluded that (a) The multiple challenges the world is facing in terms of climate change, degradation of ecosystems, food insecurity, etc. require an integrated approach; (b) Food security requires agricultural production systems to change in the direction

of higher productivity and production; (c) Agriculture and water are closely linked. Worldwide, agriculture consumes 70% of all freshwater withdrawals. Adaptation efforts must therefore begin now; (d) The agriculture sector has the capacity to offer sound solutions to cope with this challenge; (e) Farmers, particularly women, youth and small holder farmers and indigenous people have an important role in transition to climate-smart agriculture; (f) farmers feed the world, yet far too many of them are living in hunger and hardship. This injustice must cease; (g) There needs to be a particular focus on those who are the most vulnerable to impacts of climate change, particularly those who live in dryland and low-lying coastal areas; (h) Agriculture has risen to the top of national and international policy agendas. The Conference concluded that a roadmap for action on agriculture, food security and climate change is urgently needed.

The above conclusions from the Global Conference on Agriculture, Food Security, and Climate Change were presented in the COP16 in Cancun by the Dutch delegation. The issues in reference to the negotiations in COP 16 were mitigation, adaptation (finance), technology transfer and access to funds and REDD (United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries). The targets were: (a) Keep global temperature rise below 2° C; (b) Annex 1 (developed) countries should cut year 2020 GHG emissions 25-40% or more beneath the 1990 level; (c) Fast-growing economies should also reduce emissions by 2020; and (d) Low-income developing countries should limit emission growth.

The major elements of the Cancun agreements include:

1. Industrialized country targets are officially recognized under the multilateral process and these countries are to develop low-carbon development plans and strategies and assess how best to meet them, including through market mechanisms, and report their inventories annually.
2. Developing country actions to reduce emissions are officially recognized under the multilateral process. A registry is to be set up to record and match developing country mitigation actions to finance and technology support from industrialized countries. Developing countries are to publish progress reports every two years.
3. Parties meeting under Kyoto Protocol agree to continue negotiations with the ainm of completing their work and ensuring there is no gap between the first and second commitment periods in the treaty.
4. The Kyoto Protocol's Clean Development Mechanism (CDM) has been strengthened to drive more major investments and technology into environmentally sound and sustainable emission reduction projects in the developing world.
5. Parties launched a set of initiatives and institutions to protect the vulnerable from climate change and to deploy the money and technology that developing countries need to plan and build their own sustainable futures.
6. A total of $30 billion in fast start finance from industrialized countries to support climate action in the developing world up to 2012 and the intention to raise $ 100 billion in the long-term funds by 2020 is included in the decision.
7. In the field of the climate finance, a process to design a Green Climate Fund under the COP, with a Board with equal representation from developed and developing countries is established.
8. A new Cancun Adaptation Framework is established to allow better planning and implementation of adaptation projects in developing countries through increased financial and technical support, including a clear process for continuing work on loss and damage.
9. Governments agree to boost action to curb emissions from deforestation and forest degradation

in developing countries with technological and financial support.

10. Parties have established a technology mechanism with a Technology Executive Committee and Climate Technology Center and Network to increase technology cooperation to support action on adaptation and mitigation.

The next Conference of Parties (COP 17) is scheduled to take place in South Africa, from 28 November to 9 December 2011.

Need for local assessment of impact of climate change

The consensus emerging from various international deliberations on climate change is that the cost of doing nothing will be enormous and action will have to start now, both on adaptation and mitigation. Coping mechanisms will have to be developed that are easy to implement for adapting to the changes that are already occurring. This will however be possible only when we have clear understanding of the impacts at local level rather than more vague regional or global levels. Global classification masks the regional differences, regional assessment masks the sub-regional differences and national classification masks the different agro-ecologies. Hence there is a need to navigate across scales (Figure 4).

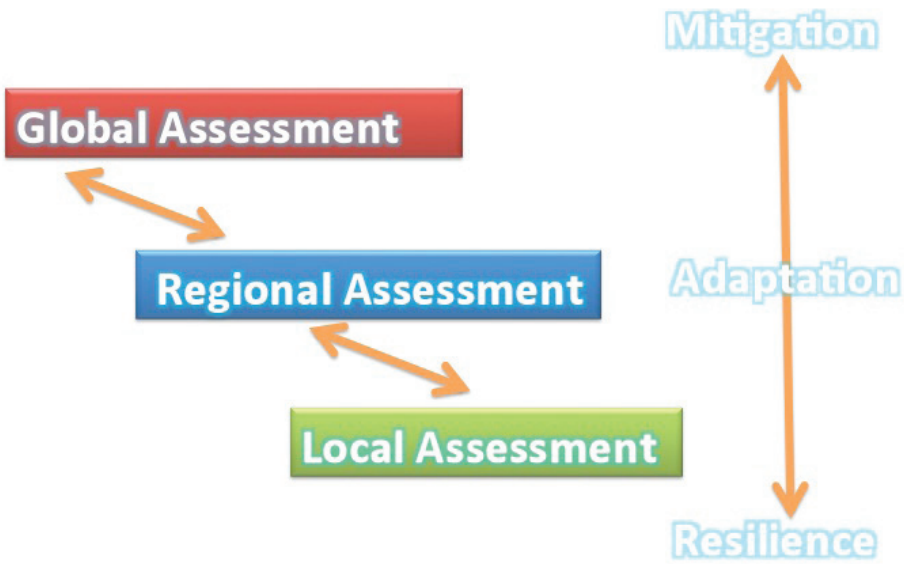

Figure 4. Regional and local informationis needed for adaptation studies

The 'Nested' Regional Climate Modelling strategy provides way forward. As the resolution of GCMs is still too coarse to capture regional and local climate processes and it simulates the response of the general circulation to large scale forcing, a 'Regional Climate Model' (RCM) is 'nested' within a GCM in order to locally increase the model resolution. The RCM simulates the effect of sub-GCM-grid scale forcing and provides fine scale regional information. Refinement of methodology in a similar style for local assessment will be needed. Efforts have already started and the state of California has taken lead. The GIS laboratory of ICARDA has innovated in this regard (Delobel et al. 2010). The national programs will need training and technology transfer to enable them to attempt precise local assessment. The WMO has been providing support to assist

the national organization to take steps for local and regional impact assessment. The agreements reached in Cancun will also facilitate this.

A precise local assessment will permit development of national strategies for adaptation to climate change. Adaptation depends upon the cooperation between different ministries and organizations – the ministry of environment, ministry of finance and planning as well as specialized agencies like geological and meteorological services and institutions for disaster prevention. Broad stakeholder involvement is a key to success. A national strategy can help to: (a) Provide a framework for coordinating adaptation activities; (b) Create a vision for mid-to long-term perspective for adaptation; (c) enable informed decision making based on information about vulnerabilities, impacts and adaptation options; (d) Raise awareness in all sectors affected; (e) Mobilize support in the country as well as from the international community; and (f) Prepare the ground for appropriate institutional structures for adaptation.

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Plenary Session Presentations

Plenary Session 1

1.1. Adaptation to the natural and social impacts of regional climate change - Declaration of the second special session of the Forum on Science and Technology in Society, Kyoto, October 2, 2009

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Extended Abstract

In October 2009, the Forum on Science and Technology in Society convened its first special session on adaptation for regional climate change. Its declaration reproduced below formed the topic of this presentation.

*Declaration of the Special Adjunct Session of the 2009 Science and Technology in Society Forum "**Developing a Framework for Regional Climate Change Impact Assessments and Local Action**", Kyoto, October 3, 2009*

- Climate change, already here, will increase in coming decades. Greenhouse gas emissions are running ahead of the worst-case scenario of IPCC, so that temperature will increase more rapidly than expected. Aerosols, because they reflect sunlight back to space, have offset the temperature increase expected from the greenhouse gas accumulation to date; as we reduce air pollution for health and environment reasons, we will see an unavoidable increase of perhaps 2 degrees C, regardless of what we do to reduce future emissions.
- Mitigation aims to cut off global warming at its source by reducing emissions of greenhouse gases, primarily carbon dioxide. Mitigation now seems harder than we once thought. Not only are there serious political and economic difficulties, but it will take decades to deploy new energy technologies on a global scale.
- In these circumstances, NAS President R. Cicerone proposes that our strategy must be to "avoid the unmanageable, and manage the unavoidable". As we continue our vital efforts on mitigation, we will have to adapt to the changes we cannot prevent.
- Assessment of the impacts of present and future climate change is the first step to adaptation. Assessment for adaptation differs from assessment for mitigation in one important aspect: key adaptation decisions will be needed from very many local leaders, rather than from the relatively smaller number of international leaders dealing with mitigation policy.
- This fact defines the basic question before this special session of world leaders in science and technology. How should the tools and institutions deployed to assess global climate change be adapted to the needs of local decision-makers in hundreds of regions around the world? What new social, institutional, technical, and financial innovations are needed?
- Regional climate change impact assessments bridge the global and local, and can enlist local decision-makers in direct and culturally appropriate ways. Regional assessments help local leaders see what the future holds for the things their populations care about, understand the decisions they will need to make, and support their public communication. In addition, local knowledge and monitoring are required to identify the uncertainties and critical triggers of the climate system and anticipate the impacts.
- Each region has a unique combination of interacting environmental, economic, and social

factors, and its own ways of reaching decisions. Local participation is essential, as is communicating in terms local people understand. To earn the trust of local populations, each region should design and carry out its own assessments, with international support but not direction.

- Climate change is only one of the problems local leaders face. It often appears less pressing than ongoing environmental degradation and resource depletion, or the need for social and economic development. Even so, the universality of the climate problem has called forth a global community of researchers and practitioners whose social techniques and technical tools can help local leaders deal with the great problems of environment and development with which climate change is intertwined.
- Adaptation requires a systems approach that links the physical and biological aspects of climate change to social response. It cannot be managed top-down. Integrated solutions should be sought through linked innovation in science, technology, policy, politics, institutions, and finance. It will have to be a distributed effort that is guided but not directed.
- Knowledge Action Networks that focus on specific regions and impacts can link the global science, technology, and policy communities to local initiatives. These are sponsored social networks connecting the generators of pertinent knowledge with local decision makers. Modern information techniques can ensure good communication within and between the global, regional, and local levels.
- Every region has knowledge leaders who can forge relationships with local decision-makers, but often there aren't enough of them. The critical mass sufficient to characterize the multiple impacts of climate change and communicate them to decision makers is often lacking. Capacity building is therefore a critical issue. Moreover, even where there is adequate human capacity, regional science and policy communities often lack access to information and tools because of bureaucratic obstacles and government security concerns. In these cases, independent organizations that provide trustworthy information are needed. Here as elsewhere, there is room for non-governmental initiatives.
- Regional assessments and adjustments in action plans will be needed throughout this century. Each region will have to monitor, model, assess, and decide, again and again. This need will spark continuous improvement of observations, models, and information systems in order to dissect and forecast the ongoing interacting changes.
- We believe that global climate change assessments should be supplemented by a mosaic of regional assessments of the impacts of climate change on natural and human systems.
- We should not expect that the globe can be sub-divided neatly into non-overlapping regions with sharp boundaries nor the regions to define the same geographical area for the different assessments they need. Each physical, biological, and human system has a natural spatial configuration that must be respected: the boundaries of assessment regions will be adapted to the problem. We should think, therefore, of forming a complex, hierarchical network of loosely connected, self-assembled regional assessments.
- We need a new institutional framework for regional assessments and the knowledge action networks that will carry them out. An international fund is needed to encourage the assembly and support of these networks. The international science, technology, and policy community should help with capacity building and technology transfer; standards and certification; and provision of data, models and observations.
- We suggest starting with water, because of its dominant role in human consumption, food security, health, and natural disasters. The capacity to model and monitor exists, and can be translated relatively easily. Moreover, every region and locality manages water, so there are working decision makers with whom scientists can interact.
- Understanding how different regions deal with science-based decision making for water may provide insight into how the even more complex problems of ecology, health, and human development can be addressed.

1.2. Pursuing triple wins within the context of climate change

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Abstract

Widespread and increasing hunger and poverty, increasing demand for food due to population growth and dietary changes and unsustainable management of natural resources, along with climate change and the threat of increasing food price volatility, call for renewed policy action by national governments and international institutions to achieve the goal of sustainable food security for all. As the world population continues to grow, water becomes scarcer, soil erosion accelerates and the negative consequences of climate change become more visible, doomsday prophecies have once again found fertile grounds. Can the triple wins of reduced hunger and poverty, expanded food supplies and sustainable management of natural resources be achieved or will obligatory trade-offs among them make it necessary to prioritize among them? That is the focus of this paper. Following a brief description of the current situation and expected trends, the presentation suggests a set of policies to be pursued in attempts to achieve the triple wins which can be successful but only with enlightened policies and accelerated application of science. This will require real changes in national and international priorities and not just another set of summits and development goals not pursued. The biggest risk to the future food and natural resource system is not lack of the earth's productive capacity, but complacency and inappropriate priorities among policy makers.

Introduction

Sustainable management of natural resources is essential to make food systems sustainable. Unfortunately, natural resources are not currently managed sustainably at the global level. Widespread soil erosion and nutrient mining; waterlogging and salinization; deforestation; contamination of surface and ground waters; overuse of water; and rapid increases in greenhouse gas emissions by the food system are illustrations of unsustainable use of natural resources. Drylands ecologies are particularly sensitive to both unsustainable production methods and climate change.

In this paper we suggest that environmental externalities associated with agricultural production –whether positive or negative – should be internalized in production costs and passed on to the consumers – something we call full costing – to assure that the current and future food demand can be met without damaging productive capacity. This will require location-specific government incentives and regulations as well as local, national and international collective action that assure full costing of environmental damage, payment for environment services (PES) and allows for natural resources to be replaced with human-made capital. Based on available evidence, we conclude that the triple goal of producing enough food for current and future generations, reducing poverty and hunger, and maintaining the productive capacity of natural resources sustainably can be pursued simultaneously through multiple-win synergies.

The food system

The agricultural system envisioned in this paper is a dynamic, behavioral system where farmers in the system engage in agricultural production in order to accomplish specific goals subject to existing constraints. These goals include providing incomes, food security, and adequate nutrition for themselves and others, producing ecological services, and maintaining sustainability in the management of the stock of productive resources. Policy-makers may have additional goals, related to ensuring farmers a minimum level of income, maintenance of a minimum number of farmers, rent seeking and the generation of the foreign currency through international trade (Bontems 2008). It is generally not possible to accomplish all of these multifaceted goals with only one policy instrument, and it is important that the pursuit of one goal does not negate the pursuit of other goals. In addition to the standard budget, time, and regulatory constraints, farmers also face environmental constraints, uncertainty and risk, cultural constraints, market and government failures, and imperfect information.

Each of these goals and constraints are interactive, creating numerous feedback loops which can mitigate, redirect, or amplify actions in ways that would be unpredictable without taking a systems approach. The need to survive in the short term can rationally override concern for the long term perspective, which can lead smallholder farmers to sell off needed physical capital or use natural resources in an unsustainable manner. Policies to prevent any degradation of the natural resource base will prove ineffective if they do not take these behavioral matters into account. If food and agricultural scientists continue to work primarily on ways to increase food production without considering environmental constraints, and if environmental scientists continue to primarily focus on ways to mitigate the damage agriculture can do to natural resources without considering the effects on hunger, poverty, and nutrition, the end result can only be professional conflict, fractured and incoherent policy-making, and suboptimal outcomes.

Differences in the definition of sustainable development have important implications for understanding and working within the tradeoffs and multiple-wins these feedback effects create. FAO (1989) is one example of the many publications which define sustainable agriculture by requiring that satisfying human needs today must "maintain or enhance" natural resources and environmental quality. This definition does not permit any exchange of natural capital for physical or human capital, an exchange implicit in any accounting framework that seeks to incorporate changes to natural capital on balance sheets. The Brundtland Commission (UN 1987) report, on the other hand, states that development is sustainable if human needs today are satisfied "without compromising the ability of future generations to meet their own needs." This allows for tradeoffs between natural and human-made resources.

Agriculture consumes and produces ecosystem services. Soil nutrients, water, land, clean air, and forest and fishery products are all essential ingredients for the agricultural system and the livelihoods of millions of agriculturalists. In exchange for these ingredients, the agricultural system provides food, fiber, fuel, medicines, cultural heritage, income for farmers, and foreign exchange. In addition to these services, the system can reduce air and water pollution as well as the damage from natural disasters, protect biodiversity, sequester carbon, and provide sustainable alternatives to fossil fuels.

Agricultural intensification – i.e., the achievement of larger production of food per unit of land, water and labor – is essential to meet future food demands. Contrary to what is argued by some, agricultural intensification does not necessarily imply a deterioration of environmental quality. Instead, it is the mismanagement of inputs, such as inappropriate water use, overgrazing, and

excessive, insufficient, or untimely applications of fertilizer and pesticides, which cause damage to the environment.

Among the environmental successes of the Green Revolution is that the increasing productivity that high-yielding varieties and intensification brought enabled farmers to produce more on less land. Goklany (1998) estimates that an increase of 80 % in the area of land under cultivation would have been needed between 1961 and 1993 to meet food demand without these productivity increases. Much of that land would be forested and poorly suited for agriculture. The resulting deforestation and soil degradation would imply severe environmental and humanitarian consequences. Negative environmental effects caused by poor water management and excessive and inappropriate use of pesticides and fertilizers could have been avoided if social costs had been incorporated into private costs. Price subsidies for pesticides and free and open access to water led to productivity increases at the expense of natural resources. Open access to grazing areas has caused severe soil degradation in many locations.

Two of the more important solutions to these problems may be found in the "Polluter Pays" (PP) and "Payment for Environmental Services" (PES) principles. PP is an attempt to capture negative externalities into the decision making process of the polluter. The aim is to bring private costs in line with social costs to seek environmentally sustainable solution through market forces. PES attempts to incorporate the social value of positive externalities created by the food system into private incentives by paying farmers and other food system agents for such ecosystem services as the preservation of biodiversity, assurance of water quality, maintenance of landscape beauty, and sequestering carbon.

The PP and PES may be perceived as part of the same continuum, one being a penalty, the other compensation. Thus, they can be combined within the same policy approach, as long as appropriate threshold levels are set to determine whether the penalty (PP) or the payment (PES) is the proper instrument (Dellink and Ruijs 2008). In either regime, the compensation or punishment should be at least as large as the opportunity cost, but not larger than the social benefit or cost. PP and PES may be viewed as part of the broader concept we have called full costing. Full costing also includes removing inefficient subsidies that encourage overuse of scarce natural resources.

Environmental Kuznets curve and an alternative hypothesis

The relationship between economic growth and certain types of environmental degradation, such as air pollution, has been shown to be represented by an inverted-U – the so-called Environmental Kuznets Curve (EKC) (Grossman and Krueger 1995). This implies that in the early stages of economic development, increasing incomes leads to increasing degradation, a situation exemplified by the last 30 years of economic development in China. Beyond the tipping point, technological progress, fulfillment of basic needs, and changing attitudes in societies towards greater concerns for the environment may lead to a negative correlation between degradation and income growth, i.e., reducing the environmental harm associated with further economic growth (Figure 1).

Grossman and Krueger (1995) suggest that this relationship is not an automatic or natural process, but a policy response based on induced innovation: At low levels of income, governments and citizens prioritize income growth over the protection of natural resources. This is explained by relative high internal rates of discount or time preference among poor people and governments of poor countries. Developments in China since the beginning of the 1980s illustrate this point.

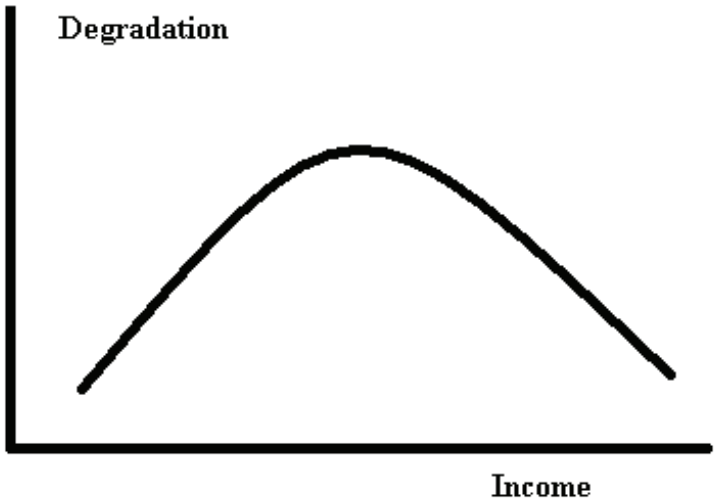

Figure 1. The Environmental Kuznets Curve.

Economic growth was prioritized over sustainable management of natural resources. As incomes increase above a certain level, citizens demand more environmentally friendly policies and products, which in turn prompt technological innovations that use natural resources more efficiently and sustainably. Increasing returns to pollution abatement technologies or large fixed costs to their adoption may contribute to the inverted-U shaped relationship (Andreoni and Levinson 2001).

A review of the empirical literature on the EKC (Webber and Allen 2004) concludes that the shape of the relationship between degradation and income per capita differs among types of degradation. Thus, the relationship needs to be estimated for each type of degradation. The inverted-U relationship cannot be expected to hold for all degradation. This paper will focus on soil degradation, an important aspect of the sustainability of drylands agricultural systems. We are particularly interested in this relationship for the low-income portion of the population of developing countries to help us understand how poverty can be alleviated while improving natural resource management and expanding food production. In other words, are there unavoidable tradeoffs among these three goals or are multiple-wins possible? Do poor people and governments have to choose between reduced poverty and sustainable natural resource management as implied by the EKC? Must increased food production necessarily imply damage to natural resources? In this paper we argue that multiple-win policies are possible and that these can generate broad popular support.

The existing empirical evidence supporting the EKC is not very helpful in answering these questions because of its focus on different environmental issues, such as air pollution that is not likely to be produced by the extremely poor. Furthermore, the EKC literature is based on national average incomes that may fail to take account of the income-degradation relationship among the poorest within those societies who are often marginalized from the full range of markets, social protections, and opportunities to generate human capital and invest in physical capital.
Poor people are more likely to face negative income shocks that threaten their survival. Assuring survival now obviously takes priority over opportunities for future consumption. Since most of the world's poor live in rural areas and depend heavily on natural resources, this implies unsustainable management of the natural resources available to them. Thus, poverty may be

an important cause of natural resource degradation and reduced poverty would reduce such degradation (Nkonya et al. 2008). We illustrate this relationship in Stage 1 of Figure 2, which we believe is ignored in the EKC as it is found in the literature.

About half of the world's poor live in marginal rural areas with poor soils, irregular rainfall and poor infrastructure. Soil degradation in the form of soil mining, i.e., the removal of more plant nutrients from the soil than what is added, is widespread in these areas and we hypothesize that the relationship between soil mining and farmer income or food production may be described as having a sideways-S relationship with income, such as that depicted in Figure 2. In Stage 1, the combination of poverty, increasing population pressures, lack of appropriate technologies, and negative shocks (e.g., drought, illness) leave poor people with few options for survival that do not involve the degrading of their natural resource base (Pinstrup-Andersen and Watson Forthcoming).

This is the context for the conclusion by Pinstrup-Andersen and Pandya-Lorch (1994) that absolute poverty is an important cause of environmental degradation. To survive, the rural poor may have no other option than to cut down trees and mine the soil even when they are fully aware of the long-term consequences. Alternatively, when poor people are given opportunities to reduce poverty, such as access to fertilizers and improved production practices, they are likely to move away from the most unsustainable practices, i.e., they move down the graph in the first stage of this modified EKC. Access to fertilizers or improved production practices, such as crop rotation and mulching, lessen or reverse soil mining, increase food production and reduce poverty, a triple win.

On the basis of a review of past studies and an in-depth study in Uganda, Nkonya et al. (2008, p. x) conclude that "agricultural modernization in Africa can achieve win-win-win outcomes, simultaneously increasing productivity, reducing poverty, and reducing land degradation." This provides empirical evidence of the relationship shown in Stage 1 of Figure 2.

As is typical in the EKC literature, as farmers become better off and get access to markets and chemical inputs, they may engage in practices that result in increasing degradation of natural resources, unless they have to pay the costs of such degradation. That explains the top graph of the second stage of the graph. As incomes continue to increase, forces mentioned above in the standard EKC literature increase the emphasis on sustainable resource management, thus resulting in Stage 3.

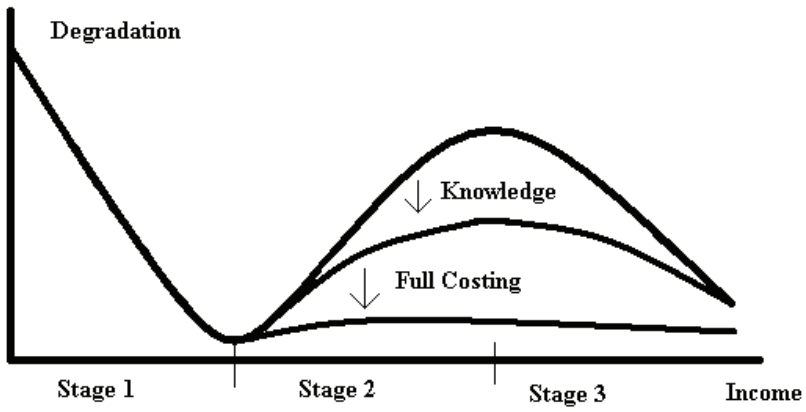

Figure 2. Hypothetical relationships between farmer income and soil degradation.

The shapes of the EKC for the water and air pollutants that have been studied change over time.

Lomborg (2001) shows that the peak level of environmental degradation occurring in developing country metropolitan areas is significantly lower than the past peak in developed countries' metropolitan areas (as in the middle line of Figure 2). This may be because of the increased availability of environmentally friendly technology and international public goods, increased political pressure from the international community, or a decrease in the costs of environmental projects. As an illustration, the reduced demand for expansions of the agricultural land resulting from the Green Revolution meant less pressure on forests and low-quality land. These changes, labeled "Knowledge" in Figure 2, represent improvements in the tradeoff between growth and the environment.

However, until social and private costs are aligned, degradation will continue. Full costing, which would include the removal of subsidies leading to excessive use of water and other inputs, would further reduce the environmental costs of economic growth: farmers would not overuse fertilizers, pesticides, or water; deforestation would slow or reverse as farmers would be penalized; consumers of wood products pay the full costs of environmental damage; and others receive payments for increasing forestation. However, full costing, even if it were politically feasible, would not prove to be sufficient to fully eliminate degradation because of the difficulty of implementation (see concluding section), and failure to avoid free-riding. The lowest line in Figure 2 illustrates such a scenario.

The degradation of resources in Stage 1 can cause a poverty trap. As the natural resources to which they have access is degraded, future incomes of the poor are likely to be lower and more susceptible to future negative shocks. As their environment becomes ever more degraded, they move up and to the left in Stage 1 of Figure 2 and their opportunities to lift themselves out of poverty continue to diminish. Are tradeoffs between the goals of poverty alleviation and sustainable management of natural resources needed or are win-win opportunities real? In trying to answer this question, it may be useful to return to Figure 2. The first phase of the sideways-S function implies such win-win possibilities. Efforts to reduce poverty reduce the need and desire by the poor to engage in unsustainable behavior such as land degradation, deforestation and moving into lands poorly suited for agriculture. Pro-poor development policies, such as research and technology to enhance agricultural productivity on small farms, may reduce the expansion of agriculture into marginal lands and resulting soil degradation. Safety net policies may result in both reduction of hunger and unsustainable use of natural resources (Barrett 2008). Granja e Barros, Mendonça, and Nogueira (2002) found evidence that a focus on poverty reduction and provision of education and other social capital assets to the poor could create similar win-win outcomes.

Tradeoffs

While multiple-wins are possible, two sets of tradeoffs are of policy importance in the context of this paper: tradeoffs between sustainability goals and other food system goals; and tradeoffs between natural resources and human-made resources. Since the global food system has to meet increasing demands for food and non-food agricultural commodities on the basis of a fixed or falling stock of natural capital, substitution between natural resources and human-made resources is essential. Such substitution may be absolute or relative, i.e., the stock of natural capital may be reduced to meet other societal goals, including other food system goals, or the efficiency of existing natural resources may be increased through research, technology and better production practices. To some, sustainable natural resource management implies that no degradation of the stock of natural capital must take place, even if the degradation is reversible and can be rectified

at a later time. To others, sustainability refers to the capability of the total capital (natural, human, physical, financial and social) to meet future demands, as suggested by the Brundtland Report.

We argue that neither of these two extreme positions is likely to be acceptable to most societies. Some natural resources, such as a beautiful landscape or a rare bird, have intrinsic values that cannot be compensated for by human-made capital. Such resources should not be considered merely as part of the total input into the economic growth process and fully replaceable by human-made capital. On the other hand, sustainable expansions of the food supply to meet future demand cannot be achieved if the stock of natural resources is to be maintained at any cost, with no replacement with human-made resources permitted. Surely, sustainable management of natural resources should not really mean conservation of these resources in their current state, whether they are renewable or non-renewable. If the elasticity of substitution between natural capital and human-made capital is high, then imposing strict conservation restrictions could actually reduce future growth and sustainability (Ruttan 1997).

Tradeoffs between goals of expanding food availability, reducing poverty and hunger, and maintaining a sustainable productive capacity are linked to tradeoffs between the welfare of current and future generations. A food system based on degradation of the stock of natural resources is prioritizing current generations over future ones, unless the degradation is fully compensated by enhanced efficiency and/or human-made resources. Rapid increases in yields per unit of land and labor caused by the Green Revolution provided such compensation. The higher yields per unit of land compensated for the reduction of land available for future agricultural production and for the soil degradation caused by water logging and salination. It is less clear whether excessive water use resulting in draw down of ground water levels and reduced flows of surface water was compensated. If a full-costing approach had been used to guide the Green Revolution, more emphasis would have been placed on improved water use efficiency.

Policy options

Policies to maintain sustainable use of natural resources

Multiple-win technologies that promote economic growth, poverty alleviation, increasing production of food, and sustainable management of the environment do exist. For example, organic and other agro-ecological production methods may improve soil quality and land productivity and improved irrigation technologies (particularly sprinkler and drip systems) may increase yields, reduce the amount of water used, and increase the water use efficiency. Biogas plants can significantly reduce costs and negative environmental impact, while increasing revenue (Olesen 2008). Wani et al. (2003) found that integrated pest management, soil and water conservation initiatives, and green manure reduced water runoff by 45% in years of heavy rainfall and 30% with little rain. The production per unit of land more than doubled; annual soil loss were reduced by two-thirds; and the groundwater increased by 27%. At the same time, the dependence on fertilizers and pesticides decreased.

Another example of multiple-win strategies is the planting of nitrogen-fixing trees and crops which restores soil fertility, reduces the need for chemical fertilizers and increases food production. Push-pull systems of pest control, mentioned earlier, can increase food production and farm incomes while reducing dependence on pesticides. Research into improved crop varieties that are pest resistant, drought tolerant, and require fewer chemical inputs can significantly increase food production and income while avoiding negative environmental effects by reducing dependence

on chemical fertilizers and pesticides.

Stern (2008) advises that pricing environmental externalities is central to good policy. Policies to reduce unsustainable use of water in agriculture, such as water pricing and allocation of water by collective action (e.g., water users associations) are an illustration. Public support of sustainable production methods in the food system in the form of additional research and knowledge dissemination specifically addressing sustainable production practices is critically important. Reviewing and possibly changing the current European and American definitions of organic production methods to include the use of chemical fertilizers where the availability of organic materials is insufficient would reduce the risk of soil mining and increase yields. Incorporating improved seeds developed by modern science including transgenetic methods, in the definition of organic production practices would further increase yields and reduce risks in sustainable production. Policies need to account for transaction and information costs, promote technological development, address differing levels of development, and be designed to reduce global costs and inequities (Stern 2008).

Open access to natural resources results in resource degradation, also known as the tragedy of the commons. Sustainable management of natural resources will occur only when the agents that use the resource are held accountable for the consequences of such use. Appropriate property rights institutions are of critical importance to avoid the tragedy of the commons. Three other forms of property rights and their effectiveness in assuring sustainable productivity increases should be mentioned: private property, state property, and communal property.

Private property rights can be highly effective in preserving natural resources simultaneous with productivity increases and poverty reduction. Farmers with a long-term interest in the land and water they control will confront tradeoffs and multiple-wins in a way that assures sustainable management of their property, unless external constraints make it impossible for survival. Relief of those constraints and full costing provide incentives for property owners to internalize social costs to reduce or avoid negative externalities. However, this presupposes that land owners have a long-term interest in the land. This means either a well-functioning land market or a perception among farmers that they will not lose the land in the future, including inheritance laws that guarantee access by future generations.

Contrary to the assumption by some, state ownership and management of land resources is not usually effective in avoiding land and water degradation (Pinstrup-Andersen and Pandya-Lorch 1994; Gill 1995). State institutions are often unable to properly control a land area and how it is managed and state ownership can be equivalent to open access and related unsustainable use.

Community property is not the same as open access. Gill (1995) and Dellink and Ruijs (2008) cite numerous case studies where communal organizations have established institutions that prevent the overuse of resources while ensuring an equitable distribution of benefits. Gill (1995) also shows that where state property management has succeeded in South Asia, it was because resource management was in fact under community control. However, sustainable management of communal lands requires a high degree of social capital, relatively equal power distribution within the community, and local enforceability of traditional institutions. The imposition of further state controls, even when aimed to create private title to land, can undermine successful communal systems and result in more degradation of land and water sources, reduced food production, or both. In order to avoid such negative outcomes, communities should be empowered to participate in national policy discussions.

Furthermore, changes to property rights laws often do not take account of pre-existing traditional property rights relationships. This may remove land rights without compensation, reducing the environmental balance of the system. Competition between pastoralists and communal lands in some parts of arid and semi-arid Sub-Saharan Africa is a case in point. Top-down approaches to institutional change can reduce sustainability and increase poverty as has been recognized by both Rodrik (2008) and Easterly (2008).

Governments of some African countries, such as Ethiopia, that have maintained state ownership of all agricultural land, are offering large tracks of land to interested foreign parties. While some governments may argue that the land is uncultivated and depopulated, the reality may be that the land is cultivated by smallholders who lack legal title or political voice to defend their traditional property rights. Recent and current attempts by middle-income countries and multinational corporations to enter into agreements with African governments to obtain control over agricultural land may result in land and water deteriorations and increasing food insecurity. This could occur if the foreign agent using the land has a shorter time horizon than traditional users who are pushed off. At the end of the lease, governments and smallholders may be left with denuded desertified land rather than the landscape of improved infrastructure and investment envisioned by proponents.

In addition to the risk of increasing food insecurity, this development raises two critical questions of relevance to this paper. First, will the transfer of land management from poor farmers practicing labor-intensive, low-productivity farming to large-scale, capital-intensive, high productivity agricultural production result in further environmental deterioration – such as land degradation, drawdown of ground water and overuse of surface water, and increased emission of greenhouse gasses – or will it reverse the on-going deteriorations for the benefit of the environment? Second, will the loss of land by millions of African farmers result in grievances, instability and armed conflict? Lack of employment options, safety nets and social cohesion can provide fertile grounds for conflict and could create a poverty-conflict trap (see Collier et al. 2003).

Implementation of full costing: difficulties to overcome

As mentioned above, a full costing approach, in which the social cost of environmental damage as well as the social benefits of environmental services are incorporated in private costs and benefits, is an effective way to use market forces to assure sustainability in the food sector. Full costing will change the behavior of farmers and other agents in the food system and induce relevant innovation in public policy and research and technology development. Vehicles for implementing full costing include taxes such as CO_2 or green taxes and payment for ecosystem services. Removing distortionary agricultural subsidies can also be beneficial (Taheripour, Khanna, and Nelson 2008).

While the concept of full costing is straightforward, there are several reasons why its implementation will be challenging. Four are mentioned below. First, estimates of environmental costs differ widely and it will be difficult to arrive at an empirical or political consensus about even the magnitude of the social costs to be converted to private cost and charged the food system agents. This is so because in the absence of guidance by public policy or unrealistically large investments in social capital among a relatively homogeneous population, the market is incapable of setting the prices for such non-market factors or externalities. Increased investment in research is needed, but is not likely to resolve the question definitively even within decades.

Second, it may be politically, logistically and ethically difficult to charge poor farmers and

consumers for environmental damage since it would imply higher production costs for poor farmers and higher food prices for poor consumers. Even if it were considered politically and ethically viable, the monitoring of farming practicing and the extraction of the penalty would be difficult because a large proportion of the rural poor are only weakly integrated into the systems needed by governments for monitoring and extraction. Instead of attempting to penalize the poor for action with negative environmental consequences (the stick), payment for ecosystem services (the carrot) may be more viable.

Third, very little is known about whether the behavior of a given system is better approximated as being linear, quadratic, or affected by significant threshold effects. If actions (e.g., livestock methane production or overuse of water) affect the environment in a roughly linear fashion, a simple linear tax on production can achieve full costing. Such a tax on actions that are characterized by increasing marginal environmental costs (e.g., deforestation, fishing, or fertilizer application) or threshold effects (e.g., pesticide application, biodiversity) may be ineffective, reducing needed input use at low levels while providing insufficient conservation incentive at high levels of use. An increasing rate of taxation would be more appropriate. Hellegers et al. (2008) cite research indicating that the poor are better off with a simple linear tax with rebate as opposed to an increasing block-rate pricing structure.

In this regard, Bontems (2008) demonstrates that the feasible set of policies depends crucially on what the regulator can observe. If a regulator could observe all factors, including farmers' innate ability and all farm characteristics, then an input tax and a land tax (or subsidy) based on heterogeneous ability can induce farmers to choose the socially optimal mix of land and inputs, redistributing benefits to poor and inactive farmers. If ability is unobserved, but farm input use can be observed, then it is possible to levy non-linear taxes on input purchases and appropriately achieve full costing. If even that is not possible, however, the only remaining option is simple linear taxes.

Fourth, efforts to implement full costing in a particular country will distort its competitive position vis-a-vis other countries. International agreements with enforcement capability are likely to be needed to avoid free-riders and provide the necessary incentives without distortions of relative competitive position. The failure to arrive at an agreement related to global warming at the Climate Summit in Copenhagen in 2009 demonstrates the difficulty of arriving at such agreements.

Conclusions

Sustainable natural resource management is essential to maintain a sustainable agricultural system. Past successes in food production have been obtained in part by unsustainable exploitation of land and water. At the same time, expanded yields per unit of land alleviated pressures to bring more land under cultivation, thus avoiding deforestation and degradation of land poorly suited for agriculture. Biodiversity and wildlife have also benefitted. Efforts to assure sustainability of the agricultural system in the future will require internalizing environmental externalities into private costs, i.e., full costing. If full costing is implemented and the revenues captured are used for investments to repair natural resource damage and create other capital to compensate for losses of natural capital, major structural and behavioral adjustments would take place in the food system, moving it closer to sustainability.

The risk of land degradation is particularly high in the drylands areas with poor infrastructure,

irregular rainfall and limited access to affordable plant nutrients. These are also the areas likely to be most severely affected by climate change.

Governments and civil society, including NGOs, should pursue multiple-wins interventions to simultaneously reduce rural poverty, increase food production and improve the natural resource base. Nowhere is that more urgent and important than in the drylands. We propose a modification and re-interpretation of the Environmental Kuznets Curve to show where such multiple-wins are possible and how full costing can reduce the trade-offs between increases in incomes and food production on the one hand and degradation of the natural resource base on the other. Our justification of Stage 1 of the Modified Environmental Kuznets Curve is based on very limited empirical evidence. More empirical research is needed to verify the extent of its existence and to identify appropriate policy interventions to achieve multiple-wins.

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1.3. Agriculture in an era of climate change and resource scarcity. Are we ready?

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Abstract

If anything, policy makers and climate scientists alike have underestimated the impact climate change, water, energy and nutrient constraints will have on food production. Most adversely affected will be those areas that are hot and dry today. Today's agricultural environments are about to become extinct; in country after country, crops will face growing conditions never before experienced. While many actions will be required to address such issues, no one can doubt that preparing crops in the field to deal with new conditions there has to be a first order priority. National and global preparedness, however, is woefully lacking. While significant capacity exists, there are serious gaps in the pipeline from the collection, conservation and screening of genetic resources, to information systems, to plant breeding and seed delivery. Both subsistence and highly productive input-intensive agricultural systems will be hard pressed to adapt quickly enough to avoid major dislocations. Given the long lead time in plant breeding, preparations should now begin in earnest to get agriculture ready for the significant climatic changes predicted as early as 2030. Elements of such a strategy are outlined.

Introduction

In region after region and for crop after crop, our agricultural system will soon be experiencing climatic conditions unlike any in the history of agriculture. Temperatures will be "out-of-bounds." In the future, the coldest growing seasons will be hotter than the hottest of the past in many countries.

To state the obvious, crops are on the front line of climate change. They will be the first to experience it. We would be mistaken to think that today's crop varieties come automatically or well adapted to conditions never seen in the 12,000 years since crops began to be domesticated.

The central imperative of our time, therefore, is to get agriculture ready for climate change. Darwin unlocked the mystery of adaptation and evolution more than 150 years ago. He realized that diversity and inheritance, subjected to natural selection would, over time, lead to evolution, i.e., to the adaptation of populations. The first chapter of 'On the Origin of Species' dealt with domesticated plants and animals. He understood then, as most farmers do, that crops must evolve, or they will perish. The striking and profound difference between our domesticated crops and wild plants is that evolution for domesticated crops is in our hands, in the hands of plant breeders and those farmers who select and save seeds annually.

Agricultural adaptation thus means crop adaptation; it means developing varieties that are suited to new and to variable climates. In this regard, it behooves us to focus on the pipeline that could potentially produce "climate-ready" crop varieties, and in particular on Darwin's four elements: Diversity, Inheritance, Selection, and Time.

Diversity

Though much diversity has undoubtedly been lost, the world's genebanks still hold a dazzling array of diversity, a large portion of which is yet to be researched, documented and used. Collections of major crops are particularly impressive, though most are deficient in the crop wild relatives they hold. Collections of "minor" crops are much less complete, and in many cases there are no collections as large as 5000 accessions. Still, the genetic diversity to fuel adaptation efforts exists. The challenge is to fill the genetic gaps in the collections, ensure stable and sustainable funding for conservation, and encourage legal and practical availability to all without regards to political or other impediments.

Inheritance

It works the way it always has!

Selection

For domesticated crops, selection is in our hands. For rapid, difficult and large feats of adaption, it is largely in the hands of scientifically-trained plant breeders, though farmers also manage crop evolution particularly for crops for which there are few or no breeders, i.e., for many crops. Support for public plant breeding is tenuous. The task of adapting crops to various, rapidly changing conditions will not be accomplished successfully or in time unless large new investments are made in plant breeding. Bluntly stated, the world is going to need more plant breeders working on more crops.

Time

With the needed diversity and sufficient time, we could hypothesize that crops could adapt to anything. Darwin, upon seeing a bear swimming in a lake, once lightheartedly suggested that a bear could evolve into a whale given enough time. We do not have eons, however. Climate change necessitates quick, not glacial progress. For such progress to be made we will have to summon the tools we have – the genetic resources and human expertise to address the problem of crop adaptation.

Looking more closely at the genetic resources component of the solution, we find that the world still does not have what anyone could term a rational, efficient, effective, sustainable Global System for conservation and availability. Some 150 countries committed to building such a system at the Leipzig Conference in 1996. It hasn't been done. Many genebanks offer poor conservation services. Availability is restricted for technical or political reasons. Nevertheless, the technology exists to ensure the long-term conservation of all crop diversity. The "problem" is not technical. It is, in part, financial. While conservation of virtually all unique crop diversity in the world might be had for less than $20 million a year, the only guaranteed funding (produced by the Global Crop Diversity Trust's endowment) provides but $2 million.

The striking reality about crop diversity is the degree of interdependence, or rather the dependence that all countries have on each other for the genetic resources that underpin their agricultural system. Australia, for example, possesses just 3% of the total of wheat samples held in genebanks. Brazil has 2% of the world's soy samples. Both countries have huge industries built around these crops and yet are obviously dependent in the long term on foreign supplies of germplasm.

Interdependence should prompt cooperation. It should be the basis of a win-win scenario. Sadly, this is not always the case.

There is a "mathematics of access." Consider the following very simple but revealing game:

- You give me 10 samples from your genebank; I give you 8.

Did you add or subtract the numbers? Did you calculate that you were down by 2 or ahead by 8?

In a truly global and cooperative system, such as that mandated by the International Treaty on Plant Genetic Resources, I would argue that you should think of your situation as dramatically improved, not diminished. You now have 18 samples, 8 from another country and therefore possibly quite different, that you didn't have before. Yes, you gave them 10 samples, 2 more than you received. But you did not actually lose the 10 you provided them. You still have those 10… plus 8 more. 18 in total!

Unfortunately, there are institutes and countries that subtract rather than add. And this leads them not to share, counter to the International Treaty that many have ratified. This failure to share affects everyone, because in an interdependent world in which no country is self-reliant, every country's collection effectively becomes part of another's "national program." Restricted access for whatever reason and whether officially acknowledged or not, diminishes each country's national capacity. If the International Treaty is functioning as envisaged, the global system is the national system for each and every country.

Are we ready ?

Technically and in terms of capacity, we are not yet ready to meet the challenges of climate change and food insecurity. An "every man for himself" attitude still pervades the crop diversity community, when a culture of cooperation and Treaty implementation would do wonders for conservation and availability. It would even provide cost savings, enabling existing efforts to be channeled more towards serving users (plant breeders and farmers), thus generating even more benefits. In short, and to be blunt, there is too much short-term, institutional-focused thinking and not enough long-term, goal oriented thinking, and cooperation.

The world in which work with plant genetic resources is undertaken has changed. There is a new, enabling context – one that creates the foundation for agriculture becoming prepared to meet future challenges – if we choose to make use of it. That new context includes:

- International Treaty on Plant Genetic Resources for Food and Agriculture
- Agreed Strategies: Global Plan of Action, plus crop and regional strategies developed by crop experts with support of the Global Crop Diversity Trust
- Information & Transport Systems: a new genebank management system (GRIN-Global) freely available to all, a global accession-level information system tying far-flung genebanks together (GeneSys); and transportation systems (e.g., FedEx) that facilitate worldwide shipment of samples thus allowing us to "think globally" rather than just nationally or regionally about systems that can effectively conserve germplasm and serve plant breeders worldwide.
- Global Crop Diversity Trust that provides a structure for ensuring the financing for long-term conservation and availability
- Svalbard Global Seed Vault that provides a fail-safe (and free) insurance policy for genebanks to protect a duplicate copy of all unique genebank accessions (conserved as seed).

Building the Global System

Focused on helping build the Global System, the Global Crop Diversity Trust has:

- Formulated a basic vision of how that system might operate and what the Trust's role would be in it. This vision is captured in the Trust's Fund Disbursement Strategy, endorsed by the Governing Body of the International Treaty, and adopted by the Executive Board of the Trust.
- (http://www.croptrust.org/documents/WebPDF/GCDT%20Fund%20Disbursement%20 Strategy%20FINAL.pdf)
- The Trust has moved quickly and decisively to rescue genetic resources, partnering with 72 developing countries in the regeneration and safety duplication of more than 90,000 unique genebank accessions.
- With funding from the Government of Norway, the Trust has initiated a 10-year project to identify and fill the genetic gaps in current collections of 26 major crops. The initiative will deal exclusively on crop wild relatives, genetic resources that contain tremendous diversity of potential use for climate change adaptation. The major focus of the work will involve support to pre-breeding efforts to ensure that this new diversity enters the plant breeding pipeline.
- The Trust has supported development of the key information system components of a Global System: GRIN-Global for genebank management, and GeneSys for accessing accession-level information across genebanks.
- The Trust has initiated long-term grants to support 15 major crop collections, theoretically in perpetuity. These are the collections that currently comprise the bulk of materials under the International Treaty on Plant Genetic Resources, and they account for the majority of transfers under the Treaty.
- Finally, the Trust has been and continues to be quite involved as one of three major partners in the operation and funding of the Svalbard Global Seed Vault that provides secure back-up storage for genebanks – a global insurance policy for crop diversity.

The development of a Global System offers possibilities and options that could scarcely be imagined short decades ago when Otto Frankel and Erna Bennett published their classic Genetic Resources in Plants. For the first time, we dare imagine that we might have secure long-term conservation for unique diversity – secure both physically, financially and legally. We are on the cusp of having robust and powerful information systems for conservation management and to serve the needs of breeders and researchers.

An efficient and sustainable global system, however, is not comprised of hundreds of genebanks each attempting to provide long-term storage. Far fewer are required to this. Thus, the emergence of a true global system opens the possibility that many genebanks could move closer to users by facilitating the acquisition, research, multiplication and supply (to both breeders and even farmers) of materials needed, for example, for climate change adaptation. These facilities could do so in partnership with those engaged in long-term conservation, and they could also contribute to this effort by managing regeneration work in the environments in which the materials were originally collected in order to minimize genetic drift.

How we as an international community manage and oversee Darwin's four elements of evolution – diversity, selection, inheritance and time – in regards to our domesticated agricultural crops will largely determine how well we respond to the central challenges of our time – to climate change, population growth, and impending shortages of water, energy and nutrients. Standing

alone, no country's national plant breeding system can stand alone! In an interdependent world, each country will benefit from cooperating to create a Global System. In a very real sense, the Global System will function as each country's National System.

The path is not yet clear towards the realization of this Global System, however. Institutional politics and inertia are evident. Leadership is in short supply. Implementation of the International Treaty is spotty. Suspicions persist. And funding remains problematic. The stakes, however, are too high to fail. As Jack Harlan once famously stated, "these resources stand between us and catastrophic starvation on a scale we cannot imagine." In the face of climate change and widespread food insecurity, failure to cooperate to conserve and provide crop diversity is an option we certainly cannot afford to take any longer.

Darwin once observed "It is not the strongest of the species that survives, nor the most intelligent, but the one most responsive to change."

Change is about us and we must respond. What then, is required of us? We are called upon to think, plan, and act globally. To think in terms of the outcomes we want. To think big. And to act decisively.

1.4. Adaptation strategies to climate variability and climate change in dryland agriculture of southwest Western Australia

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Abstract

The agricultural region in southwest Western Australia has a Mediterranean-type climate, characterised by winter dominant rainfall and hot, dry summers. The majority of crops are sown in autumn and harvested in late spring. Agricultural production in much of the region contends with hostile soils, low rainfall and inter-seasonal rainfall variability, with terminal drought in spring causing the greatest reduction in yields. In addition, global climate change is already impacting Western Australia through lower average winter rainfall. Despite these constraints, agricultural production increased during the twentieth century due to improved agronomic practices, new varieties and diversification of farming systems. However, climate change threatens future production levels in the region through increased risk of prolonged drought, higher average temperatures, particularly during the critical stage of grain filling, and more extreme temperatures. With high seasonal variability it is essential that maximum grain yields are achieved in average and better seasons. Simulation models can assist with forecasting and identify management strategies that may optimise potential grain yields. Crop simulation models have been widely used to assess the impact of climate change, but the lack of adequate experimental data hinders the accuracy of predictions. The greatest advances in addressing the challenge that climate change presents will come from research leading to a better understanding of crop physiology and genetics that can enhance further genetic improvements. This research is needed now to develop crops adapted to the future climate in targeted growing regions.

Introduction

The southwest of Western Australia produces most of Australia's cereals (40%), oilseeds (52%) and pulses (46%; includes 84% lupins) (ABARE 2010). These crops rely entirely on rainfall, which is highly variable even in the wettest months and has declined over the past century. Soils in the region are also hostile, restricting root growth, and water and nutrient uptake. Despite these physical constraints, production has increased over the past 80 years, with yields of some crops such as wheat and barley doubling since 1980 (Turner and Asseng 2005). Adaptation strategies that enabled this increased crop production are due to a combination of agronomic and genetic improvements (Anderson et al. 2005; Turner and Asseng 2005). This paper provides a snapshot of those improvements by first describing the key features of the agricultural region and then the on-farm practices and development of new varieties that led to improved yields. The focus is on the dominant crop wheat, which occupies more than 60% of the agricultural land area each year, but examples from other crop species are also included where applicable. The final part of the paper addresses the future of agriculture in Western Australia in relation to climate change and the need for major research and development for long-term sustainability of crop yields in the region.

Growing conditions

The agricultural region in Western Australia has a Mediterranean-type climate. Most rainfall occurs during the winter months May to October, when temperatures are also coolest (Fig. 1). However, there is a high degree of variability in rainfall within season and from year to year (Cowling et al. 2005). In addition, winter rainfall has declined by approximately 7 mm per decade since 1900 (Australian Bureau of Meteorology http://www.bom.gov.au/cgi-bin/climate/change/timeseries.cgi). Dryland crops are sown in autumn, taking advantage of early season rains that provide sufficient water for germination and crop establishment. However, crop failures occur due to year-to-year variation in rainfall (Turner and Asseng 2005) and false starts to the season. According to rainfall patterns since 1948, there is 50% probability of no rain for 23 days after sowing (Armstrong et al. 1996). In years when crop establishment is successful, during early growth stages water and nutrients drain beyond the rooting depth. Crops are harvested in late spring/early summer when rainfall is decreasing and temperature and pan evaporation are increasing, often resulting in water deficit during grain filling and seed set.

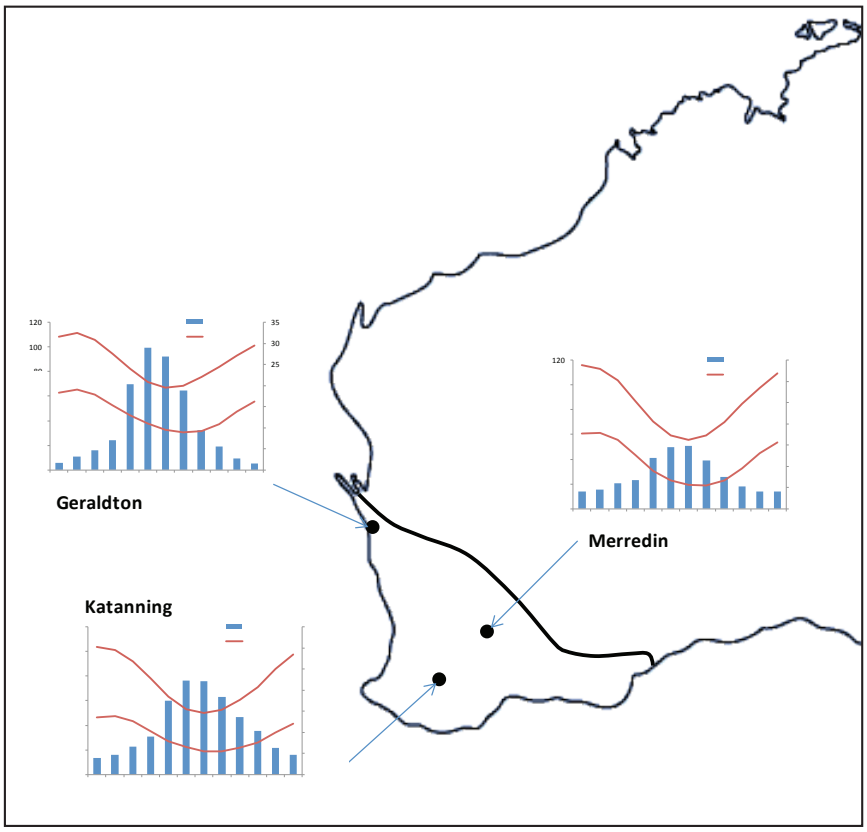

Figure 1. Mean monthly rainfall, and maximum and minimum temperatures for three towns in the agricultural region of Western Australia.

About 60% of Western Australia's agricultural regions feature duplex soils. Duplex soils consist of coarse surface soil overlying finer-textured subsoil, with a distinct boundary between the two soil types (Northcote 1979). In Western Australia, surface soils are a shallow (≤0.6 m depth) sandy loam with high water permeability, low nutrient concentrations and low pH (Dracup et al. 1993; Tennant et al. 1992). The surface soils overlie light- to heavy-clay subsoil, which often has high bulk density, low porosity, low hydraulic conductivity and alkaline pH (Dracup et al. 1992; Tennant et al. 1992). Due to the physical and chemical characteristics of duplex soils, root

growth of crops may experience a number of stresses in any given season (Belford et al. 1992). Differences in pH between the two soil horizons may affect growth, particularly varieties that are not tolerant to a wide range of pH, but also the extremes of pH affect the availability of nutrients for uptake. The mechanical resistance of the subsoil may impede root growth, limiting uptake of water and nutrients to the shallow surface soil (Dracup et al. 1993). Shallow root systems will be more vulnerable to fluctuations in climate conditions. Duplex soils are also susceptible to waterlogging in winter due to the contrast in water permeability between the surface soil and clay subsoil. During periods of high rainfall and depending on location in the landscape, crops such as wheat, lupin and canola may be transiently waterlogged for several days to weeks at a time (Belford et al. 1992; Zhang et al. 2004). Although wheat tolerates waterlogging better than lupins (Bramley et al. 2010) and legume crops vary in their tolerance to waterlogging (Solaiman et al. 2007), none of these crops are particularly well-adapted to waterlogged environments. Roots and the rhizosphere become hypoxic when soils are waterlogged, which reduces plant growth and ultimately decreases crop yields (Dracup et al. 1992; Zhang et al. 2004).

Adaptation strategies for improved production

The trend in yield improvement for wheat, along with management strategies that led to improved grain yields during the second half of the 20th century in Western Australia is shown in Fig. 2. Rotation of cereal crops with pasture legumes and pulses had a positive effect on cereal yields compared with successive cropping because it reduces the incidence of cereal root diseases, improves soil fertility and structure, and allows the use of herbicides to manage grass weeds. Weed management through the use of herbicides allowed crop sowing with minimum tillage. Minimum tillage and retention of stubble from the previous crop reduces soil erosion and evaporation, and improves rainfall infiltration. Improved weed control and reduced tillage allow for earlier sowing so that crops flower earlier in the season when water supply is more abundant, lowering the risk of water deficit during the critical grain filling and seed setting stages. With adoption of the above practices, wheat was sown, on average, three weeks earlier (Anderson et al. 2005). However, earlier sowing also increases the likelihood of water deficit during early growth, but this is considered less inhibitive on yield as some crops such as faba bean often compensate when rainfall returns (French 2010). Application of nitrogen and potassium to improve plant nutrition also increased after the adoption of the above practices, although excessive fertiliser use can lead to smaller grains (van Herwaarden et al. 1998).

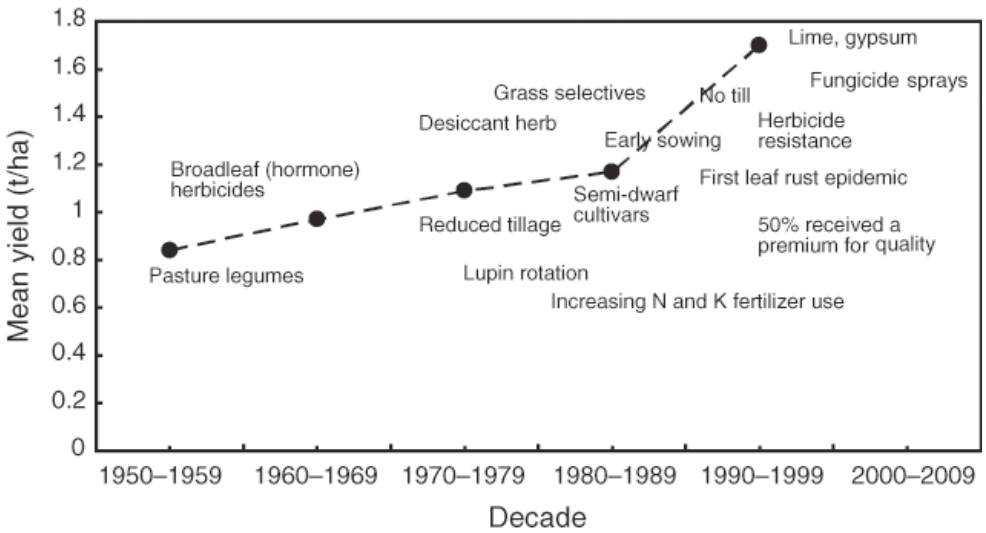

Figure 2. Wheat yield trend in Western Australia and major management strategies that contributed to yield improvements (from Anderson et al. 2005).

Despite the overall trend of increasing wheat yields in the 20th century, variability in yields has increased since 2000 (Fig. 3). Environmental factors cause the greatest variation in grain yields, accounting for 80% of the variability in Western Australia (Anderson 2009). Management strategies within and across seasons provide additive benefits to address variability in yields due to the environment, particularly in regions with rainfall >250 mm (Anderson 2009). Other practices not regularly used, but may maintain yields, include application of lime to the surface and at depth to increase the pH of acidic soils; deep ripping and application of gypsum to reduce surface compaction; surface drains to remove excess soil-water in parts of the landscape prone to waterlogging; and return of unharvested crops to improve soil structure and fertility of sandy soils (Anderson *et al.* 2005). However, these practices are not regularly used because they are expensive and unlikely to be primary drivers of yield improvements (Anderson *et al.* 2005).

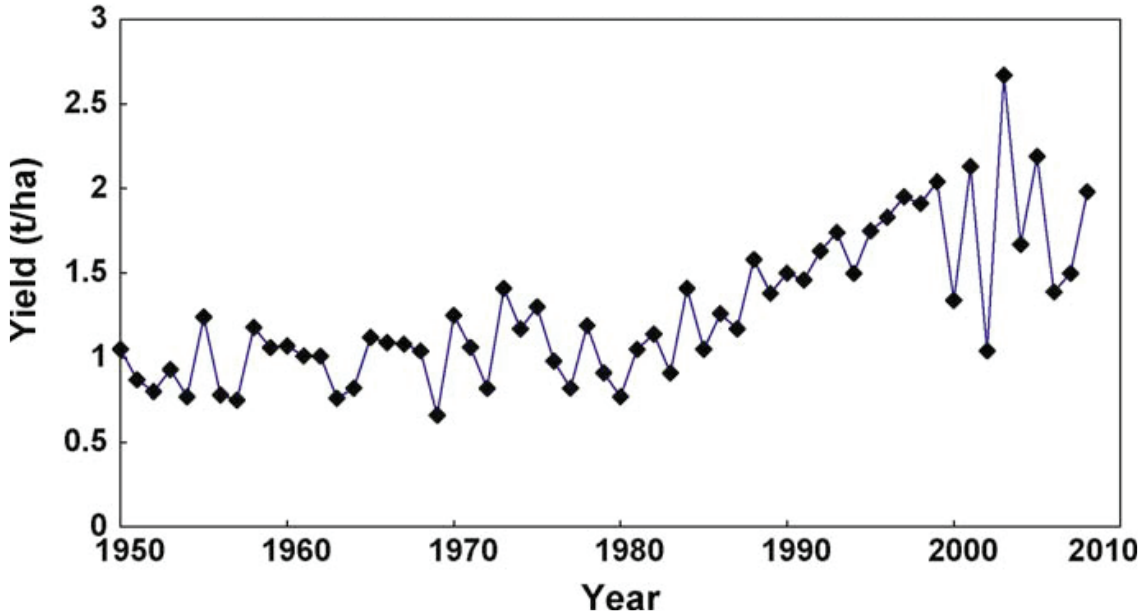

Figure 3. Average wheat yield in Western Australia from 1950 to 2008. (From Anderson 2010).

Processes of improved crop production in Western Australia have also included breeding and development of new varieties which, to some extent, has been achieved through greater understanding in crop physiology and their responses to the environment. Phenology has been adapted to the region; for example, modern wheat varieties selected for Western Australia develop faster and flower earlier (Siddique et al. 1989a). Earlier flowering was also achieved from the first breeding efforts for narrow-leafed lupin (Gladstones 1982) and early flowering lupin varieties also have greater seed filling rates (Palta et al. 2004). Semi-dwarf wheat varieties, adopted for their improved harvest index and lodging resistance, produce more grain due to reduced stem elongation, which enables increased partitioning of assimilates to grains (Evans 1993; Siddique at al. 1989b). Breeding for improved yield components also unintentionally led to characteristics in modern varieties that are better adapted to the Western Australian environment. For example, modern varieties of wheat have greater water use efficiency compared with old varieties (Siddique et al. 1990). Modern varieties also have fewer tillers, which are stronger and have greater survival rates than the numerous sub-tillers in old varieties (Siddique et al. 1989a). Modern wheat varieties also have smaller root systems and invest a smaller proportion of total biomass in roots than shoots (Siddique et al. 1990). Although a smaller investment in roots may enable diversion of dry matter into grain production, a smaller root system may limit the amount of water extracted from the soil in a Mediterranean-type environment.

Climate change and future impacts on crop production

The decrease in annual rainfall in the agricultural zone of south-western Australia has resulted in an overall reduction of 60 mm over the past 50 years (Hennessy et al. 2008; CSIRO and Bureau of Meteorology 2010). However, the 11% decline in growing season rainfall since the 1970s has apparently had little impact on wheat yields because rainfall has decreased mainly in June and July, when rainfall exceeds crop demand for water (Ludwig et al. 2009). This surprising result highlights the importance of climate analyses within and across seasons, as climate events will have varying impacts on crop responses depending on developmental stage. The Ludwig et al. (2009) study also demonstrates the importance of climate and crop simulation models that are able to investigate the impact of changes to individual components of the climate/crop/soil system that would otherwise be impossible in field experiments.

Growing season rainfall in Western Australia is predicted to decline by a further 10 to 20% by 2030 (Pittock 2003) and, unlike historical rainfall patterns, this further reduction will potentially have a significant impact on crop yields because the reduction is expected to be greater in spring (Pittock 2003). Crop demand for water in spring is high because crops are flowering, and developing and filling grains. Daily temperatures are also increasing. Post-anthesis water use of several cool season legumes is correlated with grain yield (Siddique et al. 2001), indicating that water availability is a major factor determining yield. Water deficit during this critical period (called "terminal drought") causes pod and seed abortion in narrow-leafed lupin, and smaller grains due to reduced carbon assimilation and increased leaf senescence in wheat (Palta et al. 2004; Yang and Zhang 2005). Terminal drought causes the greatest reduction in crop yields (Dracup et al. 1998). More late seasonal breaks in autumn are also expected, after which there is sufficient rainfall to sustain growth. Breaks late in the season will result in later sowing or risking water deficit during germination and crop establishment.

Temperatures in the agricultural zone of south-western Australia have increased by 0.2 °C per decade resulting in an increase of 0.9 °C over the past 50 years (Hennessy et al. 2008; CSIRO and Bureau of Meteorology 2010). The resultant increase in mean temperature is an increase in the number of exceptionally hot years and number of days above 35 °C, and a decrease in the risk of frosts (Hennessy et al. 2008; CSIRO 2007).

Average daily temperatures in the region are expected to increase further by 1-2 °C in the next 30 years (Pittock 2003). Increased temperature speeds up growth and phenology, due to the effects on gas exchange, respiration and meristematic cell division. Western Australian cropping regions can therefore expect a shorter growing season. The shorter duration of developmental stages under elevated temperature is generally not compensated by higher growth rates, with the overall result of decreased crop yields. For example, in wheat the duration of grain filling is critical in determining final grain yield (Loss and Siddique 1994) and although more heat-tolerant cultivars tend to have greater rates of grain filling, the rate is insufficient to compensate for a shorter grain-filling duration (Wardlaw and Moncur 1995; Zahedi and Jenner 2003). However, flowering earlier can be positive under terminal drought and heat stress conditions (van Ittersum et al. 2003) as flowering and the period of grain filling will potentially occur when conditions are cooler and wetter.

Asseng et al. (2010) used the APSIM-N model to assess the impact of heat events on wheat yield in Western Australia. They identified that variations of ±2 °C in the average growing season temperature could account for up to 50% reductions in grain production. Most of the reduction

in grain production was attributed to increased leaf senescence at temperatures above 34 °C. The APSIM-N model estimated that grain yields decrease by 5% for every additional day above 34 °C (Fig. 4). Analysis of historical temperatures during grain filling of Australian wheat has shown that the number of days with maximum temperature above 34°C has increased (Asseng et al. 2010). The incidence of extreme temperature events are also expected to increase in the future (Pittock 2003). Elevated temperature due to climate change will, therefore, not only shorten the growing season, but crops will also need greater thermo-tolerance to survive and quickly recover from extreme heat events. In addition, elevated temperature will deplete soil moisture quicker, and any adverse impacts of temperature on crop yields are likely to be exacerbated by water deficit.

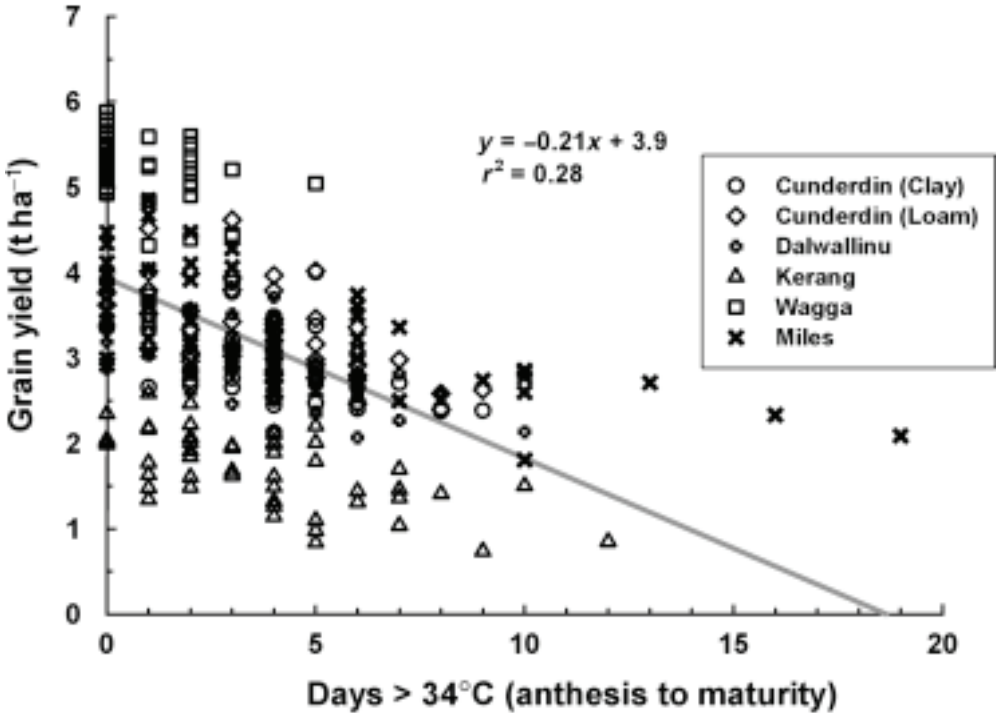

Figure 4. Relationship between simulated wheat grain yields and number of days where temperature exceeded 34°C for five Australian locations (from Asseng et al. 2010).

Atmospheric CO_2 is predicted to increase to 450-550 ppm by 2050 (Pittock 2003), even if mitigation strategies to curtail anthropogenic sources of CO_2 are successful. Crops are expected to respond positively to elevated CO_2 (Amthor 2003; Kimball *et al.* 2002) but yield gains are likely to be offset by higher temperatures and lower rainfall, the extent of which is dependent on soil type and location (Fig. 5; Ludwig and Asseng 2006). Simulation results indicate that future climate will increase potential wheat yields in southern regions (e.g. Kojonup) of the wheatbelt that are cooler and wetter (Fig. 5). In contrast, wheat yields in the drier, northern and central parts of the wheatbelt will depend on the level of interaction between CO_2, temperature and rainfall. Average yields are expected to remain relatively constant in the short-term on sandy and duplex soils (Fig. 5), because simulated levels of CO_2 (525 ppm) and temperature (+2 °C) are predicted to compensate for the forecasted reduction in rainfall (Ludwig and Asseng 2006). But the future scenario by 2100 is expected to cause dramatic reductions in wheat yield (Fig. 5) under the current management strategies and varieties (Ludwig and Asseng 2006).

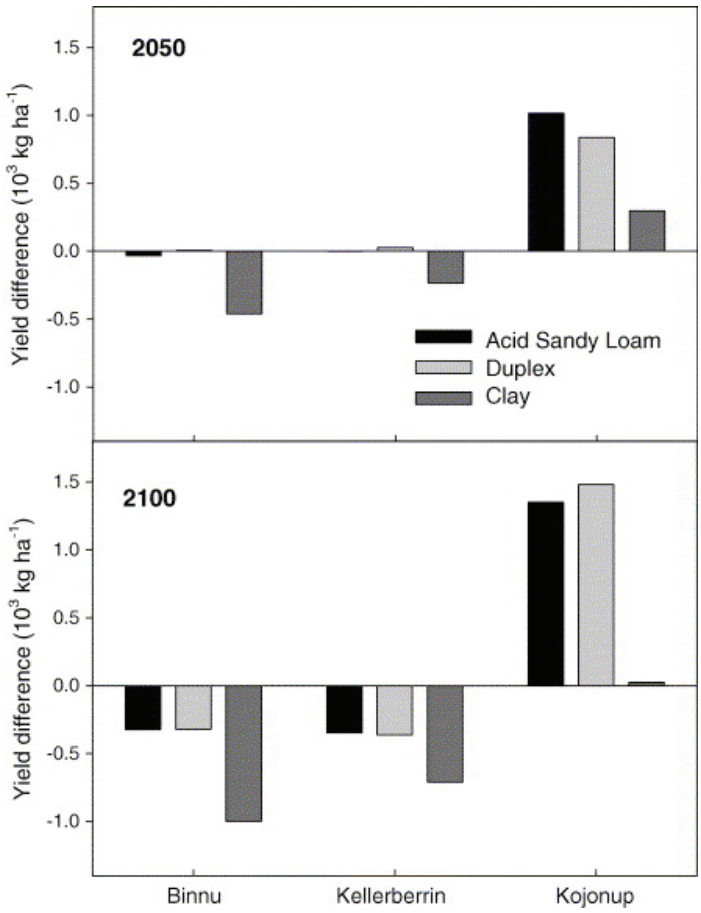

Figure 5. Simulated changes in average wheat yields compared with historical yields under future climate scenarios. The simulated climate in 2050 was 525 ppm CO2, +2°C and 15% lower rainfall and the scenario in 2100 was 700 ppm CO2, +4°C and 30% lower rainfall (from Ludwig and Asseng 2006).

Adaptation strategies for future climate change

Despite significant improvements in crop production in Western Australia over the last century, further improvements are required to meet global demands for food and to adapt to future changes in climate. Current agronomic strategies have been successful in improving yields, but they need to be practiced with greater efficiency. There is also room for improvement in these common practices, as identified by Borger et al. (2010) who demonstrated that sowing wheat and barley in rows orientated to receive the greatest light absorption (east-west in Western Australia winter) improved weed control and crop yields. New technologies such as precision agriculture, farming to land-type and diversification of land use will optimise responsive areas and maintain yield improvements. However, the major innovation in adapting future crop production to climate change will come from a better understanding of crop physiology and genetics that can be used to drive genetic improvement and breeding programs.

Pre-breeding research in wheat at CSIRO and UWA is focusing on identifying characteristics that will benefit targeted environments. One aspect is the potential of early root vigour to capture more water and nutrients, particularly early in the season when there is a significant risk of drainage beyond the root zone and leaching of nitrogen (Palta and Watt 2009). Early vigour lines have faster root growth and higher root length density due to increased branching, which increases

the rate of nitrogen uptake (Liao et al. 2006). Water and nitrogen uptake are closely associated, so vigorous wheat varieties may also have greater rates of water uptake. Root vigour may be advantageous in spring if water deeper in the soil profile can be sourced, but high vigour roots may also deplete soil moisture faster during the vegetative stage, causing water deficit during grain filling. Predictions from simulation models suggest that early root vigour will improve yields under future climate conditions of elevated CO_2 and temperature, particularly in regions with greater rainfall (Ludwig and Asseng 2010). If root vigour is identified as an appropriate selection trait for new varieties it will be a shift from the existing paradigm that wheat root systems in Mediterranean agriculture are unnecessarily large (Passioura 1983; Siddique et al. 1990).

Wheat varieties with early vigour tend to have higher specific leaf areas, but thinner leaves, so they are expected to have lower efficiencies in utilising rainfall (Ludwig and Asseng 2010). However, early vigour lines flower earlier, which is beneficial in avoiding terminal drought, but not if elevated temperature reduces the length of the growing season. Ludwig and Asseng (2010) assessed the potential effects of future climate predictions on yield of a hypothetical vigour variety with high specific leaf area, root growth and rainfall use efficiency and earlier flowering. Under elevated CO_2 and temperature, early vigour improved yield compared with traditional wheat varieties, particularly on sandy soils. Experimental field research confirming these results is required before breeding programs select vigour traits for new varieties.

Predictions from crop simulation models of future wheat yields in Western Australia are being evaluated at CSIRO and UWA's field station using poly tunnels. Genotypes contrasting in specific adaptive traits such as vigour and tillering are being grown under future climate scenarios of elevated CO_2, high temperature and the interaction with terminal drought analysed. It is expected that the yield response of the genotypes will differ, enabling identification of key traits that will sustain or enhance yields under future climate conditions. Research is also focusing on identifying mechanisms that control water use from the cell to whole plant levels and how future climate conditions will influence those mechanisms.

More research is required to understand the physiological responses to future climate scenarios before breeding solutions can be found for southwestern Australian crops. Screening for genetic variation and prioritising for traits under specific environments and conditions will enable a targeted approach to adapting crops for a specific region. Other physiological studies selecting genotypes from the screening trials, with contrasting responses to the treatments imposed will identify mechanisms and genes responsible for those responses that may ultimately lead to genetic modification of important crops. In addition, more research is also required in understanding the interaction of elevated CO_2, heat and water deficit on crop growth and yield, as the response of crops to these climate variables has predominantly been investigated in isolation of each other. Crop simulation modelling will be a useful tool in assessing potential effects on crop productivity when the expression of selected traits is altered.

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Plenary Session 2

2.1. Climatic mitigation, adaptation and dryland food production

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Abstract

Within the international agricultural research (ARD) community, especially in the arid and semi-arid regions, the dialogue naturally emphasizes the capacity to adapt production systems to future demand and probable environmental conditions. It is recognized the global climate change will impose an additional threat to systems already burdened by climatic stochasticity and water shortages, by increasing competition for available water and land, by land degradation and by increasing demands due to continuing population growth and changing diets. The consensus data suggest that food production accounts for about 20% of current national greenhouse gas emissions in a wide range of countries. Lobby groups concerned at tropic forest destruction to provide soya and other animal feeds maintain an even higher figure. Agriculture and land use differ from most other human activity sectors in that nitrous oxide (N_2O) and methane (CH_4) are major greenhouse gases (GHGs). The former is emitted as a result of microbial metabolism of applied fertilizer nitrogen (both organic and inorganic) especially in partly anaerobic soils. Methane emissions arise from both enteric ruminant fermentation and anaerobic degradation of manure and other wastes. Thus methane emissions are an essential component of all low-intensity range-land systems (as well as of intensive feed-lot systems) and a source of GHGs. There are no alternatives to pastoral ruminant agriculture in most semi-arid and upland/mountain regions on which large human populations depend. A further important source of atmospheric CH_4 is anaerobic microbial activity in rice paddies. Prime facie there is major dilemma in that current technologies to maintain food security especially in dry lands depend on applied N and animal-based agriculture which themselves may be aggravating climate change and resource depletion. This paper places the GHG agricultural emission in global context and consider [a] if in the event (unlikely?) of the major global cuts in CO_2 emission from hydrocarbon combustion (i.e. cutting current mean emissions from some 5t CO_2 per person per year to > 2t CO_2 per person per year and global population of 9 billion), what will be the global implication for methane and nitrous oxide emissions from agriculture? [b] Are there potential technologies and interventions for limiting emissions while increasing production to maintain food supply? [c] Should mitigation as well as adaptation feature in the international ADR agenda?

Introduction

During the Amman conference on 'Regional Food Security and Climate Change' in February 2010 (ICARDA 2010), the dryland agricultural research and development (ARD) community was focused squarely on adaptation -- how food production, already subjected to major climatic and social challenges, can cope with the changes expected to materialize shortly as climate change and global warming tighten their grip. Little was said about the contribution to global greenhouse gas (GHG) emissions from agriculture itself or from associated land use and land use and forest changes (LULUCF), such as planting and deforestation and including soil carbon

loss. Also missing was any analysis of the rest of the food chain – food distribution, storage and consumption (including cooking) and (especially in the developed world) food waste.

All these aspects must be considered if a complete picture of the relationship of greenhouse gas (GHG) emissions to our food supply is to be achieved (Dorin and Paillard 2009; Foresight 2011; Taylor and Edwards-Jones 2009; Wyn Jones and Prosser 2010). The un-acknowledged assumption appeared to be that food production is either a non-negotiable necessity threatened by, but largely unrelated to, the drivers of climate change or is of little relevance to the global picture compared with CO_2 emissions from fossil fuel burning. The latter emissions are of course dominated, past and present, by the developed western world. Increasingly however, countries such as China, India, Brazil and the Gulf states, as they emerge to global eminence, are contributing their total and growing per capita GHG emissions from rising energy use (Fig.1). Globally, an affluent 'middle class' is emerging in very many countries which is adopting a higher energy-use, higher GHG lifestyle; a lifestyle often involving changes in diet and food consumption patterns (Girod and De Haan 2010).

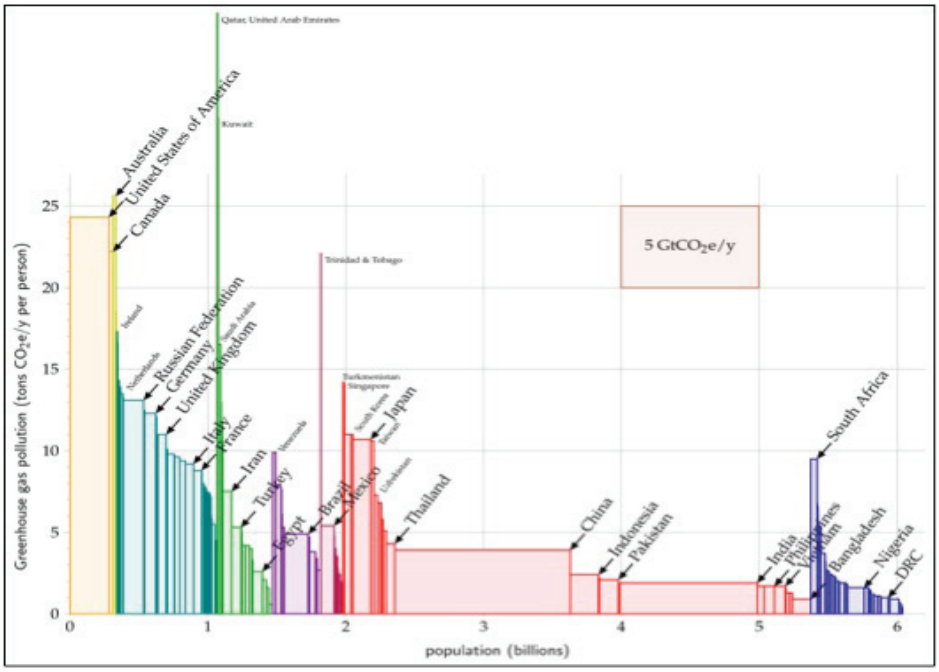

Figure 1. Annual per-capita GHG emissions by country in 2000. (MacKay 2009).

This paper will explore a number of basic questions.

1. What proportions of current GHG emissions are attributable to agricultural practices and the global food chain?
2. Given that by 2050 the global population is expected to approach 10 billion *(ESA 2011), what may be the GHG emissions associated with food production and use, extrapolating from current practices and trends? Human population estimates vary between 8-11 billion by 2050 (ESA 2011)
3. Could these emissions alone perpetuate damaging climate change, even if all energy sources and use e.g. electricity generation, aviation as well as car propulsion, space heating or cooling, cement manufacture etc. are de-carbonized?
4. If so, can we find ways to combat these challenges?
5. What are the implications of this analysis for the world's drylands and its already marginalized poor?

Context

In 2000 global emissions of all anthropogenic 'greenhouse' gases were estimated at ~34 Gt CO_2e per year (Fig.1). But by 2008/9, total global emissions (the Kyoto Accord and a global recession notwithstanding) had risen to about 44 Gt with a world population approaching 7 billion [NB giga=billion=10^{x9}] i.e. ~6 tons of emissions *per capita per annum* (cf. Fig.1). These are still distributed very unevenly: 24 tons and more per person in countries such as USA, Australia and Gulf States, about 5 tons in China, a little over 2 tons in India but below a ton in some Sahelian counties (Fig. 1). However there are in all probability, but less publicized, equally large, perhaps even greater, differences between the 'jet-setters' and the very poor within a given country (Girod and De Haan 2010).

A number of estimates exist of the proportion of current global emissions that can be attributed to agriculture and the food chain. Fig. 2 shows such an estimate of global GHG emissions by gas and by sector, comprising direct emissions from agriculture (e.g. methane from animals, nitrous oxides from manure and N fertilizer application) and more indirect emissions from land use changes e.g. deforestation and the burning or loss of biomass, which are a consequence of the conversion of land to food production. It should be emphasized that neither of these estimates attributes the total commercial and/or local food chain (e.g. refrigerated transport, food processing and cooking) or external energy costs of fertilizers (especially N fixation) to the direct agricultural or LULUCF sectors. Rather these are distributed in a number of other sectors in Fig. 2.

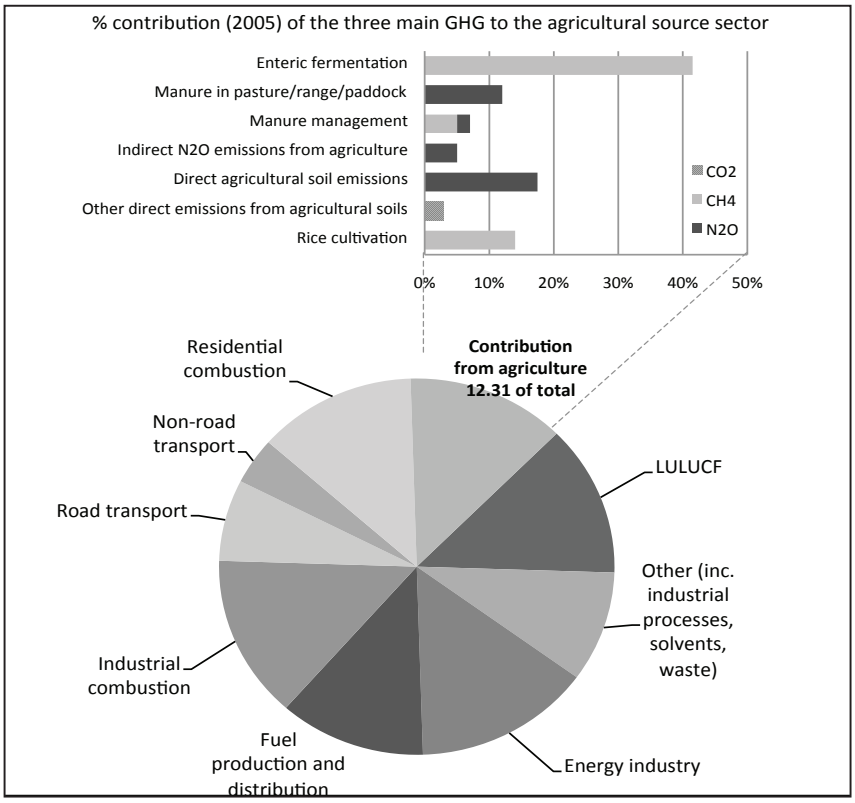

Figure 2. Composition in 2005 of the contributing sectors to global GHG emissions (EDGAR 2010).

Although the data vary, a number of salient conclusions emerge.

1. Over 25% of current global GHG emissions can be attributed to agricultural activity including land use changes.
2. This is due to the release, not only of CO_2 from the oxidation/burning of organic matter and

fossil fuel use but, of comparable significance, of methane (CH_4) and nitrous oxide (N_2O), both powerful greenhouse gases with respectively 21-24 and 290-300 times the warming effect of CO_2 (on a 100-year time-scale). In analysis the integrated impacts of all GHGs are summarized as CO2equivalents (CO_2e) using 23 (CO_2) and 296 (N_2O) (IPCC 1996).

3. Agri-food production is the major source of methane and nitrous oxide which together contribute >10 to 15 % to current emissions i.e. ~0.5 - 0.7 tCO_2e per person per year taken globally. Fig. 2 also shows the breakdown of these emissions by agricultural activity.

One of the most important sources of methane is ruminant animals both because of direct enteric release of methane (Column 4A in the expanded agriculture section, Fig. 2) and from anaerobic fermentation of manures and slurries, either on fields and rangeland or in storage (Column 4B, Fig. 2). N_2O emissions derive from soil microbial action on inorganic and organic nitrogen applied to soil and similar microbial activity during manure handling and after deposition by grazing animals (Columns 4D1 to 3, Fig. 2). The emission of methane from rice paddy production is another important GHG source. However, it is clear from these figures that animal production systems - especially those based on ruminant animals - together with fodder production land and use changes (some of which are brought about by demand for fodder for animals) are significant contributors to the global GHG profile. It must also be noted that nitrogen application for crop production for direct human use also releases N_2O.

Some carbon dioxide is emitted by on-farm combustion of fuel, but far more by aerobic microbial decay of biomass such as aerobic metabolism of soil organic matter (SOM) e.g. after ploughing. In arable systems SOM usually decreases over the years unless the trend is combated. More dramatic is the oxidation of peat soils e.g. many meters in the English fens over several centuries and the release of stored carbon and the loss of fixation potential with destruction of tropical rain forest. To these emissions must be added 'embedded' CO_2 (emissions from production) in applied fertilizers and in other agro-chemicals – especially N as the Haber-Bosch process is very energy demanding. Thus agro-chemical prices are closely linked to oil prices. Indeed it has been said that 'modern agriculture is the use of land to convert petroleum to food' (MacKay 2008).

Currently N_2O and CH_4 alone contribute, globally, about 0.5 to 0.7 tons per capita CO_2e each year and farm food production, including land use change, at least 1.5 to 2.0 tons per capita but if the whole chain is considered the total is probably over 2.5t (cf. total of 6 tons per head) (FAO 2010). This, of course, despite our current problems of rising commodity prices and regions of growing poverty and worsening food security.

Data also show that, while direct emissions from developed countries continue to grow slowly (partly because of the increased import of manufactured goods with high levels of embedded GHGs from the developing world especially China), those of developing countries outside the Kyoto Accord (Non Annex 1 countries) are growing rapidly especially those from land use change and forestry (LULUCF) (Fig 3.). It is of course also true that most of the global population growth also is occurring in the Non Annex 1 countries.

Trends in animal numbers

Figure 4 shows the trends in world animal numbers over the last half century. The dominant feature is a huge rise in poultry production but the % increases in cattle, buffalo and goats are also substantial. Alongside the human population increase from ~3 billion in 1960 to nearly 7 billion in 2010, global meat production has increased 242% since the 1950's to over 200 million

Mt, and per capita meat production has itself increased by more than 60% over the same period (FAO 2010). Table 1 gives more detail of the regional breakdown for Europe, Asia and North Africa.

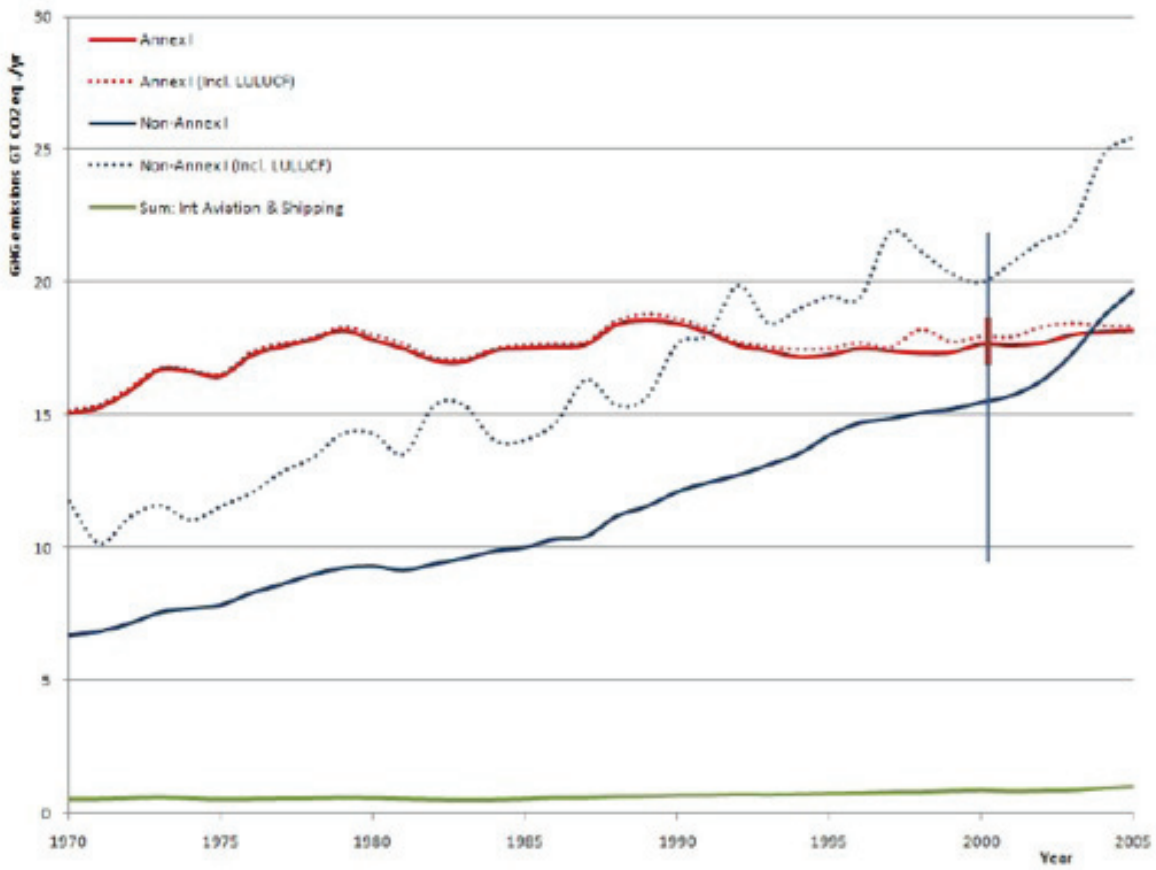

Figure 3. GHG trends in industrialized and developing countries (1970-2005) from EDGAR (2010). Developing countries (many located in the tropics) and industrialized ones (mainly at higher Northern latitudes) produce different amounts of emissions from large-scale biomass burning. GHG emissions therefore compared for Annex I and Non-Annex I countries, with and without LULUCF emissions. International shipping and aviation are plotted separately.

These data display some striking trends. While ruminant animal numbers have fallen substantially in Europe, they have risen in Asia and North Africa; the latter from a much lower baseline. However poultry numbers have soared; increasing by over 500% in Asia and North Africa but with a much more modest increase of 37% in Europe. Not unexpectedly pig numbers have risen much more in Asia than in North Africa. These numbers reflect, in all probability, the rapid economic advance of many Asian countries and the attendant dietary and life style changes.

As noted previously, enteric fermentation in all ruminants, domestically mainly cattle, buffalo, sheep and goats, is a direct source of atmospheric methane to which CH_4 from the anaerobic degradation of the manures must be added. The emission factors agreed by the IPCC show a very wide range e.g. from 128 kg CH_4 per head per year attributed to highly intensive but productive US-style dairy cattle (average yields: 8,400 kg milk h^{-1} y^{-1}), to 46 to 58 kg CH_4 attributed to less productive dairy herds (yielding about 475-900 kg of milk per year per head) to as low as 27 for

small non-dairy cattle on the Sub-Continent (IPCC 1996; 2010). Although emission factors vary by perhaps threefold in dairy cattle and twofold in other cattle, yields and productivity vary by 10 or 20 fold. From a global warming perspective the yield of product per unit GHG emitted is the important criterion. Clearly this is greater in high than in low productivity systems (Edwards-Jones *et al* 2009).

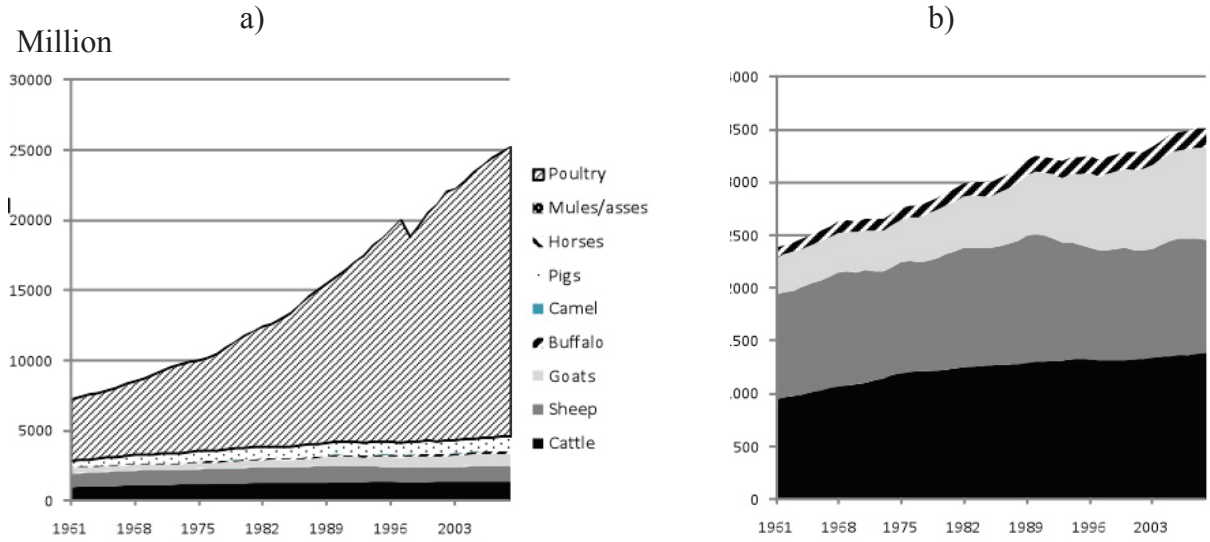

Figure 4. Trends in global animal populations 1961-2009 by a) all groups and b) ruminants only (FAO 2010).

Table 1: Changes in animal numbers in Europe, Asia and North Africa – 2006 to 2009 (data from FAOSTAT 2010)

Regional annual totals	1969			2009			Percentage change 1969-2009		
	Europe	Asia	North Africa	Europe	Asia	North Africa	Europe	Asia	North Africa
Poultry	1,610,793,000	1,752,808,000	85,828,000	2,198,987,000	11,282,156,000	559,039,000	37	544	551
Pigs	173,199,896	225,788,632	45,000	187,654,883	560,425,232	57,700	8	148	28
Equines	18,682,686	33,543,374	4,198,717	6,945,734	30,974,596	5,596,615	-63	-8	33
Cattle	218,603,923	340,273,599	19,302,662	124,222,434	439,175,098	51,959,200	-43	29	169
Sheep	269,192,142	266,414,974	44,231,072	131,222,254	452,629,700	108,464,500	-51	70	145
Goats	17,883,720	213,220,733	22,868,153	15,911,631	516,660,762	61,044,200	-11	142	167
Buffalo	690,996	103,444,902	1,976,000	346,045	182,793,123	4,000,000	-50	77	102
Camel	263,000	4,161,710	3,536,393	7,022	3,863,924	5,368,000	-97	-7	52

However there may potentially be confounding issues. For example, does the cattle feed supporting intensive production include ingredients produced by the clearing of rainforest (with large associated release of CO_2 and a decline in the biosphere's capacity to absorbed CO_2)? Some reports attribute up to a third of net anthropogenic CO_2 emissions to tropical deforestation.

Secondly, does the animal diet compete directly with possible human nutritional use (e.g. many grain- and soya-based concentrates in feed-lots), or does 'waste' comprise a large proportion of the feed? Finally, to what extent do the ruminants access and utilize rangeland browse or fodder which are not suitable (for biological or geographical reasons) for human consumption? The advantage of the latter would however be reduced substantially if overgrazing leads to desertification and to net loss of stored soil carbon.

Livestock agriculture consumes significant amounts of cereals and other crops (and process wastes e.g. from oilseeds). Many of these crops are dependent on the use of nitrogen fertilizers. The default figure in the IPCC guidelines on soils emissions is that about 1.25% of applied nitrogen is lost as N_20. Thus some 100 million tons of inorganic N is produced annually by the Haber-Bosch process which will produce an estimated N_20 emission equivalent to some 0.3Gt CO_2e per year. A recent paper (Davidson 2009) suggested a higher rate of loss: 2 to 2.5% which would give a figure of 0.6 to 0.8 Gt CO_2e. As the Haber process itself is very energy intensive, this has a further CO_2 cost estimated at 3 -5% of the world's natural gas production or 1 to 2% of global energy use - perhaps another 0.3 Gt CO_2. Soil microbes do not distinguish between inorganic and organic N so another tranche of N20 emissions, probably of a similar magnitude (see Foresight report) must be attributed to organic residues, manure and slurry, used on crops and grazing land, so a total attributable to nitrogen fertilization alone of well over 0.6 t CO_2e i.e. 10% of the 'ration' is not unreasonable. As this conference is primarily concerned with the drylands, methane emission from paddy rice will not be discussed but is not unimportant.

While ruminant products e.g. beef, lamb and goat meat, milk, cheese, yoghurt etc. carry the largest GHG foot prints per kg produced, other animal-base products including poultry meat have a significant impact; the latter much magnified by a total global poultry population of over 23 billion. Intensive systems of livestock agriculture also produce significant indirect emissions. These are an increasing focus of research, and are estimated or calculated through the application of life-cycle analysis (LCA). We have already alluded to feed-concentrates but we need also to consider the requirements in livestock farming systems for electricity, bedding and housing, fuel used in land management and product or input transport, fertilizers and agrochemicals used in the production of feeds and the management of grasslands, and soil emissions (primarily N_2O) from grazed and arable land supporting the livestock. With the exception of soil emissions, these are not included in the agriculture section of Figure 2 but instead make very significant contributions to most of the other sectors (see also below). In most ruminant production systems these emissions represent about 50% of the total GHG footprint – but in non-ruminant production, without the large methane emissions associated with enteric fermentation, they exceed 90% of emissions (Edwards-Jones et al 2009; Vayssieres et al 2010). In consequence, the actual contribution of livestock agriculture to global GHG emissions is under-represented by Figure 2 as the 50-95% of agricultural emissions depending on species is attributed to other sectors, much of it in global industry and transport.

Predicting future GHG contributions from livestock agriculture

Livestock emissions

In order to assess the future proportion of total GHG emissions arising from food production and use by 2050, two approaches have been adopted. [1.] Current proportions of different animal types and their diets and associated GHG emissions are assumed to be maintained as global demand increases with human population growth ("linear stock increase"). [2.] Trends in the proportions

of livestock observed since 1960 are extrapolated, as an increasing per capita demand for meat - i.e. de facto a steady growth in global 'middle class' prosperity ("incremental stock increase"). Both scenarios assume that calamities can be avoided and that more resources are not diverted to energy crops at the expense of food production. Emissions from livestock agriculture (Fig. 4) are calculated from these resultant animal populations in three ways: [a] considering only the direct emissions (methane and nitrous oxide) from the animals themselves; [b] these direct emissions plus the typical indirect emissions (as listed above) associated with that type of livestock (adapted from Edwards-Jones et al 2009; Vayssieres et al 2010) and [c] direct and indirect emissions plus extrapolated land use change (LULUCF) emissions, associated with the expansion of livestock agriculture, required to meet demand by the increasing human population. LULUCF emissions are, however, held at 2005 values because a) Fig.3 suggests that their global contribution to GHG emissions has been broadly stable at 5Gt CO_2e / year since 1970 (FAO 2010) and b) the future extent of land conversion and emissions from biomass are difficult to predict given the uncertainty in climate change scenarios and the potential for agricultural intensification in already-deforested lands.

In 2009, direct gas emissions from livestock produced approximately 0.5t CO_2e / person / year: adding the indirect emissions from livestock agriculture raises this total to 2.2t CO_2e. This increment is large because the global stock population includes a high proportion of (non-ruminant) poultry and pigs, both widely produced in intensive systems heavily dependent on concentrate feeds (high emissions from cereal, soya and fertilizer production, transport etc.) and producing very nitrogen-rich waste (high waste and soils emissions). A further 0.5t CO_2e from LULUCF emissions (2005 value, FAO 2010) brings the 2009 total to approx. 2.75 t CO_2e per capita.

Direct emissions from livestock in the 'linear stock increase' scenario remain constant at 0.5 t CO_2e; i.e. while **total** emissions will rise in line with population, there is no ***per capita*** change. However when the historic increase in meat consumption is also projected – then livestock direct emissions increase to approx. 0.75 t CO_2e *per capita* by 2050. The projections based on combining both direct and indirect emissions (including poultry and pigs), and these two elements plus a constant component from LULUCF show a decreasing trend in *per capita* emissions. But, as noted in the early paragraphs, this projection is based on the highly optimistic assumption that all global energy-related CO_2 emission will decrease so that the global energy supply and use system – and hence most indirect emissions -will be progressively de-carbonized. This may not be realistic but allows the animal and land components of the agricultural food chain to be critically examined. Despite the decreasing *per capita* total, by 2050 emissions will be between 1.2 and 1.7 t CO_2e (assuming that global dietary trends continue). It should be noted that these are probably underestimates as no allowances are made for additional rice production, grain for direct human use or any acceleration in land clearance or deforestation to provide additional fodder.

Emissions reductions required to minimize climate change

A number of projections have been made by atmospheric scientists of the trajectories of global emissions that are compatible with limiting the mean global temperature rise to 20C. More recently, as this limit seems increasing likely to be exceeded, similar work on a mean 40C scenario has been published by **Royal Society**. These extrapolations are based on the critical total additive anthropogenic CO_2e load, mainly CO_2 itself, that can be added to the planetary atmosphere in the next decades (CO_2 resides for over 100 years). Estimates of this critical load for a 20C

temperature rise are of the order of 750 Gt CO_2 (Baer 2008) to 1000 Gt CO_2 (Meinshausen et al 2009). Since global emissions are approaching and may soon reach 50 Gt per year, this implies that, within 40 years at best, anthropogenic emissions should (improbably) be reduced to zero.

One logical outcome of this argument is that the longer the world waits to start making substantive cuts, the steeper these cuts must be to stay within the total critical load. Otherwise the world will have to seek to accommodate a 3 to 4^0C mean temperature increase. But broadly it is reasonable to suggest that to have any chance of re-equilibrating atmospheric radiation fluxes, all anthropogenic emissions must fall to between 1 and 1.5 t per head by 2050 for a (predicted) population approaching 10 billion. Figure 5 is an example of one of these emissions reduction scenarios, BUT based on a stable global human population of 6 billion (Baer 2008).

In the projected livestock emissions (Figs. 5 and see also Fig.7) the 2009 direct plus indirect emissions decline from ~1.7 t CO_2e to 0.7 or 1.2 t CO_2e *per capita* by 2050; taking the (optimistic) view that GHG reductions within the global energy economy are fully reflected in the agricultural indirect emissions footprint. We have held the LULUCF contribution at its 2005 value but the increased cereal production required to support intensified livestock production is likely to continue to put pressure on land in developing countries and this again may be too optimistic.

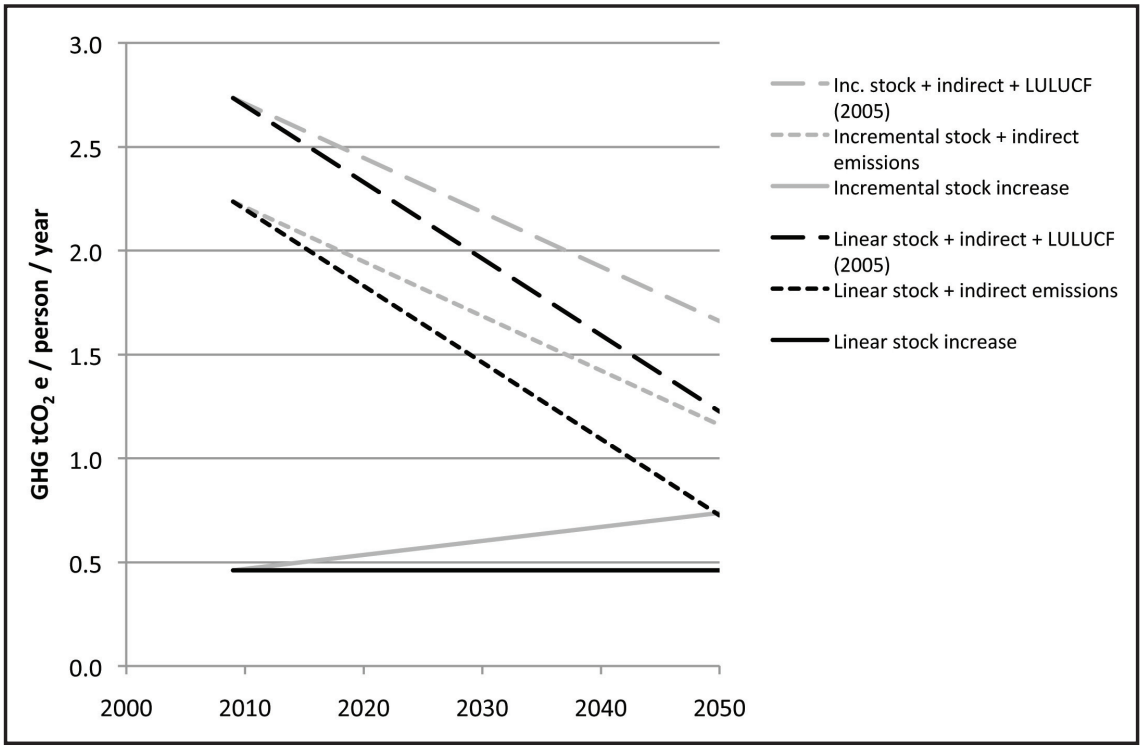

Figure 5: Predicted 2009-2050 per capita GHG emissions from livestock agriculture and land-use change.

Plotting Figures 4 and 5 on the same axes (GHG in tCO_2e *per capita* with time) Fig 7 shows clearly that even at 2009 *per capita* rates of meat demand, by 2050 livestock agriculture alone will produce more than 60 % of the human GHG emissions budget set to minimize the risk of significant global climate change. If we continue to demand more meat *per capita* globally, before 2050 livestock agriculture will account for more than our individual GHG budgets; and including land use change emissions brings this crisis forwards by about a decade.

Finally, we note that our GHG projections assume an increasing human population, while the emission reduction curves fallaciously assume a stable human population of six billion. If increasing population were to be factored into the projections, the curves from Baer (2008) should be shifted to the left – bringing their intersection with the livestock and food production emissions projections even earlier.

Implications

This paper is not intended to assess the many and various components of the food chain that lead to methane, nitrous oxide or CO_2 emission from agricultural systems and food production, storage, processing and home use and associated waste. It is sufficient to note that many aspects of the latter are very closely tied into the fossil-fuel dependent, CO_2-generating energy market and for this exercise, this is assumed to fall in a world of de-carbonised energy. Our point is to note that, even ignoring the details of energy demand and fossil fuel use, very serious problems are clearly on the horizon.

Projections suggest a global population of 9 to 10 billion by 2050 and it seems reasonable to use the latter figure in this paper. Unless the global economy collapses or major environmental catastrophes strike, this growth will be accompanied by a change in diet with a greater demand for meat and dairy products e.g. milk, cheese, yoghurt, butter etc. Meat preferences reflect local religious and social norms and so product demand will vary regionally (with implications for the regional GHG profile) but overall there must be every prospect of a doubling of demand for meat and related products. It should be noted that the dairy and beef sectors overlap strongly and are interdependent both economically and systematically.

Assuming a doubling of total meat production - retaining the current livestock species profile, and using current technologies, then global emissions of ~1.7 Gt CO_2e per year *per capita* must be anticipated. This therefore would take up the whole personal allowance of all world citizens by 2050 on the basis of the best climate scenarios (Fig. 7: Baer 2008 (14-32%) line) – those designed to avoid a $>2^0$C rise in mean global temperature [noting that population growth is not factored into Fig 6]. Clearly, projecting further forward is even worse as the GHG allowances (expressed as a global total or per head) should continue to fall in order to re-equilibrate global atmospheric forcing. This scenario is predicated on the improbable assumption that all CO_2 emissions arising from energy generation, transport, including aircraft, cement manufacture and, of course, food processing and miles will be removed either at source or by some global geo-engineering. Any remaining emissions from these sectors will, of course, worsen the situation.

These conclusions present very real challenges to food production, both globally and especially to dry land systems with their pastoral communities.

The prime objective of this paper is very simple: to emphasize the case for putting mitigation i.e. finding ways to maintain production but with much lower GHG emissions, firmly on the dry agriculture research for development agenda in the dry lands.

However some general points must be made:

1. The international community is alerted to the revolutionary challenge of meeting global food demand of a population nearing 9 to10 billion in the next decades given physical constraints of climate change, water and land allocation and desertification as well as socio- economic issues.

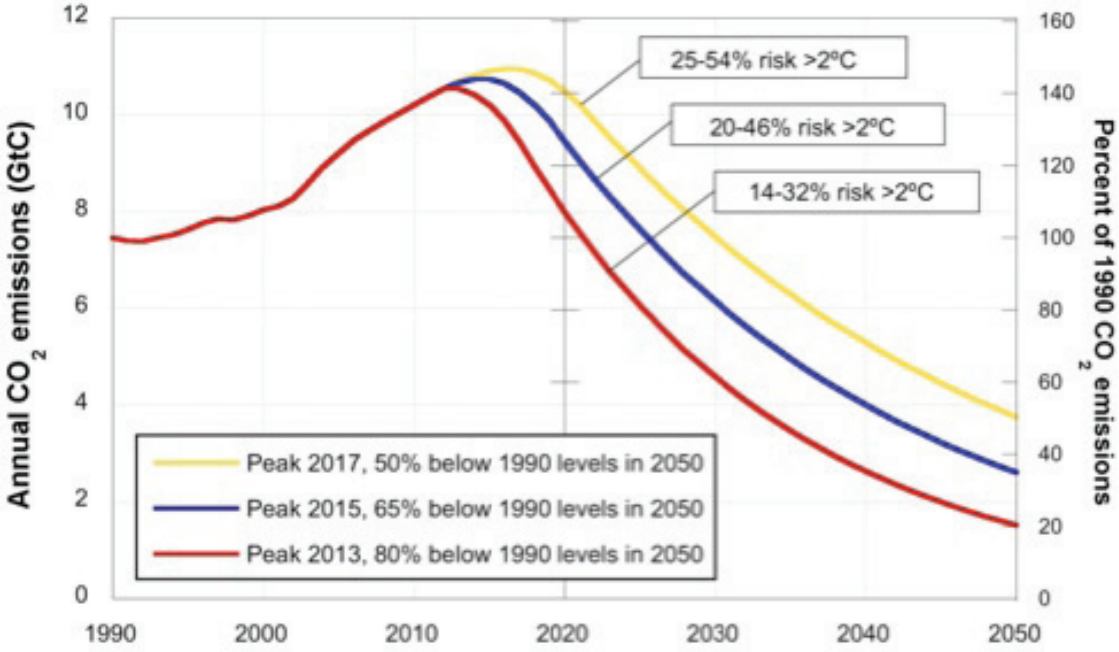

Figure 6: Global emissions (t CO2e) for three climate change scenarios based on a human population of six billion. Curves represent global emissions trends associated with different probabilities of a significant rise (>20C) in global temperatures (Baer 2008).

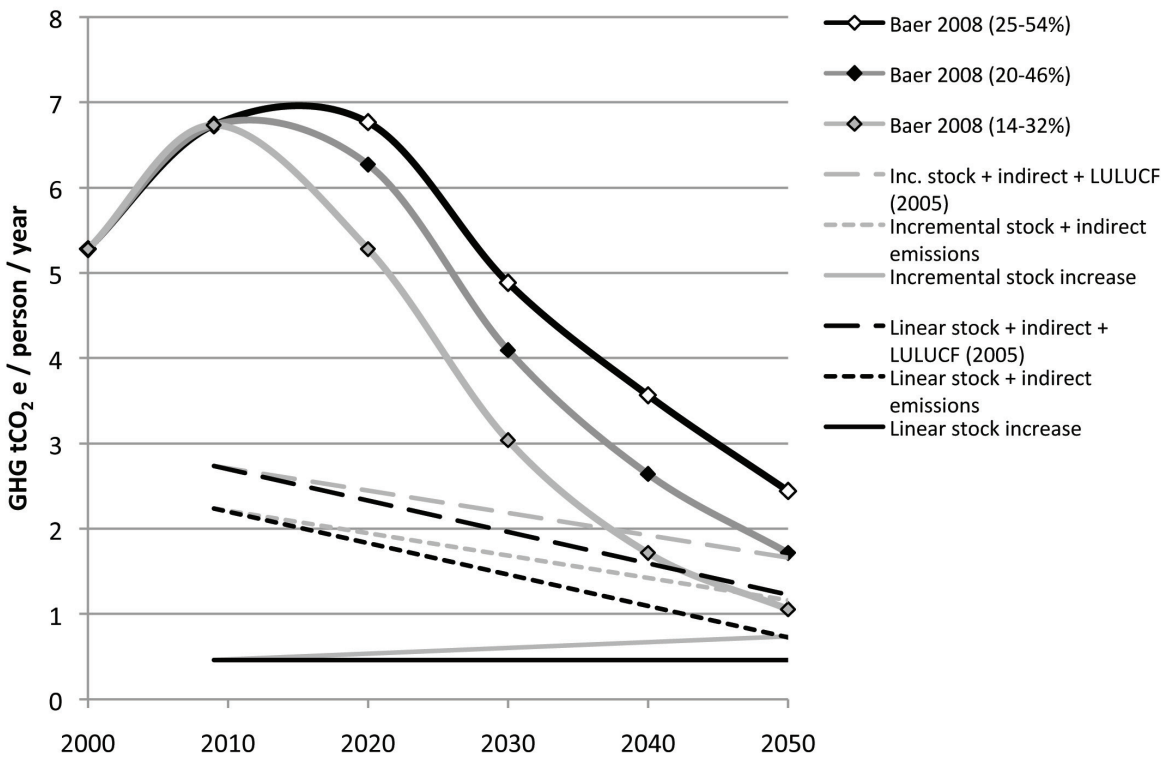

Figure 7: Per capita global emissions scenarios plotted against predicted emissions from livestock agriculture.

2. The challenge of doing so without the food chain itself becoming a perpetuator of damaging climate change and exacerbating the problem noted above, even condemning this planet to a downward spiral, is much less acknowledged.

3. Population is a major driver as it follows inexorably that the higher the global population the lower the personal GHG allowance compatible with climate stability.

4. Simply to complain about red meat production and consumption is misleading and naïve. Very large areas of the planet and many peoples, some of whom are very poor and marginalized, depend on animal-based pastoral systems.

5. Nevertheless dietary options and preferences are critical, especially in the developed world.

6. A revolution is required not just in total production and productivity but in production methodology and in the whole food chain to make drastic cuts of the order of 70 to 80 % in emissions [N2O, CH4 and CO2] per unit product.

From a drylands perspective there are real dangers. In the first place evidence shows intensive systems to be more efficient in terms of product [meat or milk] per unit GHG emitted (but noting the caveats listed earlier). This may work against extensive pastoral systems. Secondly, intensive systems may be more amenable to further efficiency gains such as from anaerobic digestion of manures and slurry to produce useable biogas, methane scrubbing of gases from housed systems etc. Thirdly, many dryland and mountain pastoral communities are highly traditional as well as being marginalized and may be slow to embrace change - or indeed have a limited capacity to do so. For example, evidence suggests that some feed additives will decrease enteric emissions but supplementation may not be possible to implement in local systems. Finally dryland and some mountain pastoral systems themselves are very susceptible to weather patterns and projected climate changes.

If, in a decade or so, events dictate a major global push to make dramatic and rapid cuts in emissions, such pastoral communities may elicit little sympathy or concern. They may even be seen, perhaps unfairly, as the authors of their own problems. It should be recognized that the residence time of methane in the atmosphere is much shorter than that of CO_2 - so that a decline in methane emissions could be construed as having a greater short-term impact and consequently be a convenient target for rapid GHG reductions.

We would argue that mitigation is of special significance to drylands because of their climatic fragility, because of their high dependence on integrated ruminant-based systems and because of the cultural and social significance of livestock to their societies.

The scenarios developed in this paper pose major technical, social and ethical problems. The technical issues relate to the possibility of making drastic cuts in methane and N_2O emissions from within agri-food production - especially ruminant-based systems. Space does not admit any discussion of these.
However given the conservative, traditional nature of many agricultural communities, it must be doubted whether even if research in the next 10 to 15 years makes enormous strides in developing low-emission livestock production systems - e.g. GM low methane sheep and goats - it will be possible to roll out such systems to the whole world by 2035. Such systems may also be capital - and knowledge - intensive. After all, the successes of the CGIAR have been most apparent in the productive, most accessible regions. Many dryland systems have changed little.

Social pressures, in parts of northern Europe - mainly related to obesity, health issues and body consciousness - may drive down red meat consumption; with environmental concerns also playing a small role. There is little evidence that a vegetarian diet (of which there are many variants) using eggs, milk, yoghurt and cheese as well as grains, grams, fruits, nuts etc. will solve the problem. A rigorous vegan diet would undoubtedly make a major difference but without an agreed global scheme of formal rationing it is very difficult to envisage, still more enforce. Such considerations

will have little or no leverage in the developing world given current hunger, the fear of future shortages and the huge reservoir of un-fulfilled ambition. Yet the data suggest, uncomfortably, that a significant part of the projected problem to 2050 both in population numbers and in dietary change lies here. There seems little likelihood of a rapid mass transition to a vegetarian or vegan diet in the developed world; nor it is clear that it would provide a satisfactory solution. Moreover we suggest that the term 'developed' should refer to all those individuals in any country able to afford and aspiring to live a particular life and dietary style, not an over-simplistic country or regional definition.

But there remain major ethical issues particularly pertinent to the drylands. The semi-arid, arid and mountainous areas have historically depended on pastoral systems, usually ruminant based, to utilize the dispersed and irregular pastures. Many cultures have evolved from Mongolia to Mauritania from Lesotho to Lapland based to a symbiotic relationship between humans and animals. Traditionally such societies have had a low ecological footprint - although, in the modern world some have (by a partial adoption of facets of modernity) contributed to desertification. Many of these communities appear to be at particular risk from climate change as well as being reliant on a system making, inadvertently, a modest contribution to this global problem. Consideration must be given to the rights and futures of such societies. One cannot imagine the Masai Mara without the Masai or the Badia without the Bedu. These and countless other societies also have their legitimate historic rights while also desiring to improve their living standard. Climate change is predominantly a problem derived from the developed world (wherever located). There can be no case for the pastoral herders being asked to shoulder an additional GHG burden over and above the social burden imposed by adapting to climate change. As increasing stock number is unlikely to offer a route out of rural poverty - and increasing productivity will be problematical - it follows that if they are soon to have a low GHG foot-print, non-agricultural development routes must be prioritized. But it may become important to record and formalize the claims of cultural groups to protect their traditional rights while the great majority of intensive animal production systems, especially those feed lot-type systems using nutrients directly competing with human use, will have to be more rigorously controlled.

Both internationally and in the drylands, mitigation and adaptation must be seen as partners, lest we enter a futile downward 'vicious cycle' of climate change brought about by our own agricultural systems for feeding the growing population. Without such a partnership the search for resilience will be futile.

Summary

There are serious dangers that within 30 years, the agriculture and food chain sector will become the perpetuator of damaging climate change and global warming, even if other technologies are in place to minimize other CO_2 emissions. We seek to make the case that mitigation of GHG from this sector is as important as adaptation; particularly as climate change will be highly detrimental to the dry lands. Given the importance of animal-based systems in these areas as well as their fragility, we suggest that mitigation must become a major research and developmental priority in the drylands.

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2.2. Enhancing agricultural productivity in dry areas: the key role of scientific innovation

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Abstract

Dry areas cover 41% of the earth's surface, and are home to the majority of the world's poor. Agriculture in these areas is threatened by a number of biophysical as well as socio-economic constraints – particularly by the likely impacts of climate change in the near future. Dry areas, more so than other ecoregions, are highly vulnerable to climate change – which will exacerbate many of the biophysical constraints including drought, temperature extremes and resource degradation. This paper discusses the challenges to dry-area agriculture in the context of climate change, and technologies that have been used successfully to overcome these challenges. It highlights the role that scientific innovation and partnerships can play to help farmers cope with climate change. ICARDA's approach combines three elements: adaptation, ecosystem resilience and mitigation. This approach includes, for example, developing improved, stress-tolerant crop varieties, improved management of water and land resources, diversifying and intensifying crop-livestock systems, and other measures that will strengthen the adaptive capacity of rural communities, particularly smallholder farmers and pastoralists. Successful technologies described here include identification of novel genes and sources of valuable plant traits (resistance/tolerance to biotic and abiotic stresses), improved crop varieties, disease and pest management, protected agriculture, value addition through home or community-based processing, conservation agriculture, integrated crop-livestock systems, and socio-economic research to understand the drivers of change and improve research and development targeting. Perhaps most important in dry areas is water management: water harvesting, supplemental irrigation, deficit irrigation and other methods to increase water productivity.

Crucially, research outputs must be supported by enabling policies, strong institutional frameworks and sufficient political will to encourage technology adoption, efficient use of scarce natural resources, equitable market access, and above all sustained investment in research and development. The paper stresses the need for three further elements: (i) broad-based partnerships, with multiple institutions working towards a shared goal, (ii) integration of the three pillars of research: natural resource management and inputs, crop and livestock genetic improvement, and socio-economics, policy and institutions, (iii) engagement of all stakeholders at all stages of the research-development continuum, from advanced strategic research to adaptive research and dissemination.

1. Introduction

Dry areas (Fig. 1) cover 41% of the earth's surface, and are home to over 1.7 billion people – and the majority of the world's poor. Of these about 16% of the population lives in chronic poverty, particularly in marginal rainfed areas.

Dry areas particularly in developing countries, present significant challenges to smallholder agriculture. These include:

- Fragile ecosystems
- Severe water scarcity: low and erratic rainfall, frequent droughts, groundwater depletion, etc.
- Rapid natural resource degradation and desertification (Fig. 2)
- Salinity

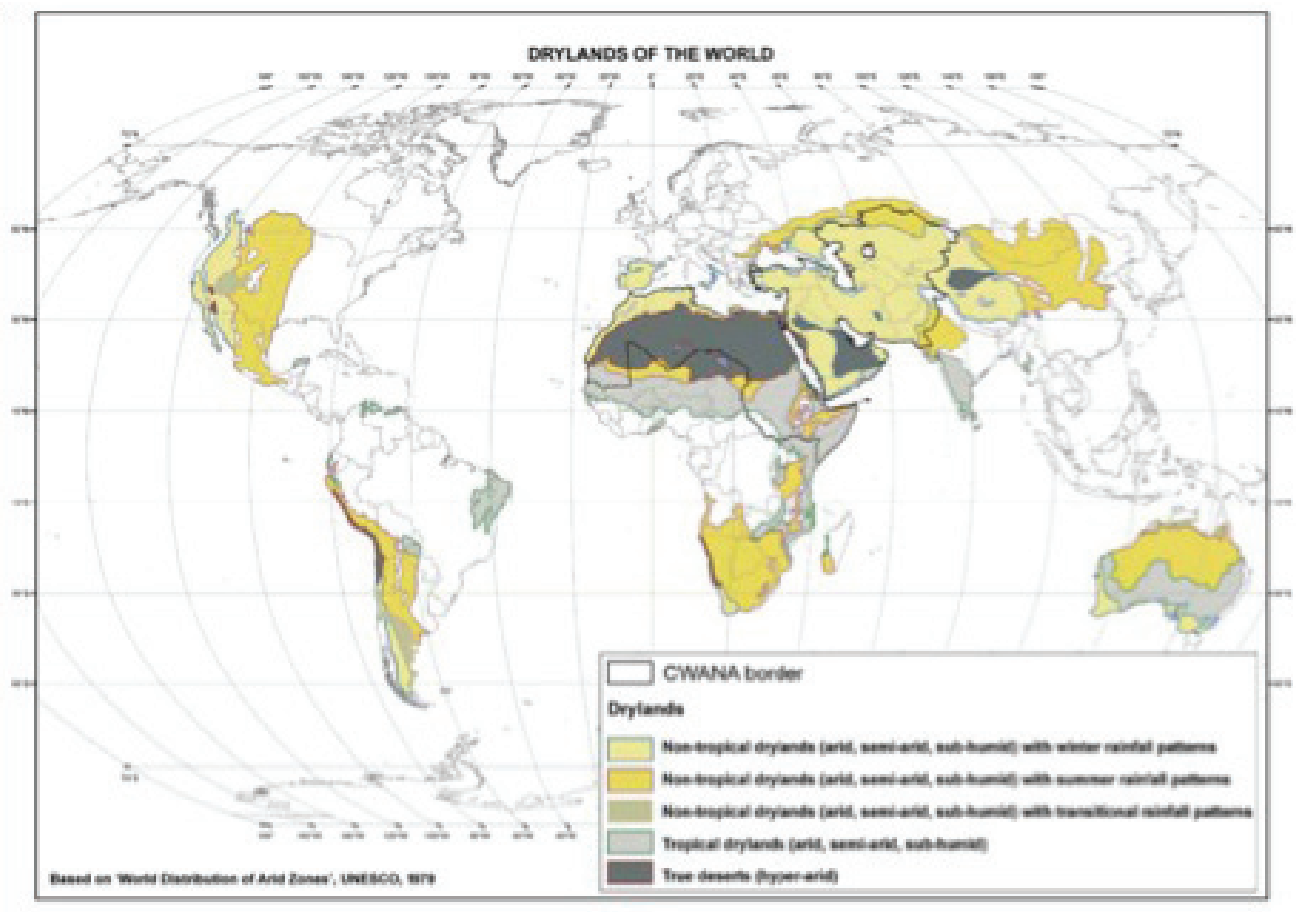


Figure 1. Dryland regions, classified following standard nomenclature.

In addition, dry areas, more so than other eco-regions, are highly vulnerable to climate change. Most standard climate models predict that climate change will exacerbate many of the challenges listed above.

This paper will describe some of the challenges, discuss the potential impacts of climate change, describe technologies that have been used successfully to overcome these challenges, and highlight the role that scientific innovation and partnerships can play to help farmers and pastoralists in dry areas cope with climate change.

2. Implications of climate change

The likely impacts of climate change on temperature, precipitation, crop productivity etc are widely discussed in the literature. In summary, climate change is expected to lead to:

- Changes in precipitation total and distribution, and drought occurrence and intensity
- Extreme temperatures
- Changes in agro-climatic zones
- Changes in length of growing season
- Newly emerging diseases and insect pest threats.

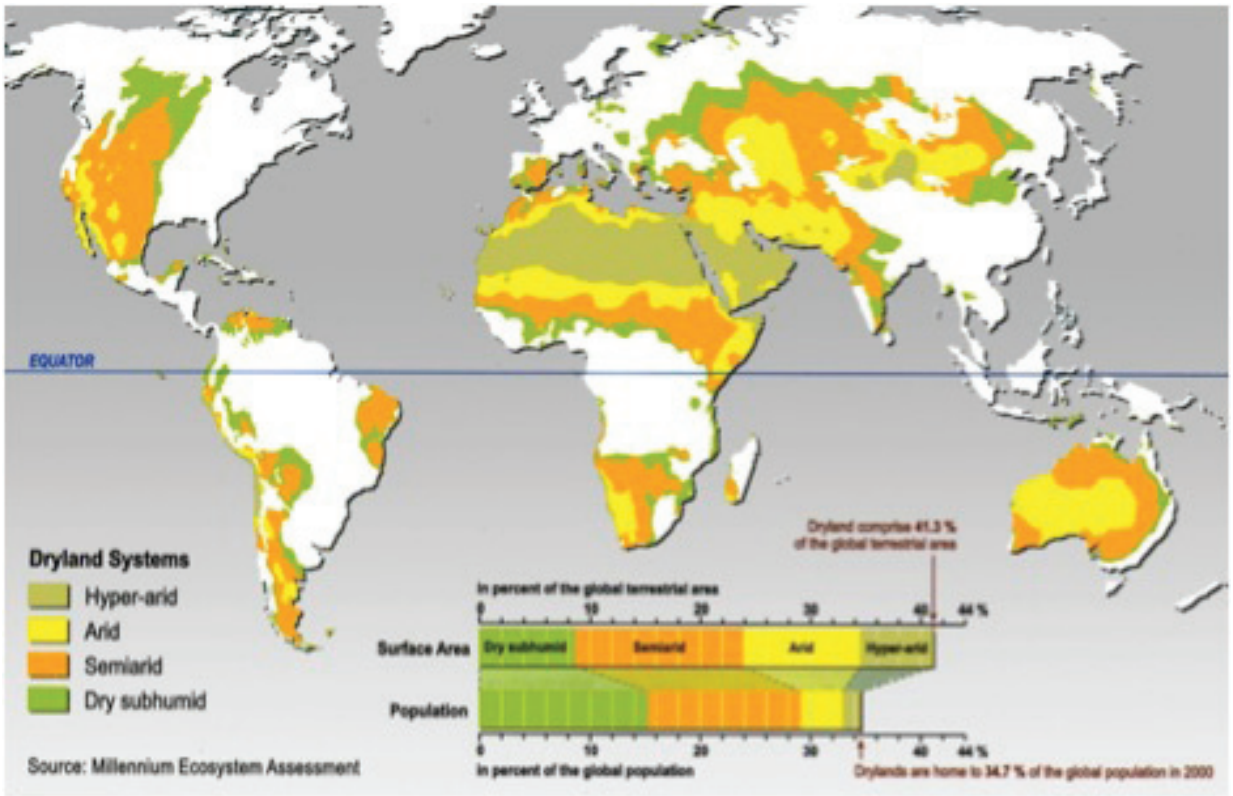


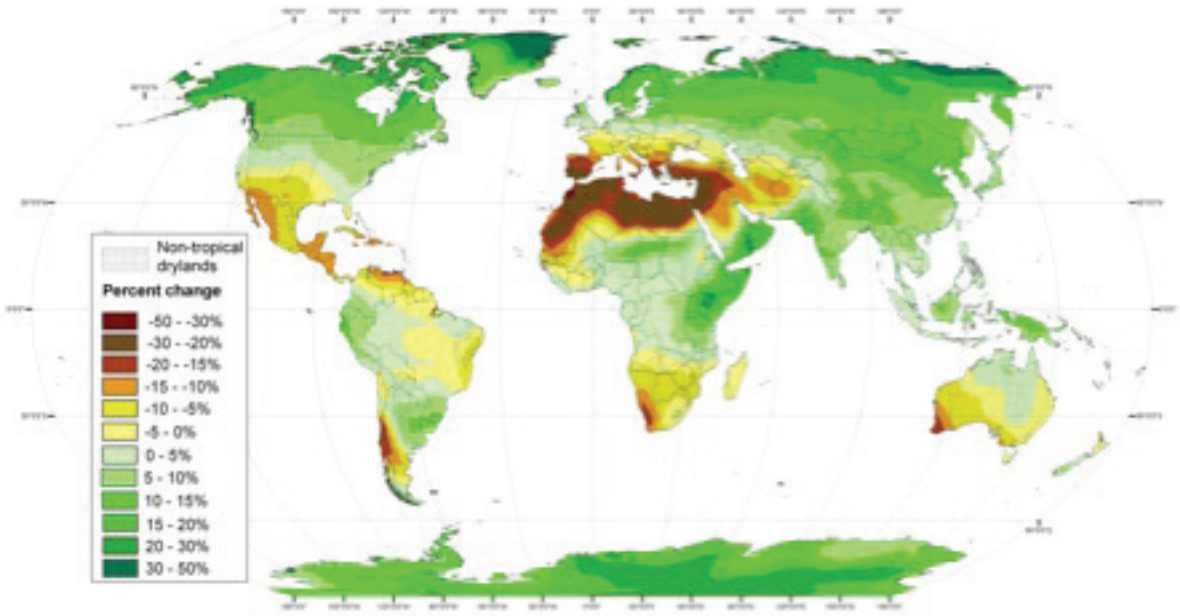
Figure 2. Dry areas are highly vulnerable to desertification.

2.1. Precipitation

Figure 3 shows expected changes in precipitation, averaged over a large number of general circulation models (GCMs). Clearly, the Mediterranean region – more broadly, West Asia and North Africa – will be severely affected by climate change, with a large part of the region experiencing at least a 20% decrease in rainfall. Climate change will also increase the frequency and severity of drought in the region, as illustrated in Fig. 4.

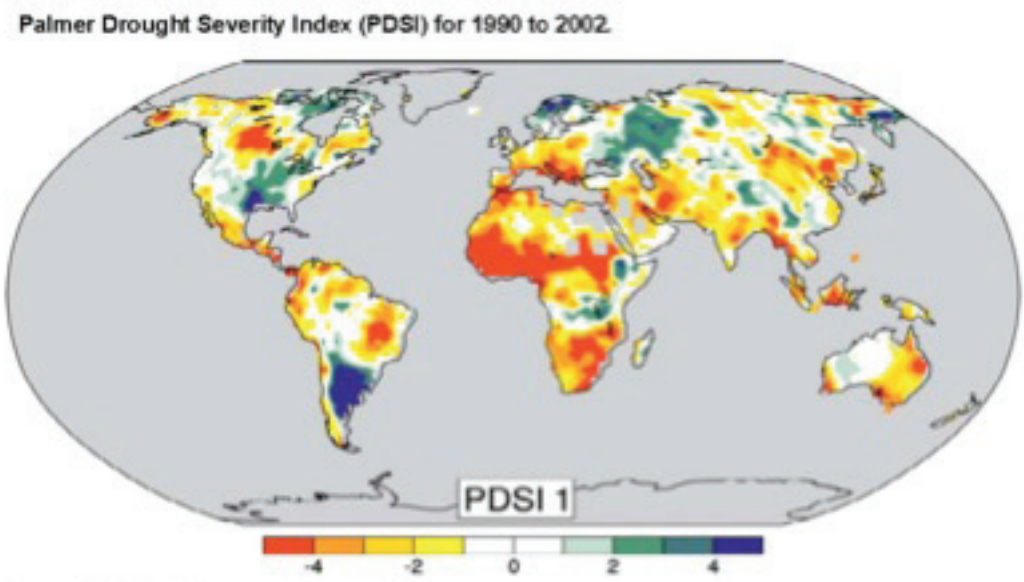
2.2. Change in climatic zones and growing season

Studies for the Eastern Mediterranean, using a medium-term prediction period of 2010 to 2040, suggest that 90% of the lands in the study area will remain in the same climatic zone (according to the classification of Köppen), while 10% will change into other climatic zones. Syria and Jordan will be among the worst affected countries: 30% of the land will change from a steppe to a desert climate. Lebanon and the West Bank will also witness substantial shifts of climate zones.



Scenario A1b, average of 21 GCMs (compiled by GIS Unit ICARDA, based on partial maps in Christensen et al., 2007)

Figure 3. Relative change of mean annual precipitation 1980/1999 to 2080/2099.



Source: IPCC Fourth Assessment Report, 2007

The Palmer Index measures drought as normalized departure of temperature and precipitation from long terms normals. In the Maghreb and parts of the Mashreq, there have been extreme droughts in 1990-2002 (Palmer index of -4)

Figure 4. Increased drought frequency in North Africa and West Asia, 1992-2002.

In terms of length of growing season, the study suggests that most of the study area in the Eastern Mediterranean is likely to experience moderate reductions (up to 15 days) in the growing period. In certain parts of Iraq, Syria, the West Bank and Cyprus the reduction in the growing season will be more pronounced and in the range of 15 to 30 days. In some of the high mountain areas of Lebanon, the growing period will actually increase due to higher temperatures, which will reduce the number of days when low temperatures limit growth.

2.3. Disease and insect pests

Climate change is likely to significantly alter environmental conditions, and therefore the incidence and spread of diseases and insect pests. In addition to creating technical challenges for breeders, this raises the possibility of disease and insect pest epidemics that could cause drastic losses in food output. To give two examples, Syria experienced heavy yellow rust infestation in the 2009/10 season, causing widespread damage to wheat – the staple food crop. In 2008/09 large-scale infestations of the barley stem gall midge (which is not normally prevalent in the country) affected barley, the main source of livestock feed.

3. Vulnerability

Resource-poor farmers are the most vulnerable. The poor will be disproportionately affected by climate change because of their greater dependence on agriculture and their lower ability to adapt. In the poorest countries farmers will not be able to adapt to climate change without outside help.

Farmers are already using various strategies to adapt to climate change: including planting new early-maturing varieties or different crops, changing planting dates, and adapting crop management practices to shorter growing seasons. Agricultural constraints in dry areas will increase in the future, implying that smallholder farmers will require even more assistance. This must be urgently addressed – especially since research investments, institutional support and enabling policies have all been inadequate for decades.

4. ICARDA's approach

ICARDA and its partners take a holistic view in our collaborative research-for-development projects. The aim is to help farmers achieve sustainable increases in crop and livestock productivity, and more efficient use of natural resources, and to better cope with climate change impacts. The strategy combines three elements:

- Adaptation
- Ecosystem resilience
- Mitigation

For example, climate change adaptation involves developing improved crop varieties with more tolerance to drought, extreme temperatures and encroaching salinity. Ecosystem resilience is developed through diversification and sustainable intensification of integrated crop-livestock systems that create broader and more stable sources of livelihoods. Risk management tools help strengthen the adaptive capacity of rural communities, particularly smallholder farmers and pastoralists. Crucially, research outputs must be supported by enabling policies to encourage technology adoption, efficient use of scarce natural resources, and equitable market access.

5. Role of scientific innovation

New technologies can help farmers cope with climate change. Many of these technologies have been tested in dry areas, and shown to be successful in enhancing food security and improving livelihoods. This section presents some of these technologies, developed, tested, validated and promoted by ICARDA and its partners. These partners include national agricultural research and extension systems, sister CGIAR Centers, universities, advanced research institutes, farmer organizations, NGOs and the private sector.

5.1. Conservation and use of diversity

Researchers are using genetic diversity – germplasm from diverse sources – to develop improved, adapted crop varieties that can offer higher yields and simultaneously help to cope with climate change.

The genebank at ICARDA's headquarters in Tel Hadya, Syria, holds 135,780 accessions. Most of these accessions are safely duplicated in other reliable genebanks around the world. For example, more than 90,000 accessions are being stored in Svalbard Global Seed Vault in Norway, under an agreement involving multiple international centers.

About two-thirds of ICARDA's genebank holdings comprise unique sets of landraces and wild relatives, collected mostly from dryland areas in the CWANA region (Central and West Asia, North Africa). This region encompasses four major Vavilovian Centers of diversity; and the origin of many of the world's most important crops. For these crops, and many others, the CWANA region contains tremendous diversity, both in cultivated landraces and wild species. Efforts to conserve and freely share these genetic resources are ongoing and will continue. Previous collection efforts focused on landraces and wild relatives – from diverse ecogeographic origins. Future collections will be based on gap analysis and targeting of species with valuable traits.

5.2. Novel genes

ICARDA and its partners are working to identify novel genes or sources of specific traits from wild or progenitor species, and transfer these into cultivated varieties. Genes from these species can be transferred by direct hybridization, homologous or homeologous recombination, backcrossing and selection. For example, in wheat, the program targets gene-transfer from the wild primary gene pool and from *Aegilops* and *Triticum* species. Using wide crosses, potential sources have been identified for a number of valuable traits. These include disease resistance (yellow rust, leaf rust, *Septoria*), insect pest resistance (aphids, Sunn pest), earliness, drought tolerance, and agronomic traits such as tillering, spike productivity, plant height and others. "Synthetic" wheat lines, developed by crossing cultivated and wild genotypes, have demonstrated tolerance to severe drought (Fig. 5).

5.3. Biotechnology tools

In collaboration with national research programs in CWANA and advanced research institutes in Australia, Europe and the Americas, a range of biotechnology tools – genomics, marker-assisted selection, double haploids, embryo rescue, tissue culture, DNA fingerprinting – are being used to develop improved cultivars or breeding lines. For example, 600 barley genotypes have been

screened, using diagnostic molecular markers, to identify sources of resistance to major barley diseases. Successes include

- Scald – *Rrs1*
- Cereal cyst nematode – *Ha2, Ha4*
- Powdery mildew – *mla, mlo*
- BYDV – *yd2, yd3*

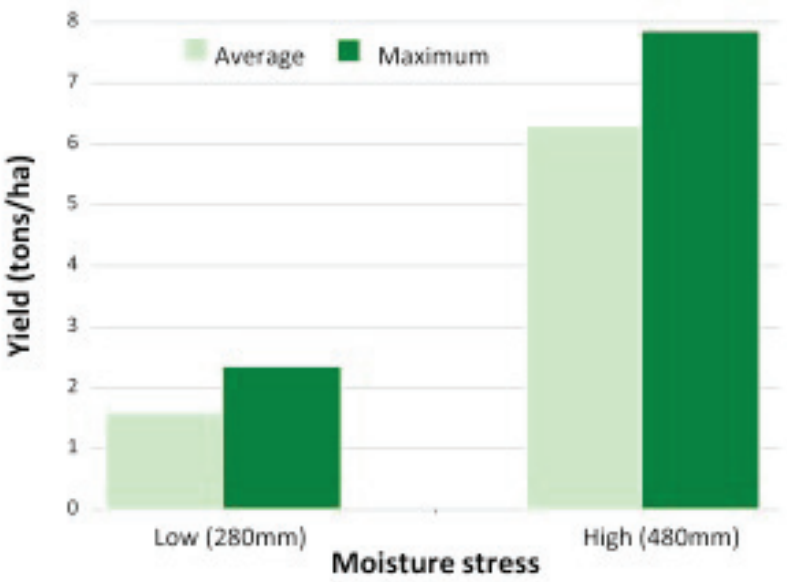


Figure 5. Grain yield of synthetic wheat lines under extremes of moisture.

5.4. Improved crop varieties

A number of improved crop varieties have been developed from ICARDA-supplied germplasm, either directly through collaborative projects or by national programs using ICARDA germplasm. The new varieties offer a range of valuable traits that are directly relevant in the context of climate change adaptation.

- High yield potential
- Agronomic traits such as earliness, and improved plant architecture
- Tolerance to abiotic stresses such as drought, heat, cold and salinity
- Resistance/tolerance to biotic stresses (diseases, insect pests, parasitic weeds)

For example, several high-yielding wheat cultivars with tolerance to heat stress (a key trait under climate change) have been developed in Sudan. This has made wheat an attractive crop south of Khartoum, where heat stress once prevented its cultivation.

Another example is the kabuli chickpea variety Gokce, developed by ICARDA and Turkish national scientists. The variety withstood a severe drought in 2007, producing yields when most other crops failed completely. Gokce is used on about 85% of the country's chickpea area (over 550,000 ha). With a yield advantage of 300 kg/ha over other varieties, and world prices over USD 1000/t, this represents an additional USD 165 million for Turkish farmers, in 2007 alone.

Crop improvement research combines traditional methods (conventional plant breeding) with modern biotechnology tools. This has been enhanced by the construction of a new state-of-the-art biosafety facility at ICARDA's headquarters, established in 2010. ICARDA has also pioneered the use of participatory breeding methods – which are being institutionalized by national programs in several CWANA countries.

More than 760 crop varieties, developed from ICARDA germplasm, have been released to date (Table 1). The new varieties have generated net benefits worth an estimated US $850 million per year.

Table 1. Improved crop varieties developed using ICARDA-supplied germplasm

Crop	to 2009 1977		Past 2 years, all countries
	Developing countries	Industrialized countries	
Barley	175	31	6
Durum wheat	102	14	1
Bread wheat	224	6	9
Chickpea	108	31	9
Faba bean	51	6	1
Lentil	96	16	9
Forages	30	2	2
Peas	9	0	0
Total	**761**	**120**	**24**

5.5. Seed production

Lack of seed is often a major reason for the slow adoption of new varieties. ICARDA has a specialized Seed Systems Section that focuses on improving seed systems, both formal and informal. This work includes supply of nucleus seed, technical support and training for seed production and variety maintenance, as well as innovative approaches such as village-based seed enterprises (VBSEs) that have proved highly successful in smallholder communities in Afghanistan, Pakistan, Eritrea and Egypt. In Afghanistan, 17 VBSEs have been established in eight provinces; all are viable and self-sustaining, and provide high quality seed at fair prices – and also create employment in remote rural areas. Another example is the 'grain for seed' system to cope with drought. In a good season with no seed shortage about 75% of the seed required for planting comes from farmers themselves. In a drought year (increasingly frequent as a result of climate change), seed shortages can be severe. However, it is possible with advanced planning and management to convert grain for seed for planting. This can be used to maintain an adequate supply of certified seed with known varietal purity and performance.

5.6. Stem rust disease

ICARDA and its partners are playing a key role in combating a new race of stem rust disease, Ug99, that could threaten global food security. The new race has spread from East Africa, across the Red Sea into West Asia, and now threatens South Asia and other regions. Partnerships

involving more than 30 countries, have led to major advances. Working with the national programs of Egypt, Ethiopia, Sudan and Yemen, possible routes of spread of the pathogen have been mapped using GIS technology. Disease surveillance and monitoring networks have been established. Recently, two Ug99-resistant durum lines (Bakalcha and Malefia) were released in Ethiopia. For bread wheat, several resistant lines have been developed, and seed is now being multiplied in Egypt, Ethiopia, Iran and Pakistan.

5.7. Winter legumes

Food legumes such as chickpea are a vital source of protein, as well as cash income, for smallholder farmers throughout the region. ICARDA and its partners have pioneered winter-sowing technology that enables the crop to better utilize available moisture and significantly increase yield. This innovation has been made possible by developing varieties resistant to Ascochyta blight disease and tolerant to cold – which earlier made winter sowing highly risky. With the new technology packages, chickpea can be grown in areas that were considered too dry or too cold. This is a good example of innovations needed to cope with ecological changes expected as a result of climate change.

5.8. Integrated pest management

The Sunn pest complex affects more than 15 million ha of wheat in North Africa, West Asia, Central Asia and East Europe. Severe infestations have been known to reduce wheat yields by 50-90% in some areas. In the highly successful Integrated Pest Management (IPM) program, researchers focus on several components:

- Establishment of economic thresholds for insecticide use
- Hand collection of Sunn pest in overwintering sites
- Use of insect-killing fungi in overwintering sites
- Enhancement and conservation of egg parasitoids
- Genetic resistance at the vegetative stage

The IPM package combined improved varieties, better crop management, judicious use of chemicals, with a major biocontrol component. The use of natural enemies (parasitoids which attack Sunn pest eggs) reduces pest populations without the need for excessive doses of pesticide – thus reducing farmers' costs as well as protecting the environment. This research has helped change national policies in West Asia: government-supported aerial sprays have been replaced with limited targeted ground applications, on over 3 million ha. In addition, revised 'economic thresholds' have been implemented, significantly reducing pesticide use.

5.9. Water management

Climate change will exacerbate water scarcity in dry areas – many of which are already reaching critical levels of scarcity. Scientific innovation has led to several different approaches for more effective management of water in agriculture. ICARDA's water research focuses on increasing water productivity (the amount of crop or biomass produced per unit of water used) both at the farm and basin levels. The flagship project, involving ten WANA countries, aims to promote community participation, efficient use of resources, and adoption of new technologies that increase water productivity. These technologies can be considered under three groups: rainwater

harvesting, supplemental irrigation, and deficit irrigation. Results from field trials in different countries have demonstrated that water productivity is significantly higher under supplemental irrigation (small amounts of water provided, optimally timed) compared to fully rainfed or fully irrigated crops. One example is shown in Fig. 6. The project has tested and is promoting the use of the Vallerani plow, a specially designed tractor-drawn plow that can mechanize the construction of micro-catchments on marginal lands, at efficiencies of up to 40 hectares per day.

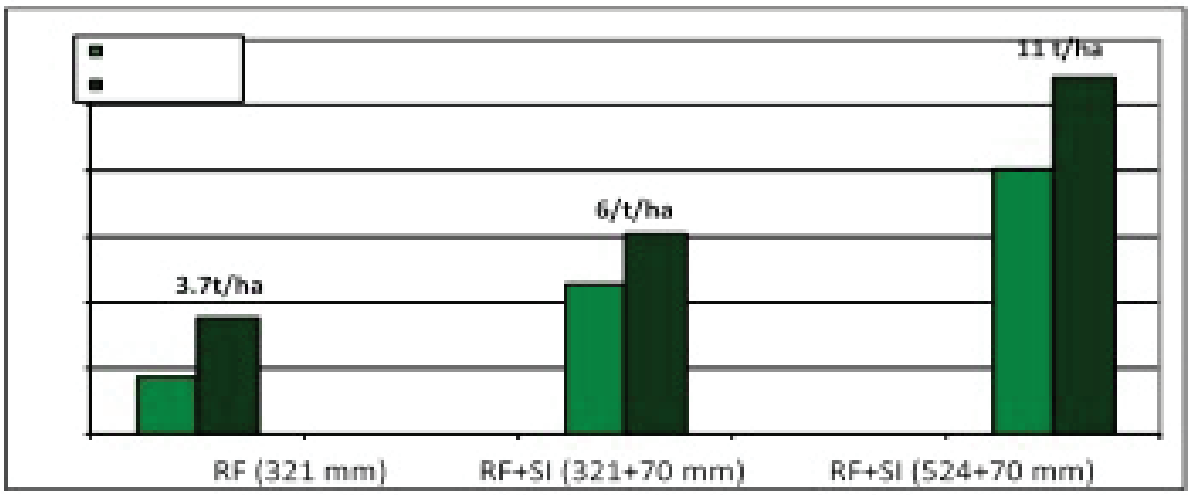


Figure 6. Grain yield of improved durum wheat genotypes under different moisture regimes in field trials in Tel Hadya and Idleb, Syria. RF = Rainfed, SI = Supplemental irrigation.

The project covers three major agro-ecosystems: marginal rangelands, rainfed systems, and irrigated systems. In rainfed systems, the package combines optimal supplemental irrigation, early sowing and other components. In irrigated systems, the focus is on increasing water productivity and economic returns on water investment; management of saline water and soils; policies and institutions; and modifying cropping patterns in light of resource availability and market opportunities. In these rangeland areas, the focus is on rangeland rehabilitation and through water harvesting: and integrating micro-catchments with fodder production.

This research has helped understand the drivers to increase water productivity at different scales:

- At the basin level: competition among uses (environment, agriculture, domestic), water access related conflicts between countries, and equity issues
- At the national level: food security, availability of hard currency, and socio-political factors
- At the farm level: maximizing economic return, and nutrition in subsistence farming
- At the field level: maximizing biological/economic output.

ICARDA has also been studying the use of alternative water resources. For example, marginal-quality water and treated wastewater have been found useful for growing cotton, forages and trees. In Uzbekistan, studies have shown that conjunctive or blended use of drainage water with regular irrigation can optimize yields, while conserving fresh water.

5.10. Diversification and intensification of production systems

To cope with climate change, farmers will need to diversify their farming systems, in order to improve ecosystem resilience, reduce risk and simultaneously create new income opportunities.

Innovations in systems diversification include: dryland fruit trees, protected agriculture and herbal, medicinal and aromatic plants. For example, indigenous fruits, such as olives, date palm, almonds, figs and pomegranate, are a potential source of cash income. ICARDA works with partners (AVRDC-Taiwan, Arid Land Center, Medinine, Tunisia and other national institutions) to identify fruit and vegetable crops and varieties to specific dryland cropping systems. Protected agriculture technologies enable farmers to cultivate small plots and marginal lands, with very high land and water productivities. Protected agriculture research focuses on different aspects: low-cost, locally fabricated greenhouses for resource-poor communities (e.g. Afghanistan, Yemen); intensive integrated management packages for greenhouses (Arabian Peninsula); and hydroponics or soil-less culture for relatively advanced growers in the Arabian Peninsula.

5.11. Geographic Information Systems (GIS)

Geographic Information Systems (GIS) are a powerful tool to analyze spatial as well as temporal factors, and to improve the targeting of research or development interventions. GIS maps have helped highlight the critical vulnerability of WANA countries to climate change. ICARDA's GIS Unit provides support to NARS' research programs, and also conducts training programs for national research staff in dryland areas. Some examples of GIS applications include:

- Land use mapping to promote diversification of production systems
- Maps with potential areas for technology targeting, e.g. water harvesting
- Maps with potential areas for de-rocking (i.e. removing rocks to expose arable land)

5.12. Conservation agriculture

Conservation agriculture is another innovation to help farmers in dry areas cope with climate change. It combines minimum soil disturbance (zero tillage), stubble retention, crop rotations (legumes, oilseeds) and early sowing of crops. Conservation agriculture offers multiple benefits: savings in time, fuel and machinery costs for land preparation; better soil structure; better soil moisture conservation; improved trafficability; higher yield potential; less soil erosion. ICARDA and its partners are helping to promote these practices (widely used in advanced countries) in West and Central Asia, and North Africa. Conservation agriculture has already spread to about 1.2 million ha in Central Asia. In West Asia and North Africa, the bottleneck has been the lack of affordable planting equipment. This has now been resolved with the development of locally fabricated, low-cost zero-till seeders developed through an Australia-ICARDA project. The first seeders were fabricated in 2008, and are now being promoted, with support from government agencies and NGOs, to farmers in Syria and Iraq. In the 2010/11 season they were used by 400 farmers to plant almost 20,000 ha of zero-till crops.

5.13. Livestock-based production systems

Small ruminants (sheep and goats) are a key part of dryland farming systems and a key source of income and livelihood stability. In many regions, rangelands are the single largest land use category. Any strategy for climate change adaptation must pay due attention to livestock production constraints. Innovations by ICARDA focus on integrating crop and livestock production, maximizing the synergies – for example between food crop residues and livestock feed. Innovations cover animal nutrition, value addition and other areas.

In relation to nutrition, the successes include improved fodder varieties, introduction of new fodder sources (Atriplex and spineless cactus) into rainfed crop systems, promotion of low-cost

‘feed blocks’ made from farm residues and agro-industrial products. The concept of ‘strategic feeding’ – supplementation at critical periods has been successfully introduced as a solution to the common problem of high feed prices in dry years. In trials, strategic supplementation using balanced but low-cost diets resulted in a net gain of US$ 18.70 per ewe. In a typical flock of 50 ewes, farmers using this technology would earn an additional US$ 935 per year. Other related aspects include flock management (practices targeted at market sales), promotion of indigenous fodder species, rather than exotic species such as alfalfa or Rhodes grass, and rangeland management and rehabilitation through community-led grazing calendars with adequate ‘resting’ periods of the natural vegetation.

Value addition research aims to increase income opportunities for the poor, by producing dairy and other livestock products for sale. These include yogurt, cheese, mohair, etc. research, which is complemented by training programs to empower farm communities – especially women – to make best use of the new technologies.

5.14. Socio-economic and policy research

Socio-economic and policy research is an integral part of any research-for-development portfolio. ICARDA’s socio-economists help to target biophysical research to the most vulnerable groups or regions, inform policy development, measure the impact of new technologies, and understand the factors determining the adoption of these technologies. Research components include:

- Socio-economic characterization at household and community levels
- Analysis – poverty, livelihood strategies, gender dimension
- Adoption and impact assessments
- Identifying policy options that will stimulate agricultural development
- Studies of markets
- Institutional frameworks
- Natural resource economics.

6. Research-for-development continuum

In order for research to translate into measurable improvements in rural livelihoods, three factors are important:

1. Strong and broad-based partnerships, because no single institution can tackle the challenges of climate change adaptation. ICARDA works with a range of partners: national agricultural research systems, universities, CGIAR centers, advanced research institutes, IFAD, FAO and other UN organizations, regional research and development fora, NGOs, community-based organizations, farmer groups and the private sector
2. Integration of the three pillars of research: natural resource management and inputs, crop and livestock genetic improvement, and socio-economics, policy and institutions
3. The continuum approach. ICARDA is engaged at all stages of the research-for-development continuum, from advanced strategic research to adaptive research and dissemination. This helps link research with development for impact.

7. Conclusions

This brief review suggests that scientific innovation has made, and will continue to make, a difference to rural livelihoods. Research outputs will enable smallholder farmers and

pastoralists to improve output, productivity and livelihoods, and minimize the negative impacts of climate change. However, innovation must be supported by other measures:

- Enabling policies
- Government and private investment in agricultural research-for-development
- Political will to rationalize policies on natural resource use
- Capacity development and institutional support
- Broad public-private partnerships
- Increased and sustained investments in research-for-development

The impacts of climate change are already being felt, and greater impacts are expected in the near future. We all have a responsibility to work together to promote sustainable agriculture in dry areas, raise production sufficiently to ensure food security for all, and protect the livelihoods of millions of households, who depend on these ecosystems.

Plenary Session 3

3.1. Mitigating climate change by combating desertification

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Abstract

Land area prone to degradation and desertification, estimated at 35 x 10^6 km^2 (23.5% of the Earth's land), affects 1.54 billion people (23.9% of the world's population in 2007), and results in a total annual loss in net primary production (NPP) of 41.5 Tg C/yr. Another estimate, based on spatial databases of global soils and climates, shows that land area prone to human-induced desertification is 7.1 x 10^6 km^2 at low risk, 8.6 x 10^6 km^2 at moderate risks, 15.6 x 10^6 km^2 at high risk and 11.9 x 10^6 km^2 at very high risks. The land area prone to very high risk was a home to 1.4 billion inhabitants in 2000. Using the GLASOD methodology, it is estimated that 19.65 x 10^6 km^2 of land area was affected by different processes of soil degradation (i.e., erosion by water and wind, salinization, nutrient depletion). Risks of soil erosion increased by about 17% because of increase in arable land area over the 20th century. Risks of soil degradation and desertification may be exacerbated with increase in radiative forcing of 3 to 8 W m^{-2} corresponding with CO_2 increase to 540 ppm and 960 ppm by 2100, respectively. The terrestrial biosphere may become a major source of CO_2 by enhancing decomposition of soil organic matter (SOM) and the associated release of soil carbon, especially that from the soils of northern latitudes. An important characteristic of these degraded and desertified soils is the severe depletion of their ecosystem C pool because of the loss of C from soil and the biota. Thus, these ecosystems contain as low as only 20 to 25% of the antecedent C pool. Consequently, the large technical/potential C sink capacity can be realized through conversion to a restorative land use and creation of positive C, H_2O and elemental budgets. Water conservation, erosion control, soil fertility improvement, establishment of vegetation cover, and increase in NPP are essential to improving the ecosystem C budget in soils and vegetation. Even with the modest increase in ecosystem C budget of 1 Mg C/ha/yr, restoration of 3.5 billion hectares of degraded/desertified soils has a technical potential of 3.5 Pg C/yr. This potential is >80% of the net annual increase in atmospheric pool of 4.2 Pg C/yr. In addition to mitigating climate change, C sequestration through restoration of degraded/desertified soils has also numerous co-benefits. Important among these are enhancement of soil quality, improvement in use efficiency of inputs, increase in agronomic productivity, and advancement of global and regional food security. This being a truly win-win strategy, the time to act is now.

1. Introduction

Among serious global issues of the 21st century are: (i) food-insecurity affecting 963 million people in 2008, and 1020 million in 2009 (Rosegrant and Cline 2003; Bourlaug 2007; FAO 2008a) and increasing because of increase in prices of cereals and other staples since 2006 partly as a result of conversion of grains to biofuels (Battisti and Naylor 2009; FAO 2008b), (ii) a rapid increase in atmospheric concentration of CO_2 from 280 ppm in the pre-industrial era to 390 ppm

in 2010 and increasing at the rate of 0.5%/yr or 2 ppm/yr because of fossil fuel combustion, land use conversion and soil cultivation (WMO 2007, 2008; IPCC 2007), (iii) decline in per capita crop land area to <0.07 ha (hectares) by 2025 for 30 densely populated countries (e.g., China, Bangladesh, Egypt) because of increase in population, conversion to other land uses and soil degradation, (iv) reduction in renewable fresh water supply to <1000 m^3/yr for 58 countries by 2050 along with increasing competition among agricultural, industrial and urban uses (Gleik 2003), and (v) global energy consumption of 435 Quads/yr (1 Quad = 10^{15} BTU) and increasing by 2.5%/yr between 2001 and 2025 (Wiesz 2004; EIA 2007) because of increase in industrialization and rising aspiration and standards of living. All these issues are closely linked to the severe problems of soil degradation.

Desertification, soil degradation in arid regions, is exacerbated by the interactive effects of biophysical processes, ecological and human dimension factors, and land use and managerial causes (Fig 1). The complex process of desertification adversely affects the per capita availability of cropland area and renewable fresh water supply, with attendant negative impacts on agronomic production and per capita grain consumption, which have been declining globally but especially in developing countries since mid 1990s (Kondratyev et al. 2003). Availability of croplands and fresh water for agriculture are also being constrained with the demand on these limited resources for biofuel production. Increase in global temperature is likely to further reduce agronomic production affecting more the 3 billion people living in the tropics and sub-tropics, a large proportion of whom live on <$2/day and depend primarily on agriculture for their livelihood (World Bank 2008; Battisti and Naylor 2009). Consequently, the U.N. Millennium Development Goals of reducing hunger and poverty by 50% by 2015 will not be met.

Fig. 1. Desertification is caused by the interactive effects of biological factors and human activity.

As agronomic productivity sputters, as food production lags behind the demands, as hunger and malnutrition adversely affect human health and wellbeing, as soils degrade and desertify, as natural waters pollute and contaminate, as climate warms and species disappear, and as environments deteriorate and jeopardize ecosystem services, there will be a growing realization among scientists and policy makers that taking soils for granted has been the root cause of the down ward spiral. The emerging paradigm must consider the strategy of enhancing soil and ecosystem resilience so that the problems of soil degradation and desertification can be minimized. For this strategy to take hold, there is a need to: (i) nurture strong communication between scientists on the one hand and policy makers, land managers and public on the other, and (ii) develop "The Soil Ethics" that would require soil managers to consider consequences and take responsibility of their decision on adopting those land use and soil management practices which would jeopardize their quality and exacerbate the risks of soil degradation and desertification.

In essence, the issues of the 21st century include the "ecological crisis" encompassing soil degradation, and desertification exacerbated by global warming and the attendant decline in quality and quantity of water, and reduction in biodiversity. With industrialization, leading to increase in pollution and economic growth along with enhanced aspirations of materialistic possessions, the problem of soil degradation and desertification have been more severe during the 20th and 21st centuries than ever before. Thus, there is a need for development of a global instrument for soil protection and management, in accord with an "ecocentric" rather than "anthrocentric" approaches to management of natural resources. The objective of this report is to emphasize the importance of the global instrument as an integral component of any charter, resolution, policy or an action plan implemented to mitigate soil degradation and desertification, and restore degraded soils and desertified ecosystems.

2. Drylands and desertification

Drylands, where the ratio of mean annual precipitation (P) to that of the potential evapotransportation (PET) is <0.65, cover about 41% of Earth's land area and are home to about 38% of the world population of 6.5 billion in 2005 (Reynolds et al. 2007). Using the Aridity Index (AI = P: PET), dry lands are classified into hyper-arid, arid, semi-arid and dry sub-humid regions. Predominant land uses in these regions are rangeland (3.96 x 10^9 ha), urban (0.12 x 10^9 ha) and others (0.48x10^9 ha) (Safriel et al. 2002). Because of harsh climate, dry lands are prone to several soil degradation processes affecting as much as 10 to 20% of the total area. The term desertification "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNCCD 1994), has been widely debated (Reynolds et al. 2007). The land area prone to desertification has been assessed and re-assessed (Tables 1, 2, 3). Including degradation of vegetation, area affected by land degradation may be as much as 3.5 to 4.2 Bha (Tables 1 and 2). Consequently, water resources are getting scarce, especially so in Africa (Gleik 2003). With the historically strong emphasis on adverse impacts of desertification (UNCED 1978, 1992; UNEP 1991, 1992; Slegers and Stroosnijer 2008; UNCCD 1994; Le Houreau 1996, 2002), there is a need to adopt a pragmatic and a positive approach to mitigate desertification and for restoration of degraded/desertified soils. It is thus important to understand interaction of desertification with climate change, food security, and potential of carbon (C) sequestration to mitigate abrupt climate change or global warming.

For in-depth analysis on desertification and its causes and effects, readers are referred to reviews by UNEP (1991; 1992), Mainguet and da Silva (1998), and Le Houreau (2002) among others.

Table 1. Estimates of area affected by land degradation (Bai et al. 2008)	
Parameter	Value
Area affected ($10^6 km^2$)	35.06
Percent of the land area	23.54
Total NPP Loss (Tg C/y)	955
Percent of Total Population Affected	23.9
Total Population Affected (billion)	1.54

Table 2. Estimates of land area in human-induced desertification risk classes (Eswaran et al. 2001)					
Vulnerability Class	(Population Density (persons/km^2				
	10>	11-40	41<		Total
	----------$10^6 km^2$----------				
Low	7.1	3.2	4.3		14.6
Moderate	5.4	4.0	4.2		13.6
High/Very High	7.4	4.4	3.2		15.0
Total	19.9	11.6	11.7		43.2

Table 3. Comparison between Glasod estimates of desertification in dry areas with that of UNEP methodology (Lal, Hassan and Dumanski 1999)			
UNEP (1991)	Area (10^6 km^2)	Oldeman and Van Lynden (1998)	Area (10^6 km^2)
Degraded irrigated land	0.43	Water erosion	4.78
Degraded rainfed cropland	2.16	Wind erosion	5.13
Degraded rangeland (Soil & vegetation)	7.57	Chemical degradation	1.11
Sub-total	10.16	Physical degradation	0.35
Degraded rangeland (vegetation only)	25.76	Total	11.37
Grand total	35.92	Light	4.89
Total arid land area	51.72	Moderate	5.09
% degraded	69.5	Severe and extreme	1.39
		Total	11.37
		These estimates refer to soil degradation only	

Adopting an ecosystem approach is considered a useful strategy to restoring degraded soils. The term ecosystem refers to "the whole system, including not only the organism complex, but also the whole complex of physical factors forming what we call the environment" (Tansley 1935). Lindeman (cited by Schulz 1967) defined it more succinctly as "systems composed of physical-chemical-biological processes active within a space-time unit of any magnitude". Ecosystem includes not only the physical components such as the soil, water, air and light in the system but also all of the living organisms present, their interactions with each other, and their responses to the physical factors around them (Gliessman 1984). Soil restoration means rebuilding the soil so that better and higher yielding plants can be grown. Taking the near-virgin state as a reference point permits knowing in which direction and at what rates are the managed agricultural soils drifting. The goal of restoration is not necessarily to imitate nature's steady state, but to approach it (Jenny 1984).

3. Climate change and desertification

Global warming and the attendant climatic variability are likely to strongly impact susceptibility of dryland to degradation processes which exacerbate desertification (Hulme 1996; Noble and Gitay 1996; Oba et al. 2001). The widespread problems of drought and desertification in arid regions (Tables 1, 2, and 3; Le Houérou 1996) are attributed to the prevalence of harsh climate in these regions characterized by a high intensity and long duration of recurring droughts with adverse impacts on NPP. The climate is projected to exacerbate its harshness by increasing frequency and intensity of extreme events such as "drought". There is a difference between "aridity" and "drought". The term aridity refers to a low ratio of P:PET (Le Houérou 1996). The term drought refers to decrease in availability of fresh water supply, and the latter is exacerbated by soil degradation. There are four types of drought: (i) **meteorological** due to deficiency of rainfall, (ii) **hydrological** due to deficiency of runoff in rivers or decline in the ground water level, (iii) **edaphic** caused by deficiency in soil moisture reserves because of low water infiltration rate and high losses by surface runoff and evaporation, and (iv) **agricultural or ecological drought** caused by low availability of soil water at critical stages of crop/plant growth (Williams and Balling 1994; WMO 1975). The edaphic and the ecological or the agricultural droughts are triggered by soil degradation and desertification through reduction in plant available water capacity. The latter is severely reduced by desertification through: (a) reduction in the effective rooting depth because of erosion-caused truncation of soil profile, (b) decline in field moisture capacity because of decline in soil organic carbon (SOC) and clay fractions, (c) decline in aggregation and degradation of soil structure and tilth because of reduction in SOC concentration, and (d) reduction in soil fauna and biodiversity because of decline in food and habitat. These types of drought are exacerbated by prevalence of extractive farming and utter lack of good farming. Good farming is the one (Worster 1984) which: (i) preserves the earth and its network of life, (ii) promotes a more just society, and (iii) makes people healthier. The most severe adverse impacts of desertification on soil quality and farming are caused by the decline in soil structure and aggregation, removal of crop residues as fodder or fuel, excessive grazing and use of dung as fuel rather than as manure, and negative nutrient budget which depletes the SOC pool. Not only do these farming practices reduce the top soil depth by accelerating soil erosion hazard but also reduce the plant-available water capacity by decreasing the relative proportion of retention pores. Consequently, losses of water by surface runoff and evaporation are exacerbated. There is also a close interaction between drought and soil infertility. Lack of water accentuates build up of salts in the rootzone or salinization. Prevalence of dry environments also creates nutrient imbalance because of disruption in biogeochemical cycles. Most dryland soils, especially those prone to erosion and desertification are deficient in N, P, and micronutrients.

In addition to strong relationship between drought and desertification, because rainfall received does not meet the evaporation demand, there is also a strong relationship between climate and desertification. Climate change impacts desertification from four perspectives (Puidgdabregas 1998): (i) change in vegetation cover, (ii) positive feedback to atmosphere due to anthropogenic activities, (iii) adverse off-site effects, and (iv) governance and policy implications. Increase in aridization due to the projected change in climate impacts desertification through its impact on (i) reduction in total amount of rainfall or its effectiveness, (ii) duration of rainfall events, and (iii) increase in interval among consecutive rainfall events. For example, studying the process of desertification along a Mediterranean arid transect, Lavee et al. (1998) observed that potential increase in aridity with change in climate may exacerbate desertification through adverse impact on: (i) soil organic matter (SOM), (ii) soil structure, aggregation and stability, (iii) susceptibility to erosion by water and wind, and (iv) risks of salinization. Furthermore, the rate of change in these soil properties and processes is non-linear. Decrease in precipitation may also reduce the amount of water available for irrigation in arid regions (Thompson et al. 2005). Rather than being a sink of atmospheric CO_2, it is also feared that soils may become a major source of CO_2 with >3 ºC increase in temperature. Another scenario of the positive feedback on desertification with the change in climate may be due to changes in plant vegetation patterns (Ares et al. 2003), especially leading to reduction in vegetation cover and the attendant decline in the ecosystem C pool.

4. Food security and desertification

Desertification affects food security directly and indirectly (Fig. 2). Food security refers to a "situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO 2002). Thus, there are four key dimensions of food security: (i) availability, (ii) stability, (iii) access, and (iv) utilization (Schmidhuber and Tubiello 2007; Moyo 2007). The "availability" component implies ability of agricultural systems (e.g., soil and water resources, climate, agronomic systems) to produce food. The "stability" component refers to availability of food at all times to all people and implies reliability of the food availability, which may be affected by climatic factors, drought and desertification. The term "access" refers to the ability of a community to acquire sufficient food on a sustainable basis, or to the purchasing power of a household or nation. The "utilization" component involves food safety, quality and health. Number of food-insecure people has increased from 854 million in 2000 (Borlaug 2007) to 963 million in 2008 (FAO 2008a) and 1020 million in 2009 (FAO 2009). A vast majority of these people live in South Asia and Sub-Saharan Africa. However, 36.2 million live in the U.S. (FRAC 2008). Increase in the number of food-insecure people is also caused by diversion of food grains to biofuel, and increases in the price of food staples (Agola 2008). Several of these countries/regions (Lobell et al. 2008) are prone to drought and desertification (e.g., South Asia, China, West Africa, Sahel). Food insecurity is also a cause of political unrest and civil strife. Several famines recorded during the 20th century in Africa were attributed to political unrest and civil strife. Some have linked food security to "living democracy where everyone has a say in their own future, therefore, the right to life's essentials, including food" (Hurley 2008). Hunger is not necessarily a result of food insecurity. It is argued that world's agriculture produced 17% more calories per person in 2006 than it did in 1976, despite a 70% population increase. There is enough food to provide every person world wide with at least 2,720 kilocalories a day (Mousseau and Mittal 2006). It is the human dimension issues which are also extremely important to global food security. Important among these are the political stability, civil unrest, and ethnic conflict (Fig. 2).

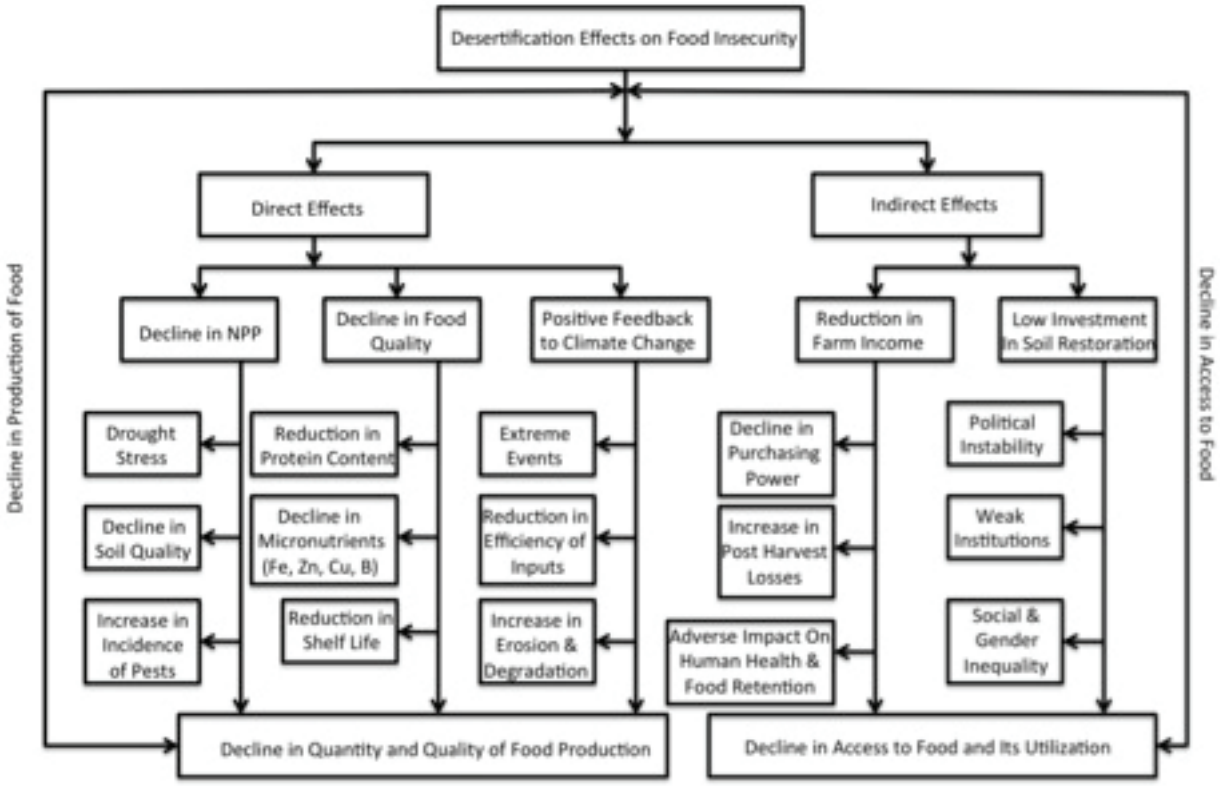

Fig. 2. Direct and indirect effects of desertification on food security.

5. Restoring desertified and degraded soils

Restoring desertified soils in arid regions needs water to restore biota, vegetation cover to control erosion and recycle C, and plant nutrients to increase NPP and strengthen biogeochemical cycles. Any restoration strategy must be based on the most fundamental concept that soil "is the living skin of the Earth" (Yaalon 2007). It is the foundation of all terrestrial life, and is the "ecstatic of the Earth" (Logan 2007). Alleviating drought stress, a major edaphic factor, requires a dependable supply of water and an effective strategy to minimize losses by water runoff controlled by surface sealing and poor soil structure, and evaporation accentuated by a high evaporative demand of the arid environment. Those civilizations which had abundance of water also had abundance of food: "There was famine in all lands, but throughout the lands of Egypt there was bread" (Genesis 42:54). However, water mismanagement and misuse can also lead to waterlogging and salinization, a serious cause of desertification. For example, soil degradation in Mesopotamia was set-in-motion by salinization of the valleys and erosion of the highlands. Increase in salinization occurred because irrigated farming with poor quality water and without drainage caused waterlogging and rise in the ground water that brought salt to the surface (Adams 1981). Erosion of the sloping lands occurred because of deforestation, excessive grazing, and plowing without use of conservation-effective measures and denudation in the watersheds of Tigris and Euphrates Rivers caused severe erosion and siltation. Soil degradation and desertification, caused by erosion and salinization along with siltation of irrigation canals, adversely affected Mesopotamians, Hittites, Aramaems, and Phoenicians (Hillel 2005; Hyams 1952; Lowdermilk 1953; Montgomery 2006). The problems of soil erosion and salinization are more severe now (Oldelman 1994; Lal 2001b, 2003; Bai et al. 2008) than in pre-historic times because of high population density and excessive demands on limited resources. Once water is available and erosion is effectively controlled, availability of plant nutrients (e.g., N, P, K, Zn) becomes essential to enhancing agronomic production. Depletion of SOM and mining of plant

nutrients, through extractive farming and losses by erosion and volatilization are major causes of soil degradation and the attendant desertification.

Similar to its adverse impacts on ancient civilizations, presently observed low productivity of soils of Sub-Sarharan Africa (SSA) and South Asia (SA) is also attributed to soil infertility (Sanchez 2002), and degradation by a range of physical, chemical and biological processes (Lal 2008). Thus, controlling desertification and restoring desertified soils necessitate knowledge of the underlying processes. The biophysical process of desertification is driven by the human dimension issues (e.g., poverty, civil strife, political instability). There is a strong interaction between the processes, causes and factors (Fig. 1). Processes of soil degradation include physical (erosion, compaction, crusting, decline in soil structure), chemical (nutrient depletion, acidification, salinization, and elemental imbalance) and biological (decline in SOM, reduction in soil biota). These processes are accentuated by the harsh climate of arid and semi-arid regions. Human activities exacerbate the process through deforestation, biomass burning, excessive grazing, residue removal etc (Fig. 3).

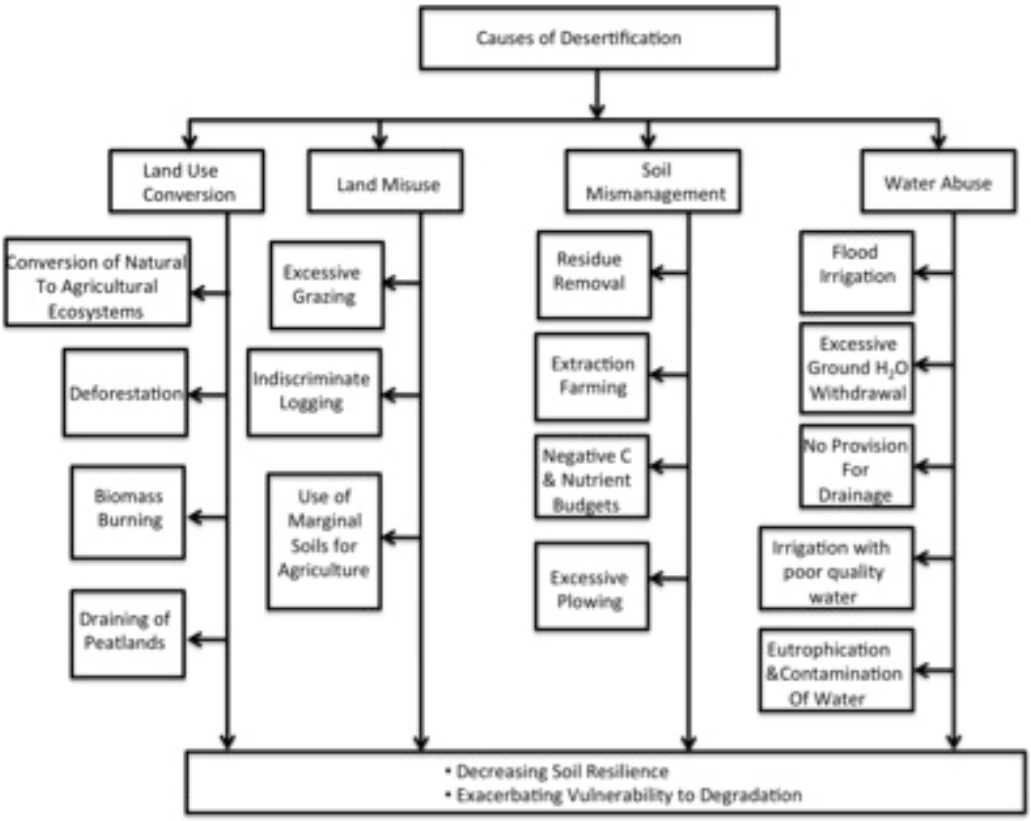

Fig. 3. Human activities that exacerbate the process of soil degradation and desertification.

In accord with these causes outlined in Fig. 3, strategies of desertification control and soil quality restoration to reverse these processes are outlined in Fig 4. The goal is to: (1) enhance water availability in the root zone by water harvesting and recycling, reducing loses by evaporation and runoff, and enhancing water use efficiency, (2) control soil erosion by providing a continuous ground cover and minimize soil disturbances, (3) improve nutrient supply through integrated nutrient management (INM) including biological nitrogen fixation (BNF), strengthening nutrient cycling, and using supplemental doses of chemical fertilizers, and (4) adopt diverse and productive farming systems. These generic recommendations must be made site-specific through local/adaptive research.

Fig. 4. Strategies for desertification control and improving soil quality for restoring ecosystem functions.

6. Ecosystem resilience against desertification

Ecosystem resilience implies ability to cope with randomness, shocks and extreme events of the arid climate and yet maintaining functions and services (Holling 1986; Gunderson and Holling 2002). The basic premise of the resilience concept is based on the assumption that "things change" and to ignore or resist change implies increasing the vulnerability of ecosystem to desertification. The change in soil ecosystem, natural or anthropogenic, may be rapid or slow. Examples of rapid change include depletion of SOM and plant nutrients along with the attendant decline in SOC pool, soil erosion, edaphic and agronomic drought. In contrast, examples of slow change include alteration in soil texture, meteorological and hydrological drought, climax vegetation etc. Two central themes of the resilience approach are to recognize the importance of: (i) threshold/critical level of key soil properties and processes (e.g., 1.1% SOC concentration, 30 cm effective rooting depth) beyond which the system undergoes a drastic regime change, (ii) four stages of adaptive cycles through which a soil ecosystem passes as a result of change (e.g., rapid growth, conservation, release and re-organization). Once the system crosses the thresholds, a severely eroded soil can undergo an irreversible degradation due to loss of the entire topsoil and severe depletion of the SOC pool. The soil-ecological system has multiple regimes or stable states, which are separated by thresholds. The degree of resilience depends on the length of the threshold. These concepts are explained in details by Walker et al. (2004), Folke et al. (2004) and Walker and Salt (2006). Knowledge of the thresholds is important to ascertain that threshold limits are not crossed to avoid the regime change or irreversible degradation. With conversion of a natural to managed ecosystem, it is important to adopt judicious soil/crop/pasture management

options so that soil retains its capacity to buffer any perturbation by erosion, fire, drought, climate change etc. while maintaining its ecosystem services and still behaving as it was before the disturbance. Resilience of the soil ecosystem is proportional to the distance of the threshold part because it reflects its ability to "get back" or "bounce back". If soil erosion is the principle perturbation, it is crucial to understand how the ball is moving, and how the erosion forces shape the "thresholds" or contour of the basin.

An irreversible degradation, such as by severe or strong erosion, when the loss of topsoil is too severe so that a soil's adaptive capacity declines to a level that is no longer able to support plant growth because of the exposed bed rock or another form of root-restrictive layer. The soil has lost its resilience and the result is an ecological crisis. Other examples of ecological crisis include severe salinization, strong depletion of SOC pool, complete elimination of soil fauna by heavy input of pesticides (e.g., furadon) resulting in collapse of soil structure, acidification and toxicity of Al, Mn etc. at extremely low pH.

A rapid climate change with rate of increase in temperature at > 0.1°C/decade can alter the hydrologic cycle, dominance of plant species, and the ecosystem C pool(s).

7. Soil carbon sequestration through desertification control

There are 5 principal global C pools. The largest C pool is oceanic (38,000 Pg) followed by geologic (4500 Pg comprising of fossil fuels), atmospheric (~800 Pg) and biotic (620 Pg comprising of all flora especially trees). The pedologic pool is estimated at 2500 Gt to 1-m depth, and comprises of 1500 Pg of soil organic carbon (SOC) and 950 Pg of soil inorganic carbon (SIC) (Lal 2004, 2006).

Depending upon the specific pool to which the atmospheric CO_2 is being transferred, a range of strategies of C sequestration include geologic, oceanic, chemical and the terrestrial. Conversion of atmospheric CO_2 into biomass is a natural process which photosynthesizes 123 Gt C into biomass annually. Thus, an amount equal to about 15% of atmospheric C pool is annually photosynthesized into biomass. However, most of the C photosynthesized is returned back to the atmosphere. Some of the biomass-C returned to the soil (e.g., crop residues, leaf litter, detritus material, root turnover) is humified and converted into humic substances and organo-mineral complexes. Thus, terrestrial C sequestration has two distinct components: (i) biomass C (above and below ground), and (ii) soil C. Soil C sequestration into the SIC pool is through formation of secondary carbonates and leaching of bicarbonates into the ground water especially in 275 Mha of irrigated soils in arid and semi-arid climates. Soil degradation depletes the SOC pool, and the goal of restoration is to enhance the SOC pool above the threshold level. Extractive farming practices mine and deplete the SOC pool. Good farming practices put more humus underground by SOC sequestration. Principal strategy of SOC sequestration is through restoration of degraded and desertified soils, by creating a positive C budget. Afforestation of saline and sodic soils in northern India by *Eucalyptus* plantations can reduce bulk density, improve soil quality and increase SOC pool at the rate of 1.1 to 1.3 Mg C/ha/yr (Table 4). The technical potential of reclaiming salt affected soils in the world is 0.4 to 1.0 Pg C/yr (Table 5). Similarly, the technical potential of desertification control, including that through restoration of salt-affected soils (shown in Table 5) is 0.6 to 1.7 Pg C/yr (Table 6). Restoration of all desertified and degraded soils (and vegetation) estimated at 3.5×10^9 ha, even at a modest rate of 1 Mg C/ha/yr (in both soils and vegetation) is 3.5 Pg C/yr. The potential rate of terrestrial C sequestration off-sets 83% of the present annual increase of 4.2 Pg C/yr in the atmosphere.

Table 4. Changes in bulk density and organic carbon concentration and pool under Eucalyptus plantations after 3 and 6 years of growth in a sodic soil of U.P. India (Recalculated from Mishra et al. 2003)					
Treatment	Soil Depth (cm)	SOC Concentration (g/kg)	Bulk density (Mg/m^3)	SOC Pool (Mg /ha)	Rate of SOC sequestration (Mg C/ha/yr)
1. Control					
	0-10 (10)	2.0	1.66	3.32	
	10-30 (20)	1.6	1.59	5.09	
	30-60 (30)	0.9	1.66	4.48	
	60-90 (30)	0.6	1.72	3.10	
	90-120 (30)	0.6	1.74	3.13	
	120-150 (30)	0.3	1.76	1.58	
	Total			20.70	Baseline
2. Three year old Plantation					
	0-10 (10)	3.2	1.39	4.45	
	10-30 (20)	2.2	1.39	6.12	
	30-60 (30)	1.2	1.48	5.33	
	60-90 (30)	0.8	1.56	3.74	
	90-120 (30)	0.7	1.63	3.42	
	120-150 (30)	0.3	1.67	1.50	
	Total			24.56	1.29
3. Six year old Plantation					
	0-10 (10)	4.2	1.27	5.33	
	10-30 (20)	2.8	1.27	7.11	
	30-60 (30)	1.0	1.38	4.14	
	60-90 (30)	0.6	1.45	2.61	
	90-120 (30)	0.7	1.52	3.19	
	120-150 (30)	1.0	1.57	4.71	
	Total			27.09	1.07
Mg = 1 metric ton (t)					

8. Adaptation to and mitigation of climate change through desertification control

The term mitigation implies activities which reduce emissions of GHGs by human activities, and enhance C sinks through natural and engineering processes. Mitigation strategies through desertification control (Fig. 5) are those which: (i) enhance C sinks in soils and vegetation, and (ii) reduce emissions through biomass burning and soil amendments (N_2O from biosolids and

fertilizers). The goal of mitigation strategies is to establish vegetation cover and enhance NPP, create favorable water and energy budgets, and improve soil quality especially with regards to nutrient pool and elemental cycling. Increasing the terrestrial sink by creating a positive C budget is the goal.

Table 5. Technical potential of reclaiming salt-affected soils on SOC sequestration (Lal 2009)

Land Use	Area (Mha)	C Sequestration Rate (Mg /ha/yr)		Technical Potential (Tg C/yr)
		Soil	Biomass	
1. Cropland				
a. Irrigated	100	1.0-2.0	-	56-112
b. Rainfed	56	0.5-1.0	-	22-24
2. Perennial Land Use	44	0.5-1.0	0.5-2.0	280-840
Total	280			358-996

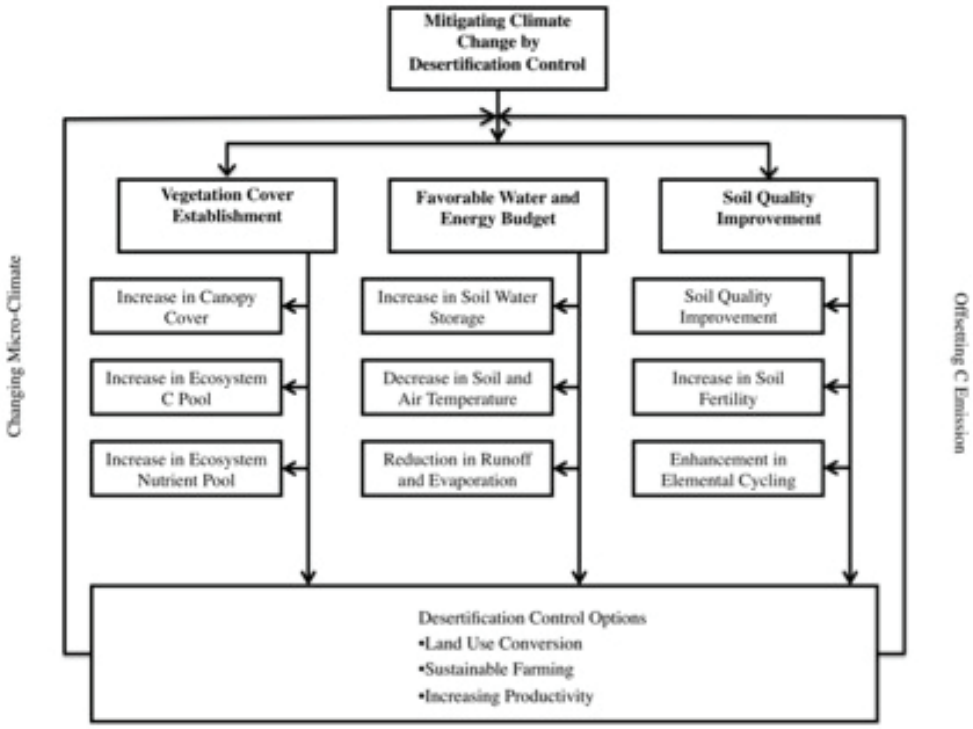

Fig. 5. Managing climate change through desertification control.

In comparison, adaptation to climate change consists of activities which reduce risks of decline in productivity because of increase in temperature, decrease in effective precipitation, and increase in frequency of extreme events (e.g., drought.). Adaptation to climate change is especially relevant for resource-poor farmers who are extremely vulnerable. Furthermore, it may not be completely possible to mitigate the climate change because reducing atmospheric concentration of GHGs to the pre-industrial level may be an extremely challenging task. Some of the technological

options for adaptation are also necessary for achieving sustainable use of soil and water (natural resources), and for restoring degraded and desertified soils.

Conceptual approaches to controlling desertification by adapting to climate change are outlined in Fig. 6. These approaches include the following: (1) moderating micro and meso-climates by reducing temperature through moderating albedo, improving vegetation cover, and using mulch materials (e.g., stones, crop residues, plastic), (2) increasing ecosystem water reserves, especially the plant available water capacity by reducing runoff and evaporation while increasing soil water storage capacity, (3) improving soil fertility especially the availability of N and P through enhancing biological N fixation (BNF), applying new generation of slow-release fertilizers (nano-enhanced and zeolites), using biosolids such as compost and biochar, (4) reversing soil degradation by improving soil structure, establishing runoff control devices (e.g., stone bunds, contour hedges, shelter belts) and reclaiming salt-affected soils, and (5) improving vegetation through introduction of dedicated plant species adapted to dry environments including genetically modified (GM) crops. These adaptation technologies have the potential to reduce the soil degradation and desertification trends. Reversal of desertification would enhance both natural and managed processes of adaptation by synthetic C effects and mutual reinforcement and supplementation.

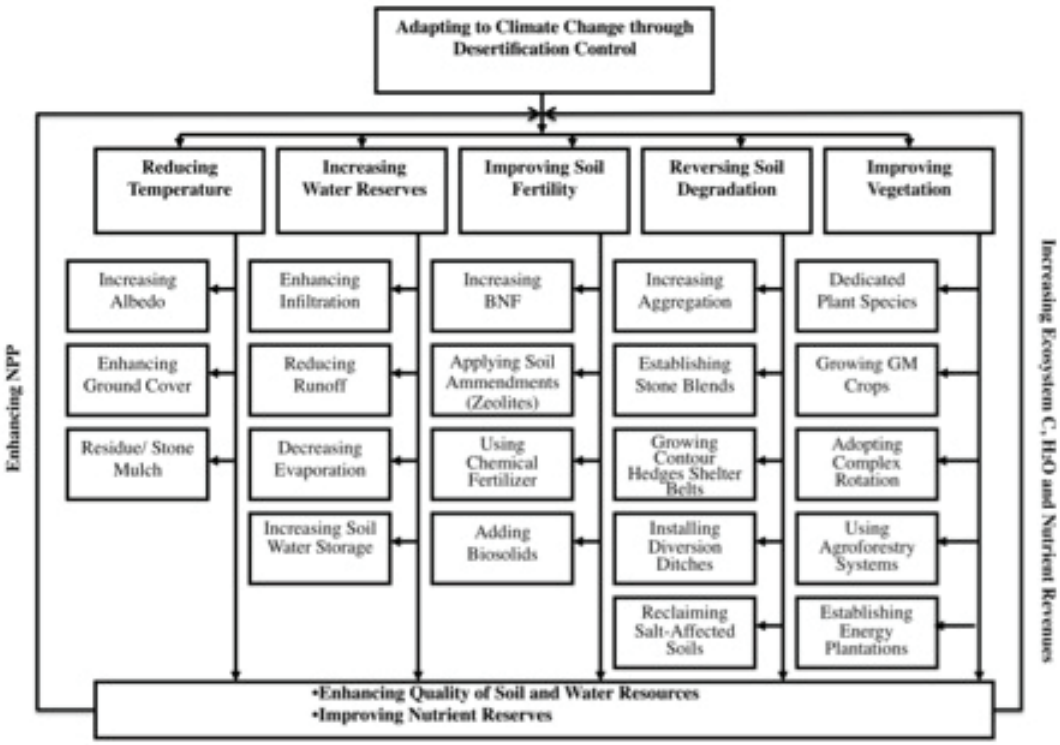

Fig. 6. Conceptual approaches to controlling desertification by adapting to climate change.

It is prudent to identify these technologies which mitigate climate change through increasing C sequestration in soils and trees, but also adapt to climate change by reducing sources and increasing sinks. The goal is to increase ecosystem resilience through innovative options such as afforestation, diverse and complex systems, soil quality restoration etc. These options will help adjustments of agricultural systems by increasing resilience and reducing vulnerability. Identification of these practices can be done in anticipation of projected change as well as in response to change that has already occurred. Desertification control and restorative measures would enhance adaptive capacity while also increasing C sinks.

9. Albedo and afforestation in dry climates

Terrestrial biosphere and the atmosphere are strongly interactive subsystems of Earth. Biosphere affects climate by surface exchange processes by influencing the physical appearance and functioning of the land surface in terms of its: (i) radiative properties, (ii) hydrological functions, (iii) turbulent characteristics, and (iv) chemical composition of the atmosphere. Climate moderates the activity of the biosphere through: (i) water availability, (ii) temperature, and (iii) radiation. These interactions are strongly influenced by human interventions.

The vast global area of dry lands in arid and semi-arid regions, with the severe problem of soil/ecosystem degradation, has a large potential to sequester C in soil and vegetation (Nosetto et al. 2006). Drylands play an important role in the terrestrial C budget and the attendant feedback to climate change (Shen et al. 2009; Silver et al. 2000). Conversely, clearing of a forest or a vegetation cover, through change in surface roughness and albedo, can also influence energy budget and hydrologic balance (Lyons et al., 2008).

Afforestation is a strategy to restore ecosystem functions of degraded soils in drylands. Increase in vegetation cover can influence the climate by changing the energy budget, water balance, and wind flow (Kleidon et al. 2006). There is a strong coupling of terrestrial C and N cycles with the hydrologic cycle (Chen and Coops 2009), which must also be considered. However, the use of forestry as a tool for mitigating climate change through C sequestration is a complex issue because of the change in albedo by the vegetation cover, especially in the arid tropical climates (Betts et al. 2006). Some studies have shown that boreal forests warm the climate because of the absorption of Sun's heat by the dark forest canopy and the decrease in albedo (Spracklen et al. 2008). Thus, the net impact of afforestation on climate change in dryland of the tropics must be objectively assessed.

The desert surface is relatively smooth, has a higher albedo and lower availability to store and recycle precipitation by evapotranspiration. In comparison, the forest surface is rougher, darker and has a much higher ability to recycle water through evapotranspiration. Albedo effect of forest is well documented. Albedo-related changes through afforestation may alter the net climate benefits of C sequestration. Because forests are relatively darker than bare or agricultural land they absorb relatively more solar radiation, which may exert a local warming influence. Thus, some forests (Boreal), despite C sequestration, may exert a net warming influence. Thus, albedo-related climatic changes stemming from afforestation and establishment of a vegetation cover must be thoroughly considered (Thompson et al. 2009).

Soil C pool also plays an important role in the ecosystem C budget of the afforested drylands (Silver et al. 2000), and alterations in its magnitude through change in land use must be appropriately considered. Whereas the albedo effect of afforested land is important and cannot be ignored (Rotenberg and Yakir 2010), there are approaches to address this issue. The heterogeneity of the vegetation cover is also important (Domingo et al. 2000). In conjunction with an optimal rotational age or duration (Thompson et al. 2009), there are numerous other management strategies. Important among these are: (i) changing management regime to increase C density at landscape level, (ii) extending the rotation age, (iii) species selection with higher albedo and deciduous species, (iv) stand management including those of: nutrients, water, density, (v) baseline assessment, and (vi) quantification of co-benefits.

It is apparent that afforestation of desertified land is essential. It also has numerous co-benefits, including: (i) soil restoration, (ii) microclimate moderation, (iii) increase in net ecosystem

productivity (NEP), and net biome productivity (NBP), (iv) increase in ecosystem C budget, and (v) water resources management. Thus, land managers must be encouraged to undertake afforestation of degraded drylands, and also adequately and fairly compensated for improving ecosystem services.

10. Ecosystems services and desertification control

Desertified soils have lost functionality especially for conserving soil and water, recycling water and nutrients/elements, storing carbon, providing habitat for flora and fauna and producing biomass as net primary productivity (NPP). Thus, the objective of desertification control is to restore these ecosystem functions (see Fig. 4). The first step is to establish vegetation cover by identifying grasses and shrubs which can grow in arid environments and relatively infertile soils of low water and nutrient reserves. Establishment of ground cove creates micro-environment (microclimate) that has cooler temperature, more humidity and favorable rhizospheric conditions for microbial processes. Progressive increase in vegetation cover also increases a favorable water and energy budgets, especially under vegetation patches. Soil beneath the patches has high water infiltration rate, low/no surface runoff, minimal crusting and higher soil organic matter (SOM) reserves. A gradual improvement in soil quality, over a decadal scale, sets-in-motion restorative processes that eventually restore degraded/desertified ecosystems.

There are three important ecosystems services of relevance to the global issues of the 21st century. The potential of C sequestration through desertification control is estimated at about 1 Gt C/yr (Lal 2001a). The potential can be more with establishment of biofuel plantations consisting of salt-tolerant plants. High biomass can be produced by growing halophytes which can be irrigated with brackish water. Rates of C sequestration in reclaimed salt-affected soils can be >1 t C/ha/yr to more than 3 t C/ha/yr. Technical potential of C sequestration in salt-affected soils is 0.4-1.0 Gt C/yr (Table 5), and that of desertification control is 1.17 Gt C/yr (Table 6). In addition, establishing biofuel plantations on desertified lands has a technical potential of offsetting industrial emissions by 0.3-0.5 Gt C/yr (Lal 2001a). Trading C credits, paying land managers for ecosystem services of societal interest, provides incentive to adopt best management practices (BMPs). Creating a mechanism for trading of C credits, a transparent and a fair/just system, is crucial to the widespread adoption of the BMPs. Commodification of C, creating another income stream for resource-poor farmers, is also important to restoring degraded/desertified soils.

Table 6. Potential of desertification control and land restoration to sequester C (Pg C/yr) (Recalculated from Lal 2001)

Process	Range	Mean	% of total potential
Restoration of eroded lands	0.2-0.3	0.25	21
Restoration of physically and chemically degraded soils	<0.01	<0.01	1
Reclamation of salt-affected soils	0.4-1.0	0.7	60
Agricultural intensification on undegraded soils	0.01-0.02	0.015	-
Sequestration as secondary carbonates	0.01-0.4	0.2	17
Total	0.62-1.72	1.17	100

These estimates have large uncertainties, the potentials of different strategies may not be additive, and adoption of recommended measures at global scale is a major challenge to humanity.

1 Pg = 1 billion metric ton or a gigaton

Among numerous ecosystems services, the importance of advancing food security through desertification control and soil quality restoration cannot be over emphasized (Lal 2009a, b). Improving pastoral and silvi-pastoral systems can greatly enhance food production in these environments. There is a lot of potential of specialized agriculture (e.g., screen house farming), and establishment of horticultural crops.

The scientific knowledge for controlling, mitigating and reversing soil degradation has been available since 1960s, and the technological innovations have been improved drastically since 1990s (Brauch and Spring 2009; Lal 2010a,b; NRC 2008). However, there has been little progress in application of this knowledge in reversing degradation trends in site-specific situations. There are numerous factors responsible for non-adoption of the specific knowledge.

Conclusions

In his book "Dirt: The Ecstatic Skin of the Earth", W.B. Logan (2007) states "How can I stand on the ground every day and not feel its power? How can I live my life stepping on this stuff and not wonder at it?". The author sums up the importance of soil and the vital role that it plays in the survival and future of humanity. There has been an increasing awareness about the widespread problems of: (i) food insecurity along with malnourishment and hunger, (ii) global warming and extreme events, and (iii) loss of biodiversity, all of which are directly and indirectly linked with degradation of soil and desertification of land. Restoration, improvement and enhancement of world's soil resources can off-set anthropogenic emissions of CO_2 through use of soils as a C sink, advance food security, improve water resources, and enhance the environment. Adoption of proven technologies can be promoted through payments for ecosystem services. This is a win-win strategy.

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3.2 Land degradation and climate change

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Abstract

The land area of the Earth covers a total of more than 140 million km^2 and land resources are finite and fragile in some regions, especially in the arid and semi-arid regions. Land degradation leads to a significant reduction of the productive capacity of land and will remain an important global issue for the 21st century because of its adverse impact on agronomic productivity, the environment, and its effect on food security and the quality of life. Climate impacts vegetation type, biomass and diversity. Evidence from observations of the climate system has led to the conclusion that human activities are contributing to a warming of the earth's atmosphere. Characteristics of the land surface are an important part of the climate system and changes of vegetation type can modify the characteristics of the regional atmospheric circulation and the large scale external moisture fluxes. Land-use and land cover change and global environmental change form a complex and interactive system linking human induced use/cover change to environmental feedbacks to their impacts and human responses. To better understand the linkages between climate change and land degradation, it is important to identify the sources and sinks of carbon, aerosols and trace gases. The challenge to double food production in the next 25 years to feed the growing human population puts additional pressure on land and hence the issue of controlling land degradation merits a serious consideration. Sustainable land management practices are needed to avoid land degradation. Technologies, policies, and measures to address the linkages between climate and land degradation are discussed.

1. Introduction

The land area of the Earth covers a total of more than 140 million km^2 — somewhat less than one-third of the Earth's surface. Land resources are finite, fragile in some regions, and non-renewable. Land degradation leads to a significant reduction of the productive capacity of land. In the recent past, climate change emerged as the single most pressing issue facing society on a global basis, with serious implications for the food security of billions of people in the developing countries. It is common knowledge that croplands, pastures, and forests in drylands are impacted by threats from climatic variability. The inter-annual, monthly and daily distribution of climate variables (e.g., temperature, radiation, precipitation, water vapor pressure in the air and wind speed) affects a number of physical, chemical and biological processes that drive the productivity of agricultural, forestry and fisheries systems (Easterling et al. 2007).

Drylands are the most vulnerable ecosystems to climate change, especially large regions in sub-Saharan Africa, Asia and Latin America, which have high rates of population growth, and natural resource degradation, with continuing high rates of poverty and food insecurity. Land use, land degradation, urbanization and pollution, affect the dryland ecosystems in these regions directly and indirectly through their effects on climate. These drivers can operate either independently or in association with one another (Lepers et al. 2004). Complex feedbacks and interactions occur on all scales from local to global. Cassman et al. (2003) emphasize that climate change will add

to the dual challenge of meeting food (cereal) demand while at the same time protecting natural resources and improving environmental quality in these regions. In the long run, climate change impacts, such as changes in temperature, shifts in growing seasons, storms, floods, droughts, and changed rainfall patterns, risk the livelihood of drylands populations. Therefore, adaptation to the adverse effects of climate change through sustainable land management is a crucial, though simultaneously challenging, task.

2. Land degradation

According to Barrow (1991) it is impossible to give a precise definition of land degradation. It may be defined "as the loss of utility or the reduction, loss or change of features or organisms which cannot be replaced" (Barrow 1991). The land is degraded when "it suffers a loss of intrinsic qualities or a decline in its capabilities" (Blaikie and Brookfield 1987). The UNEP (1992) definition emphasized the reduction of the potential of natural resources as a result of processes acting in the landscape. In the United Nations Convention to Combat Desertification (UNCCD 1999) land degradation is defined as a "reduction or loss, in arid, semi-arid, and dry subhumid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation." In the conceptual framework of the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005), Safriel and Adeel (2005) gave a simpler definition of land degradation as "reduction or loss of ecosystem services, notably the primary production service".

Land degradation will remain an important global issue for the 21st century because of its adverse impact on agronomic productivity, the environment, and its effect on food security and the quality of life (Easwaran et al. 2001). According to UNCCD, over 250 million people are directly affected by land degradation. In addition, some one billion people in over one hundred countries are at risk. These people include many of the world's poorest, most marginalized, and politically weak citizens. Land degradation affects 110 countries in Asia, Europe, Africa, Australia and North and South America.

Degradation of drylands threatens fuelwood, forage, freshwater and other services important for global food supply, particularly for impoverished pastoral and agricultural populations worldwide (Scholes and Archer 1997). The economic costs of desertification are enormous. According to UNEP, the global economy is losing US$ 42 billion each year as a result of the process of land degradation.

In assessing the extent, cost and impact of land degradation at the national level in seven countries, Berry et al. (2003) showed that all countries had problems of sustainable land management impacting the economy negatively at a rate of 3-7% of agricultural GDP and the case studies demonstrated a close link between poverty and land degradation. For example, the direct costs of land degradation in China in 1999 were estimated at $7.7 billion, about 4% of the GDP, while indirect costs were $31 billion.

Land degradation issue for world food security and the quality of the environment assumes a major significance when one considers that only about 11% of the global land surface can be

considered as prime or Class I land, and this must feed the 6.3 billion people today and the 8.2 billion expected in the year 2020 (Reich et al. 2001). At the global level, it is estimated that the annual income foregone in the areas immediately affected by desertification amounts to approximately US$ 42 billion each year.

Long-term food productivity is threatened by land degradation, which is now severe enough to reduce yields on approximately 16% of the agricultural land, especially cropland in Africa, Central America and pastures in Africa. The semi-arid to weakly arid areas of Africa are particularly vulnerable, as they have fragile soils, localized high population densities, and generally a low-input form of agriculture (Lal 1988). About 25% of land in Asian countries is vulnerable.

Africa is particularly threatened because the land degradation processes affect about 46% of continent (Reich et al. 2001). The significance of this large area becomes evident when one considers that about 43% of the land in Africa is estimated to fall within the drylands where 325 million people live (UNSO, 2002). There is only about 11% of the land mass which is humid and which by definition is excluded from land degradation processes. There is about 2.5 million km^2 of land under low risk, 3.6 million km^2 under moderate risk, 4.6 million km^2 under high risk, and 2.9 million km^2 under very high risk. The region that has the highest propensity is located along the desert margins and occupies about 5% of the landmass. It is estimated that about 22 million people (2.9% of total population) live in this area (Reich et al. 2001). The low, moderate and high vulnerability classes occupy 14, 16, and 11% respectively and together impact about 485 million people. It is estimated that losses in productivity of cropping land in sub-Saharan Africa are in the order of 0.5–1% annually, suggesting productivity loss of at least 20% over the last 40 years (Scherr 1999). Land degradation is also a serious problem in Australia with over 68% of the land estimated to have been degraded (Woods 1983).

According to UNCCD, the consequences of land degradation include undermining of food production, famines, increased social costs, decline in the quantity and quality of fresh water supplies, increased poverty and political instability, reduction in land's resilience to natural climate variability and decreased soil productivity.

3. Climate Change

The climate system is a complex, interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as any change in climate over time, whether due to natural variability or as a result of human activity (IPCC 2007a). Evidence from observations of the climate system has led to the conclusion that human activities are contributing to a warming of the Earth's atmosphere. Human activities—primarily burning of fossil fuels and changes in land cover—are modifying the concentration of atmospheric constituents or properties of the Earth's surface that absorb or scatter radiant energy. In particular, increases in the concentrations of greenhouse gases (GHGs) and aerosols are strongly implicated as contributors to climatic changes observed during the 20th century and are expected to contribute to further changes in climate in the 21st century and beyond. In the 1950s, the greenhouse gases of concern remained CO_2 and H_2O, the same two identified by Tyndall (1861) a century earlier. It was not until the 1970s that other greenhouse gases – CH_4, N_2O and CFCs – were widely recognized as important anthropogenic greenhouse gases (Ramanathan 1975; Wang et al. 1976; IPCC 2007a). By 1970s, the importance of aerosol-cloud effects in reflecting sunlight was known (Twomey 1977), and atmospheric aerosols (suspended small particles) were being proposed as climate-

forcing constituents. The amount of carbon dioxide in the atmosphere has increased by about 35% in the industrial era, and this increase is known to be due to human activities, primarily the combustion of fossil fuels and removal of forests. These changes in atmospheric composition are likely to alter temperatures, precipitation patterns, sea level, extreme events, and other aspects of climate on which the natural environment and human systems depend.

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988, by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP), to assess scientific information on climate change, as well as its environmental and socioeconomic impacts, and to formulate response strategies. As climate science and the Earth's climate have continued to evolve over recent decades, increasing evidence of anthropogenic influences on climate change has been found. Correspondingly, the IPCC has made increasingly more definitive statements about human impacts on climate. IPCC released its Fourth Assessment Report (FAR) in 2007 that focused on observed climate change and the potential impacts of future climate change. The sections below on observed and future climate change borrow heavily from the information provided in FAR.

3.1. Observed climate change

At the time of the Third Assessment Report of IPCC, scientists could say that the abundances of all the well-mixed greenhouse gases during the 1990s was greater than at any time during the last half-million years (Petit et al. 1999), and this record now extends back nearly one million years (IPCC 2007a). In 2005, the concentration of carbon dioxide exceeded the natural range that has existed over 650,000 years. According to the International Energy Agency, energy-related CO_2 emissions in 2010 climbed to a record 30.6 gigatonnes (Gt), a five-percent jump from the previous record year in 2008. The unrelenting increase in the CO_2 emissions has been the main reason for the observed increases in global surface temperatures.

Evidence from observations of the climate system show an increase of 0.74 ± 0.18°C in global average surface temperature during the hundred year period from 1906 to 2005 and an even greater warming trend over the 50 year period from 1956-2005 than over the entire 100 year period i.e., 0.13°C ± 0.03°C vs. 0.07°C ± 0.02°C per decade (IPCC 2007a). Eleven of the 12 year period between 1995 to 2006 are among the 12 warmest years since the instrumental record of global surface temperature was started in 1850 (IPCC 2007a). Land regions have warmed at a faster rate than the oceans. Warming has occurred in both land and ocean domains, and in both sea surface temperature (SST) and nighttime marine air temperature over the oceans. However, for the globe as a whole, surface air temperatures over land have risen at about double the ocean rate after 1979 (more than 0.27°C per decade vs. 0.13°C per decade).

According to WMO (2011), average global temperatures during 2010 were estimated to be 0.53°C ± 0.09°C above the 1961–1990 annual average of 14°C. This makes 2010 tied for warmest year on record in records dating back to 1880. The 2010 nominal value of +0.53°C ranks just ahead of those of 2005 (+0.52°C) and 1998 (+0.51°C). The decade 2001–2010 was also the warmest on record. Temperatures over the decade averaged 0.46°C above the 1961–1990 mean, 0.21°C warmer than the previous record decade 1991–2000.

According to IPCC (2007a), a widespread reduction in the number of frost days in mid-latitude regions, an increase in the number of warm extremes and a reduction in the number of daily cold extremes were observed in 70 to 75% of the land regions where data are available. The most

marked changes are for cold (lowest 10%, based on 1961–1990) nights, which have become rarer over the 1951 to 2003 period. Warm (highest 10%) nights have become more frequent.

Changes in climate have also been manifested in altered precipitation patterns. Over the last century, the amount of precipitation has increased significantly across eastern parts of North America and several other regions of the world (IPCC 2007a). Many land areas have likely experienced an increase in the number and intensity of heavy precipitation (5 cm of rain or more) events (IPCC 2007a). About half of the increase in total precipitation observed nationally in the United States has been attributed to the increase in intensity of storms (Karl and Knight 1998). On the other hand, downward trends were strongest in the Sahel (IPCC 2007a) but occurred in both western and eastern Africa in the past 50 years, and were reflected in the zonal means. In West Africa, the long-term decline in rainfall from the 1970s to the 1990s caused a 25-35 km southward shift of the Sahelian, Sudanese and Guinean ecological zones in the second half of the 20th century (Gonzalez 2001). This has resulted in a loss of grassland and acacia, the loss of flora/fauna, and shifting sand dunes in the Sahel (ECF and Potsdam Institute 2004).

The downward trends of precipitation in drylands are also found in southern Asia. The linear trends of rainfall decreases for 1900 to 2005 were 7.5% in both the western Africa and southern Asia regions (significant at <1%). Droughts have become more common, especially in the tropics and subtropics, since the 1970s (IPCC 2007a). Observed marked increases in drought in the past three decades arise from more intense and longer droughts over wider areas, as a critical threshold for delineating drought is exceeded over increasingly widespread areas. Decreased land precipitation and increased temperatures that enhance evapotranspiration and drying are important factors that have contributed to more regions experiencing droughts, as measured by the Palmer Drought Severity Index.

During the 20th century, the changes in temperature and precipitation described above caused important changes in hydrology over large regions. One change was a decline in spring snow cover. This trend was observed throughout the Northern Hemisphere starting in the 1920s and accelerated in the late 1970s (IPCC 2007a). Less snow generally translates to lower reservoir levels. The earlier onset of spring snowmelt exacerbates this problem. Snowmelt started 2–3 weeks earlier in 2000 than it did in 1948 (Stewart et al. 2004). Particularly worrisome is the reduction in the mass balance of the glaciers and this has serious implications for the availability of water; something like 500 million people in South Asia and 250 million people in China are likely to be affected as a result.

Another manifestation of changes in the climate system is a warming in the world's oceans. The global ocean temperature rose by 0.10°C from the surface to 700 m depth from 1961–2003 (IPCC 2007a). Warming causes seawater to expand and thus contributes to sea level rise. This factor, referred to as thermal expansion, has contributed 1.6 ± 0.5 mm per year to global average sea level over the last decade (1993–2003). Other factors contributing to sea level rise over the last decade include a decline in mountain glaciers and ice caps (0.77 ± 0.22 mm per year), losses from the Greenland ice sheets (0.21 ± 0.07 mm per year), and losses from the Antarctic ice sheets (0.21 ± 0.35 mm per year) (IPCC 2007a).

3.2. Future climate change

Looking ahead, IPCC (2007a) projects increases in global mean surface air temperature (SAT) continuing over the 21st century, driven mainly by increases in anthropogenic greenhouse gas

concentrations, with the warming proportional to the associated radiative forcing. Carbon dioxide concentrations in the atmosphere will increase throughout the 21st century according to all IPCC scenarios. The scenarios project CO2 concentrations ranging from 535 to 983 parts per million (ppm) by 2100, which is 41 to 158 percent higher than current level (IPCC 2007a). Methane concentrations in the atmosphere are projected to range from 1.46 ppm to 3.39 ppm by 2100, or about 18 percent lower to 91 percent higher than the current concentration while nitrous oxide concentrations are projected to be 0.36 to 0.46 ppm in 2100, values that are 11 to 45 percent higher than current concentrations (IPCC 2007a).

An expert assessment based on the combination of available constraints from observations and the strength of known feedbacks simulated in the models used to produce the climate change projections indicates that the equilibrium global mean SAT warming for a doubling of atmospheric carbon dioxide (CO_2), or 'equilibrium climate sensitivity', is likely to lie in the range 2°C to 4.5°C, with a most likely value of about 3°C (IPCC 2007a). Warming in the 21st century is expected to be greatest over land and at the highest northern latitudes. It is very likely that heat waves will be more intense, more frequent and longer lasting in a future warmer climate.

Increasingly reliable regional climate change projections are now available for many regions of the world due to advances in modeling and understanding of the physical processes of the climate system. IPCC (2007a) projections show that warming in Africa is very likely to be larger than the global annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics. Warming is likely to be well above the global mean in Central Asia, the Tibetan Plateau and northern Asia, above the global mean in eastern Asia and South Asia, and similar to the global mean in Southeast Asia.

Increases in the amount of precipitation are very likely in high latitudes, while decreases are likely in most subtropical land regions. Annual rainfall is likely to decrease in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall as the Mediterranean coast is approached. Rainfall in southern Africa is likely to decrease in much of the winter rainfall region and western margins. Precipitation in summer is likely to increase in northern Asia, East Asia, South Asia and most of Southeast Asia, but is likely to decrease in central Asia. Annual precipitation is likely to decrease in most of Central America and in the southern Andes, although changes in atmospheric circulation may induce large local variability in precipitation response in mountainous areas. Precipitation is likely to decrease in southern Australia in winter and spring. Precipitation is very likely to decrease in south-western Australia in winter.

Wang (2005) showed that in a future warmer climate, the models simulate summer dryness in most parts of the northern subtropics and mid-latitudes, but with a large range in the amplitude of summer dryness across models. Droughts associated with this summer drying could result in regional vegetation die-offs (Breshears et al. 2005) and contribute to an increase in the percentage of land area experiencing drought at any one time, for example, extreme drought increasing from 1% of present-day land area to 30% by the end of the century (Burke et al. 2006). For many parts of Africa the length of the growing period is projected to decrease over time (Thornton et al. 2006) and projected losses in yield amount to 50% by 2020 for some countries (IPCC 2007b).

The frequency of occurrence of climate extremes is expected to change during the next century, with increases in the frequency of heat waves and heavy precipitation events, and decreases in the frequency of frost days, as a consequence of anthropogenically-forced climate change (Easterling

et al. 2000). For example, an increase in occurrence of extreme weather events including heat wave and intense precipitation events is projected in South Asia, East Asia, and South-East Asia (Sato 2000; Lal 2003; Walsh 2004) along with an increase in the interannual variability of daily precipitation in the Asian summer monsoon (Lal et al. 2000; May, 2004; Giorgi and Bi 2005). Changes in the frequencies of extreme events will have an impact on land degradation processes such as floods and mass movements, soil erosion by both water and wind, and on soil salinisation. Studies of climate extremes in the second half of the 20th century reveal significant trends in both temperature and rainfall at the global level (Frich et al. 2002). Climate extremes encompass both extreme weather, with durations of minutes to days (the synoptic timescale), and extreme climate events with durations of months, in the case of periods of wet/stormy weather, or years, in the case of drought (McGregor et al. 2005). In all cases, the frequency of extreme events may be affected by seasonal to inter-annual fluctuations of large scale climate variations such as El Niño/ Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) (Schweirz et al. 2006).

Annual average river runoff and water availability are projected to increase by 10-40% at high latitudes and in some wet tropical areas, and decrease by 10-30% over some dry regions at mid-latitudes and in the dry tropics. The areas suitable for rainfed agriculture are expected to significantly decrease affecting adversely land productivity potential of the continent (Fischer et al. 2002).

4. Climate change impacts in the drylands

An emerging but growing body of literature indicates that over the past three decades, the changes in the climate system described above—including the anthropogenic component of warming—have caused physical and biological changes in a variety of ecosystems (Root et al. 2005; Parmesan 2006; IPCC 2007a) that are discernable at the global scale. These changes include shifts in genetics (Bradshaw and Holzapfel 2006; Franks et al. 2007), species' ranges, phenological patterns, and life cycles (reviewed in Parmesan 2006). Most (85%) of these ecological responses have been in the expected direction (e.g., poleward shifts in species distributions), and it is very unlikely that the observed responses are due to natural variability alone (IPCC 2007a).

Drylands are increasingly being exposed to threats from increased climatic variability and climate change. Abnormal changes in air temperature and rainfall and resulting increases in frequency and intensity of drought and flood events have long-term implications for the viability of these ecosystems (FAO 2007).

4.1. Impacts of enhanced temperatures

While plant response to elevated CO_2 is positive, recent studies confirm that the effects of elevated CO_2 on plant growth and yield will depend on photosynthetic pathway, species, growth stage and management regime, such as water and nitrogen (N) applications (Jablonski et al. 2002; Ainsworth and Long 2005). Increased temperatures may also reduce CO_2 effects indirectly, by increasing water demand. Rain-fed wheat grown at 450 ppm CO_2 demonstrated yield increases with temperature increases of up to 0.8°C, but declines with temperature increases beyond 1.5°C; additional irrigation was needed to counterbalance these negative effects (Xiao et al. 2005). Hence the impacts of climate change on ecosystems and their services will not be distributed equally around the world. Dryland, mountain and Mediterranean regions are likely to be more vulnerable than others (Gitay et al. 2001) and ecosystem degradation is largest in these regions (Hassan et al. 2005). Climate change is likely to cause additional inequities, as its impacts are

unevenly distributed over space and time and disproportionately affect the poor (Tol 2001; Stern 2007).

4.2. Impacts of precipitation variability

Current vulnerabilities to climate are strongly correlated with climate variability, in particular precipitation variability. These vulnerabilities are largest in the semi-arid and arid low-income countries with large tracts of drylands, where precipitation and stream flow are concentrated over a few months, and where year-to-year variations are high (Lenton 2004). In such regions a lack of deep groundwater wells or reservoirs (i.e., storage) leads to a high level of vulnerability to climate variability, and to the climate changes that are likely to further increase climate variability in future.

Rainfall change and variability is very likely to affect vegetation in tropical grassland and savanna systems with, for example, a reduction in cover and productivity simulated along an aridity gradient in southern African savanna in response to the observed drying trend of about 8 mm/yr since 1970 (Woodward and Lomas 2004). Sahelian woody plants, for example, have shown drought-induced mass mortality and subsequent regeneration during wetter periods (Hiernaux and Turner 2002). Large-scale changes in savanna vegetation cover may also feed back to regional rainfall patterns. Modeled removal of savannas from global vegetation cover has larger effects on global precipitation than for any other biome (Snyder et al. 2004) and, in four out of five savannas studied globally, modeled savanna-grassland conversion resulted in 10% lower rainfall, suggesting positive feedback between human impacts and changing climate (Hoffmann and Jackson 2000).

4.3. Impacts on land degradation

Recent international climate policy debate and negotiation processes have put the spotlight on the interplay between land use, climate change mitigation and adaptation. CO_2-induced climate change and land degradation remain inextricably linked because of feedbacks between land degradation and precipitation. Climate change might exacerbate land degradation through alteration of spatial and temporal patterns in temperature, rainfall, solar radiation, and winds. Several climate models suggest that future global warming may reduce soil moisture over large areas of semiarid grassland in North America and Asia (Manabe and Wetherald 1986). This climate change is likely to exacerbate the degradation of semiarid lands that will be caused by rapidly expanding human populations during the next decade. Emmanuel (1987) predicted that there will be a 17% increase in the world area of desert land due to the climate change expected with a doubling of atmospheric CO_2 content.

Globally the number of great inland flood catastrophes in the ten year period between 1996 and 2005 is twice as large, per decade, as between 1950 and 1980, while economic losses have increased by a factor of five (Kron and Bertz 2007). The dominant drivers of the upward trend in flood damage are socioeconomic factors, such as increased population and wealth in vulnerable areas, and land-use change. Increased frequency of floods can lead to increased rates of land degradation. However, as Clarke and Rendell (2007) explained, not every extreme event will have a similar impact on land degradation. Some individual land degradation processes like land sliding or gully incision may involve a particular threshold being crossed and subsequent events, of lower magnitude, may reactivate the landslide or develop/enlarge the gully. In addition, some land degradation processes may be enhanced by human activity, particularly land use changes

and land management practices, while others may be effectively mitigated by anthropogenic intervention measures. The main land degradation processes that could be affected in the drylands include floods, and associated channel erosion and deposition, mass movements, principally landslides and debris flows, and the more diffuse processes of soil erosion by water and wind and salinisation.

4.4. Impacts on water resources

Water resources are inextricably linked with climate, so the prospect of global climate change has serious implications for water resources and regional development (Riebsame et al. 1995). A warmer climate, with its increased climate variability, will increase the risk of both floods and droughts (Wetherald and Manabe 2002). Semi-arid and arid areas are particularly exposed to the impacts of climate change on freshwater. In semi-arid areas, climate change may extend the dry season of no or very low flows, which particularly affects water users unable to rely on reservoirs or deep groundwater wells (Giertz et al. 2006). Kundzewicz et al. (2007) explain that many of these areas (e.g., Mediterranean basin, western USA, southern Africa, and north-eastern Brazil) will suffer a decrease in water resources due to climate change. Agricultural irrigation demand in arid and semi-arid regions of Asia is estimated to increase by at least 10% for an increase in temperature of 1°C (Fischer et al. 2002; Liu 2002). Efforts to offset declining surface water availability due to increasing precipitation variability will be hampered by the fact that groundwater recharge will decrease considerably in some already water-stressed regions, where vulnerability is often exacerbated by the rapid increase in population and water demand.

The greatest impact will continue to be felt by the poor, who have the most limited access to water resources. In the drylands of Africa, farmers and pastoralists also have to contend with other extreme natural resource challenges and constraints such as poor soil fertility, pests, crop diseases, and a lack of access to inputs and improved seeds. These challenges are usually aggravated by periods of prolonged droughts and/or floods and are often particularly severe during El Nino events (Vogel 2005; Stige et al. 2006). The changes in precipitation and enhanced evaporation could have profound effects in some lakes and reservoirs. Studies show that, in the paleoclimate of Africa and in the present climate, lakes and reservoirs respond to climate variability via pronounced changes in storage, leading to complete drying up in many cases. Furthermore, these studies also show that under the present climate regime several large lakes and wetlands show a delicate balance between inflow and outflow, such that evaporative increases of 40%, for example, could result in much reduced outflow.

4.5. Impacts of increased frequency of extreme events

Several studies showed that generally, the frequency of occurrence of more intense rainfall events in many parts of Asia has increased, causing severe floods, landslides, and debris and mud flows, while the number of rainy days and total annual amount of precipitation has decreased (Mirza 2002; Lal 2003; Zhai 2004). Increasing frequency and intensity of droughts in many parts of Asia are attributed largely to a rise in temperature, particularly during the summer and normally drier months, and during El Niño Southern Oscillation (ENSO) events (Lal 2003; Gruza and Rankova 2004; Natsagdorj et al. 2005).

Short-term natural extremes, such as storms and floods, interannual and decadal climate variations, as well as large-scale circulation changes, such as the ENSO, all have important effects on crop, pasture and forest production (Tubiello 2005). For example, El Niño-like conditions increase

the probability of farm incomes falling below their long-term median by 75% across most of Australia's cropping regions, with impacts on gross domestic product (GDP) ranging from 0.75 to 1.6% (O'Meagher 2005). Increased climate extremes may promote plant disease and pest outbreaks (Gan 2004).

There is growing evidence that the frequency and extent of drought has increased as a result of global warming. The fraction of land surface area experiencing drought conditions has risen from 10-15% in the early 1970s to more than 30% by early 2000 (Dai et al. 2004). There has been a general tendency towards decreased precipitation in the semi-arid regions. For example, Henry et al. (2007) showed that during the period 1993-2006, there has been a strong and persistent rainfall deficit in eastern Australia and similarly reduced rainfall conditions in the south-west corner of Australia have continued. Reductions of up to 20% in annually averaged totals are common across large regions of Australia. A global analysis has shown that abrupt changes in rainfall are more likely to occur in the arid and semi-arid regions, and that this susceptibility is possibly linked to strong positive feedbacks between vegetation and climate interactions (Narisma et al. 2007). The socio-economic impacts of droughts may arise from the interaction between natural conditions and human factors, such as changes in land use and land cover, water demand and use. Excessive water withdrawals can exacerbate the impact of drought.

4.6. Impacts of wind erosion

The frequency of episodic transport by wind and water from arid lands is also likely to increase in response to anticipated changes in global climate (Manabe and Wetherlad 1986). Lower soil moisture and sparser vegetative cover would leave soil more susceptible to wind erosion. Reduction of organic matter inputs and increased oxidation of soil organic matter could reduce the long-term water-retention capacity of soil, exacerbating desertification. Moreover, increased wind erosion increases wind-blown mineral dust, which may increase absorption of radiation in the atmosphere (Nicholson and Kim 1997).

4.7. Impacts on crop, pasture and forest productivity

Cruz et al. (2007) concluded that the crop yield in many countries of Asia has declined, partly due to rising temperatures and extreme weather events and that future climate change is likely to affect agriculture, risk of hunger and water resource scarcity with enhanced climate variability and more rapid melting of glaciers.

African agriculture is predicted to be especially vulnerable to climate change because the region already endures high heat and low precipitation, agriculture is a large fraction of the economy, and African farmers rely on relatively basic technology (Pearce et al. 1996; McCarthy et al. 2001). It is estimated that, by the 2080s, the proportion of arid and semi-arid lands in Africa is likely to increase by 5-8% (Boko et al. 2007). Relying on farm data from an 11-country survey of over 9500 farmers, Kurukulasuriya and Mendelsohn (2008) showed that dryland farms are especially climate sensitive. Even as early as 2020, climate change could have strong negative impacts on currently dry and hot locations. By 2100, dryland crop net revenues could rise by 51% if future warming is mild and wet but fall by 43% if future climates are hot and dry. Their study showed that a marginal increase in temperature will cause substantial damage in West Africa and in areas along the Rift Valley. Drier parts of East Africa (especially in northwest Ethiopia) will also suffer adversely.

Grasslands in the drylands consisting of fast-growing, often short lived species, are sensitive to CO_2 and climate change, with the impacts related to the stability and resilience of plant communities (Mitchell and Csillag 2001). Experiments support the concept of rapid changes in species composition and diversity under climate change.

Many of the world's rangelands are affected by ENSO events. In dry regions, there are risks that severe vegetation degeneration leads to positive feedbacks between soil degradation and reduced vegetation and rainfall, with corresponding loss of pastoral areas and farmlands (Zheng et al. 2002). The natural grassland coverage and the grass yield in Asia, in general, are projected to decline with a rise in temperature and higher evaporation (Lu and Lu 2003). Projected increased temperature, combined with reduced precipitation in some regions (e.g., Southern Africa) would lead to increased loss of domestic herbivores during extreme events in drought-prone areas. Thermal stress reduces productivity and conception rates and is potentially life-threatening to livestock (Easterling et al. 2007).

Although climate change will impact the availability of forest resources, the anthropogenic impact, particularly land-use change and deforestation in tropical zones, is likely to be extremely important (Zhao et al. 2005). Droughts combined with deforestation increase fire danger (Laurance and Williamson 2001). Climate change, interacting with human drivers such as deforestation and forest fires, are a threat to Africa's forest ecosystems. Changes in grasslands and marine ecosystems are also noticeable. At the global scale, estimates show that drylands ecosystems contribute 0.23 – 0.29 Gt of carbon per year to the atmosphere, which is about 4% of global emissions from all sources combined (Safriel and Adeel 2005). This will likely be exacerbated by climate change impacts.

5. Need for pro-active action to combat climate change in the drylands

Drylands communities already have a long record of spontaneous adaptation to climate variability; yet more intensive and extensive adaptation exercises than ones currently occurring are required, including the supporting policies. This is especially important since it is estimated that, by 2080, the proportion of arid and semi-arid lands in Africa is likely to increase by 5-8% (IPCC 2007b). Following are the suggested pro-active actions to combat climate change in the drylands.

5.1. Developing appropriate adaptation strategies and encouraging their early application

In regions that are projected to be vulnerable to the climate change, early applications are crucial to avoid social problems such as mass migration and starvation. Adaptation strategies to cope with climate change impacts on agriculture, water resources, and environment need to be planned on a more permanent, large scale and structured basis. Pro-active planning is one of the principal and urgent actions needed. There is a need for interaction between climate change experts and conservation experts on issues related to the protection of natural ecosystems.

Kurukulasuriya and Mendelsohn (2008) suggested that African countries should begin to plan for climate contingencies. Governments should develop contingency plans if certain climate outcomes come to pass. They should anticipate what farmers will do, how markets will react, and what role governments need to play. They should be prepared to help people adapt to these new circumstances.

5.2. Promoting sustainable adaptation measures

Sustainable adaptation measures are those that reduce poverty, contribute to sustainable development and contribute to climate change adaptation. More specifically, these should help reduce risk to current ways of securing well-being; strengthen adaptive capacity of the poor; and address the causes of vulnerability among the poor.

5.3. Contributing to the implementation of strategies to conserve water and enhance water use efficiency

Effective water use management strategies in the rainfed areas emphasize integration of conservation and production technologies with watershed as a unit of management; ensuring maximum *in situ r*ainwater conservation; harvesting rainwater for recycling to high value crops and recharging groundwater. Partnerships must be developed between various stakeholders to improve water management and water use efficiency in the major crops/cropping systems.

5.4. Increasing carbon storage in dryland ecosystems

A significant amount of carbon is lost continuously from dryland soils due to poor management. The largely degraded soils of drylands are, for this reason, currently far from saturated with carbon and their potential to sequester carbon may be very high (Farage et al. 2003). Generally, on per unit area basis, the carbon storage potential of dryland ecosystems is lower than for moist tropical systems. However, because of the spatial extent of drylands they have, overall, significant scope for sequestration. Changes in dryland management practices can lead to greater carbon sequestration. These include: enhancing soil quality; erosion control; afforestation and woodland regeneration; no-till farming; cover crops; nutrient management; manuring and sludge application; optimal livestock densities; water conservation and harvesting; efficient irrigation; land-use change (crops to grass/trees); agroforestry; and the use of legumes.

5.5. Enhancing the understanding of the interactions between climate and land degradation and developing more effective actions to combat land degradation

Innovative and adaptive land management responses to inherent climatic variability and natural hazards (droughts, floods, landslides, sand and dust storms, wild land fires etc.) must be identified and implemented for sustainable land management. Land management practices in affected areas, particularly in Africa and other developing countries, should focus on improving the fraction of rainfall that is used in biomass production. This can be facilitated by unlimited hydro-meteorological data and increased human and institutional capacity building.

The network of climatological, hydrological and agrometeorological stations around the world should be increased and strengthened to provide data on rainfall intensities, soil temperature and soil moisture for land degradation monitoring, assessment and for the implementation of the National Action Plans. An integrated approach backed up by institutional support and regeneration of affected areas needs to be promoted by means of agro-ecological practices and other physical interventions to reduce land degradation. Direct interactions between the National Meteorological and Hydrological Services (NMHSs) and the land users can help enhance the direct communication of weather and climate information. There is a need to develop a cost-effective system to communicate early climate forecasts to various stakeholders, in particular to farmers, so that they can improve their land management practices.

5.6. Facilitating improved monitoring and early warning systems for droughts to enhance farmers' preparedness to cope with the impacts of droughts

This can be facilitated by encouraging a pro-active risk management approach to drought rather than a reactive approach after the occurrence of droughts. NMHSs have an important role to play in the development of drought preparedness plans which should contain three basic components: monitoring and early warning, risk assessment, and mitigation and response. Because of the slow onset characteristics of droughts, monitoring and early warning systems provide the foundation for an effective drought mitigation plan. Early warning systems can reduce impacts by providing timely information about the onset of drought. The drought preparedness plan must rely on accurate and timely assessments to trigger mitigation and emergency response programs.

5.7. Facilitating tactical planning and operational decisions by the farmers during the crop season through the provision of improved weather forecasts and advisories understandable to farmers

Catastrophic events like droughts, floods and cyclones, spatial and temporal changes in important weather parameters like rainfall, temperature, wind, cloud cover, humidity, etc. effect crop yields by influencing farmers' decision about selection of cultivar, use of inputs, crop management practices, etc. Short-range forecasts are normally available one day in advance, but modern agricultural practices such as sowing of weather-sensitive high yielding varieties, need-based application of fertilizer, pesticides, and insecticides, efficient irrigation and planning for harvest require weather forecast with higher lead time which enable the farmers to take ameliorative measures. Thus, for agricultural sector, location-specific weather forecast in the medium range (3 to 10 days in advance) is very important. These forecasts and advisories should be made available in a language that farmers can understand.

5.8. Integrating weather and climate information into an agricultural risk management framework

Risk management of a high input system (usually found in well-developed economies) is very different from the risk management that resource poor farmers in the drylands need to adopt. Often it is not a matter of optimizing production, which could in fact increase profits as well as risks, but more a matter of maximizing input efficiencies. To create climate knowledge, climate science can provide insights into climatic processes, agricultural systems science can translate these insights into management options and rural sociology can help to determine the options that are most feasible or desirable. Promoting the use of an integrated risk management framework that takes into account preparedness, monitoring, assessment, mitigation, and adaptation is essential for ensuring food security. Current strategies for conservation and management of natural resources need to be re-evaluated and incorporated into preparedness and mitigation plans to effectively cope with the increasing frequency of extreme events and natural disasters and their impacts on agriculture.

5.9. Enhancing the knowledge of the rural communities regarding the climatic regimes in which they operate and responding to their needs for weather and climate information

More emphasis needs to be placed on educating the dryland farmers on the applications of weather and climate information and on strategies to cope with the projected climate change through the organization of roving seminars in collaboration with agricultural research and

extension agencies. This can be done through the organization of seminars on "Weather, Climate and Farmers" in local languages. This involves bringing groups of farmers from several villages at a centralized location for a one-day seminar to interact with the agrometeorologists and the agricultural extension services and to provide feedback on the farmers' needs. Through such efforts rural applications of weather and climate information can be promoted and strengthened.

5.10. Development and communication of tools to support decision making

A key challenge is how to engage the agriculture, water resource, and environmental communities in the development and communication of tools to support the decision making process. Disseminating climate information is part of a process that begins with scientific knowledge and understanding and ends with the evaluation of the information. Internet is one of the new and cost-effective technologies that can provide this information in an accurate and timely manner. Use of mobile phones and text messages on a real-time basis needs to be accelerated to inform the rural communities in the dryland regions.

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3.3. Climate change mitigation in drylands

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Abstract

Mitigating global climate change requires policies to reduce greenhouse gas (GHG) emissions and enhance carbon sinks. In rural areas, mitigation measures include improved cropland and pasture management, increased afforestation and decreased deforestation, improved forest management, increased biofuel production, and reduced energy use. The Clean Development Mechanism (CDM) and other tools can be used to promote these measures in developing countries. A review of the limited number of CDM projects related to rural development conducted to date indicated that most of them are related either to the use and treatment of manure and animal waste or the utilization of biomass, but other areas also have the potential to promote sustainable rural development along with mitigating climate change. Several ways to make greater use of CDM projects for sustainable rural development, particularly in drylands, are discussed. First, approved CDM methodologies must be developed in cropland and pasture management for soil carbon sequestration and in rice field management to reduce methane emissions. Second, the use of CDM projects should be expanded to areas where a limited number of projects has thus far been conducted, particularly to reduce the use of synthetic nitrogen fertilizers, produce and use biofuels, develop more energy-efficient agricultural facilities, and encourage afforestation and reforestation activities. Finally, more attention should be paid to the relationship between climate change mitigation and other issues such as sustainable development and combating desertification. We need to seek synergies and avoid trade-offs between climate change mitigation and sustainable development as well as between climate change and desertification. New studies in dryland science and technology are needed to provide scientific evidence to support agricultural functions in reducing GHG emissions by developing mitigation technologies, cost-effective and reliable GHG monitoring systems, and appropriate methodologies to assess the impact of mitigation on sustainable development.

1. Introduction

Climate change threatens dryland dwellers, especially poor people engaged in agriculture in developing countries, through increased risk of crop failure and livestock deaths and decreased income. Poor farmers are affected more seriously than wealthy farmers because they are more limited in their ability to adapt to the impacts of climate change.

Appropriate adaptation measures are necessary to alleviate climate change impacts in the agricultural sector. In particular, it is essential to develop cost-effective and relatively inexpensive measures that can be introduced even to poor farmers and to disseminate these measures in rural areas. Agricultural lands occupy 37% of the earth's land surface, and agriculture accounts for 52 and 84% of global anthropogenic methane and nitrous oxide emissions, respectively (Smith et al. 2008). Therefore, the agricultural sector can contribute to greenhouse gas (GHG) emissions reduction through better land use and agricultural practices, the use of biomass as an energy source, and other measures.

Climate change mitigation should be considered when developing appropriate solutions to alleviate poverty for dryland farmers through financial mechanisms such as the Clean Development Mechanism (CDM). In this paper, I investigate the current status of climate change mitigation in drylands, paying special attention to CDM, and discuss how climate change mitigation should be undertaken to achieve synergies and avoid trade-offs between climate change mitigation and sustainable development in drylands.

2. Mitigation in the UNFCCC framework

The United Nations Framework Convention on Climate Change (UNFCCC) defines mitigation as "actions to control, reduce or prevent GHG emissions, hence reduce climate change," which includes limiting or reducing GHG emissions by sources as well as preserving and enhancing GHG sinks and reservoirs.

The Kyoto Protocol seeks an overall emissions reduction of 5% between 2008 and 2012 by Annex I Parties and has legally binding reduction targets for industrialized countries that are Parties to the Kyoto Protocol. The Kyoto Protocol provides for flexible mechanisms (so-called "Kyoto mechanisms") to lower the overall costs of achieving reduction targets and contribute to sustainable development in developing countries. The Kyoto mechanisms include emissions trading, the Clean Development Mechanism (CDM), and Joint Implementation. Joint Implementation and CDM are both project-based mechanisms that feed the carbon market. Joint Implementation enables industrialized countries to carry out Joint Implementation projects with other developed countries, whereas CDM involves investment in sustainable development projects that reduce emissions in developing countries. In general, a CDM project is held in a Non-Annex I country (a developing country), and a developed Annex I country buys certified emission reductions (CERs, each equivalent to 1 t CO_2) from the developing country. The CERs can then be used by the developed country to meet a part of their Kyoto Protocol emissions reduction target. Thus, money moves from developed countries to developing countries via CDM projects, providing developing countries (including dryland countries) the chance to use the money for sustainable development while also implementing climate change mitigation.

3. Mitigation measures

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) classified emissions reduction solutions into different sectors, such as energy conservation and efficiency, fossil fuel replacement, renewable energy sources, nuclear power, carbon capture and storage, and forest sinks, both for the short term (until 2030) and the long term (until the end of this century). Short- and long-term measures are different because of expected technological innovation, rising carbon prices, and other related factors.

According to the World Development Report 2008 (World Bank 2007), 63% of total GHG emissions are from the energy sector, 15% from agriculture, and 11% from deforestation. Agriculture and associated deforestation are therefore considered to be major sources of GHG emissions for developing countries.

Mitigation measures that can be applied in rural dryland areas in developing countries include improving energy efficiency in the energy supply and use sector; switching fuels and other options in the transportation and building sectors; using forest management to increase afforestation and avoid deforestation in the forestry sector; producing biofuels; and improving management of cropland, pastures, and livestock in the agricultural sector.

In the context of agricultural management, there are three important GHGs: carbon dioxide (CO_2), methane, and nitrous oxide. Climate change can be mitigated through a reduction in emissions of methane and nitrous oxide, an increase in carbon sequestration in agricultural soils, and the growth of energy crops to substitute for fossil fuels in the production of energy (Olesen and Bindi 2002). Proper management of cropland and grazing land as well as the restoration of cultivated organic soils have the potential to significantly reduce CO_2 emissions. Methane emissions are related to the production and management of rice and livestock, whereas nitrous oxide emissions are primarily related to cropland management, especially the use of nitrogen fertilizers.

Many studies have been conducted on the effects of these mitigation measures. Soil carbon sequestration can be realized through a variety of measures, including reversion to forest and the use of no-till or reduced-tillage crops and crop rotation with perennial crops. Care needs to be taken, however, because agricultural management impacts on soil organic carbon storage will vary depending on climatic conditions that influence the plant and soil processes driving soil organic matter dynamics (Ogle et al. 2005).

Agroforestry systems that integrate tree production with crop and animal production systems are believed to have a higher potential to sequester carbon than pastures or field crops (Nair et al. 2009). Conservation tillage has been reported to increase soil organic matter in tropical agricultural areas in Brazil (Cerri et al. 2007). A reduction in the use of synthetic nitrogen fertilizers can be realized using crop rotation with legumes, precision farming, and slow-release fertilizers. Rice field management to reduce methane emissions can be realized by draining wetland rice fields, growing rice with low exudation rates, and improving water management.

4. CDM

4.1. Outline of CDM

As previously discussed, the CDM mechanism stimulates both sustainable development and emission reductions, while giving industrialized countries some flexibility in meeting their emissions reduction limitation targets. The carbon trade volume peaked in 2007 at about 600 Mt CO_2 equivalent, and the price peaked at about USD16 for 1 t CO_2 equivalent in 2008 (World Bank 2010). Recently, both the trade volume and price have been declining, primarily as a result of the global financial crisis and economic recession that began in 2008.

All CDM projects are compiled in a database and can be analyzed using the Project Search Web site (http://cdm.unfccc.int/Projects/projsearch.html). As of 8 May 2011, 139 projects were registered by the UNFCCC and categorized in the agricultural sector, accounting for 3.9% of all CDM projects in the 15 CDM sectors. Table 1 shows the number of agricultural projects and amount of GHG emissions reductions by year. The peak year for both the number of projects and emissions reductions was 2006, with 66 registered projects and reductions of about 6.4 Mt CO2 equivalent. Table 2 shows the host developing countries; Brazil had the most projects at 42, followed by Mexico (24) and the Philippines (23). The United Kingdom has sponsored the largest number projects (80), followed by Switzerland (61) and Japan (15).

4.2. The CDM process

All CDM projects proposed to the UNFCCC need to use an approved methodology, and the core elements of the Project Design Document (PDD) should follow the approved methodology's format. Proposals must include detailed features of the project in the PDD, for example,

applicability conditions, approach, project owner, additionality, baseline, project emissions, leakage, emission reductions, sustainable development impact, stakeholder involvement, and monitoring.

Table 1. CDM projects in agricultural sector by registered year

Year	Number of projects	Emissions reduction*	Average reduction
2005	6	684,533	114,089
2006	66	6,382,776	96,709
2007	11	419,703	38,155
2008	9	256,077	28,453
2009	31	505,084	16,293
2010	11	436,386	39,671
2011	5	154,189	30,838
Total	139	8,838,748	63,588

Data source: http://cdm.unfccc.int/Projects/projsearch.html (as of 8 May 2011)

** The mean amount of emissions reductions (t CO_2 equivalent) per year.*

4.3. CDM projects related to rural development

CDM methodologies are categorized by sector, and the agricultural sector has five approved methodologies (UNFCCC 2010). Three of the methodologies (AM0073, ACM0010, and AMS-III.D.) are related to the collection and treatment of manure. One (AMS-III.R.) is related to methane recovery in agricultural activities, and one (AMS-III.A.) is about offsetting the use of synthetic nitrogen fertilizers with the application of inoculants in legume–grass rotations.

It should be noted that there are other methodologies which are not categorized as agricultural but are deeply related to agriculture and rural development. The approved methodologies related to agriculture and rural development can be divided into six types (Table 3):

Type A: Reduced use of nitrogen fertilizer is realized by offsetting the use of synthetic nitrogen fertilizers with the application of inoculants in legume–grass rotations to reduce nitrous oxide emissions.

Type B: Manure, animal waste, and wastewater are collected and treated to produce biogas or avoid methane emissions.

Type C: Biomass residues are used instead of fossil fuels to generate electricity and heat, thereby reducing CO_2 emissions.

Type D: Plant oil and biodiesel are produced and used for fuel and transport applications, thereby reducing the use of fossil fuels and reducing CO_2 emissions.

Type E: Energy efficiency is increased by improving agricultural facilities, increasing irrigation efficiency, reducing the amount of power used per unit area of land, or decreasing fuel consumption through increased efficiency or reduced machinery use to reduce CO_2 emissions.

Type F: Degraded land is restored through afforestation and reforestation, and reforestation or afforestation is implemented for land currently under agricultural, pastoral, and other agricultural uses to enhance carbon sequestration in organic soils.

Table 2. CDM projects in agricultural sector by host country

Country	Number of projects	Emissions reduction*	Average reduction
Argentina	1	43,680	43,680
Armenia	1	62,832	62,832
Brazil	42	3,406,493	81,107
Cambodia	2	57,213	28,607
Chile	8	677,594	84,699
China	6	369,512	61,585
Cyprus	3	40,483	13,494
Ecuador	3	26,030	8,677
Guatemala	1	30,333	30,333
Honduras	2	34,917	17,459
India	10	425,625	42,563
Indonesia	1	166,000	166,000
Malaysia	9	1,589,370	176,597
Mexico	24	1,553,347	64,723
Peru	1	26,719	26,719
Philippines	23	264,809	11,513
South Africa	1	32,660	32,660
Thailand	1	31,131	31,131
Total	139	8,838,748	63,588

Data source: http://cdm.unfccc.int/Projects/projsearch.html (as of 8 May 2011)

** The mean amount of emissions reductions (t CO2 equivalent) per year.*

The approved CDM methodologies cover a wide area related to rural development, but soil carbon sequestration through agricultural practices such as tillage management and crop rotation with perennial crops is not included in the approved methodologies. This omission is most likely because of the difficulty in developing appropriate cost-effective long-term methodologies and of scientific monitoring as well as the lesser impact on sustainable development.

As described in Section 4.1, 139 CDM projects have been categorized in the agricultural sector. Table 4 shows the methodologies used in those 139 projects, 51 of which used more than one methodology. All of these CDM projects were either Type B (manure and animal waste) or C (biomass utilization).

Table 3. Types of CDM projects related to rural development and their methodologies

Type	CDM methodology used*
A: Reduced N fertilizer	Small: AMS-III.A.
B: Manure and animal waste	Large: AM0006, AM0016, AM0053, AM0069, AM0073, AM0075, ACM0010 Small: AMS-III.D., AMS-III.H., AMS-III.I., AMS-III.O., AMS-III.R.
C: Biomass utilization	Large: AM0036, ACM0002, ACM0006 Small: AMS-I.A., AMS-I.C., AMS-I.D., AMS-I.E., AMS-III.E., AMS-III.G.
D: Biofuel production and use	Large: ACM0017 Small: AMS-II.G., AMS-III.T.
E: More energy-efficient agricultural facilities and activities	Small: AMS-II.F.
F: Afforestation and reforestation	Large: AR-AM0002, 4, 5, 6, 7, 9, 10, 11, AR-ACM0001, 0002 Small: AR-AMS0001, 2, 3, 4, 5, 6, 7

** "Large" and "small" indicate methodologies for large- and small-scale CDM project activities, respectively.*

4.4. Examples of CDM projects related to rural development

Four examples of CDM projects related to rural development are discussed below, especially from the viewpoint of methodologies used and the contributions to sustainable rural development in drylands. The materials were derived from each case's PDD, which can be downloaded from the Project Search Web Site of UNFCCC/CDM. A summary of the projects is given in Table 5.

4.4.1. Hubei Eco-Farming Biogas Project Phase I (Type B)

This Type B project targets pig-breeding farms and aims to prevent methane emissions originating from pig manure by collecting the methane and using it as an energy source. Biogas digesters will be installed so that the pig manure can be fermented in a biogas digester instead of being stored in a deep pit under anaerobic conditions. The project will also support improvements of toilets and pig pens, kitchen renovations, and installation of a gas burner in each household. The biogas produced in the digesters will be used as thermal energy to replace the fossil fuel (coal) currently used to meet households' daily energy needs for cooking and heating. In addition, the recovery and utilization of biogas from the digested slurry in the biogas digester will reduce methane emissions from the slurry that would otherwise have been stored in a deep pit (Hubei Eco-Farming Biogas Project Phase I 2008).

The project uses two methodologies: AMS-III.R. (methane recovery in agricultural activities at the household/small farm level) and AMS-I.C. (thermal energy for a user with or without

electricity). The use of AMS-III.R. in CDM projects is very limited—this is currently the only project using it. The number of projects using AMS-I.C. is greater; 125 out of 3597 CDM projects use it as do 11 of the 139 agricultural CDM projects.

Table 4. CDM projects in the agricultural sector by methodology

Methodology	Type of project*	Number of projects**	Number of single methodology projects	Emissions reductions (t CO_2 equivalent)	Average reduction (t CO_2 equivalent)
AM0006	B	10	10	871,644	87,164
AM0016	B	40	40	2,902,855	72,571
ACM0002	C	1	0	—	—
ACM0010	B	5	5	274,111	54,822
AMS-I.A.	C	3	0	—	—
AMS-I.C.	C	11	0	—	—
AMS-I.D.	C	41	4	928,340	232,085
AMS-III.D.	B	47	22	579,529	26,342
AMS-III.E.	C	24	3	331,063	110,354
AMS-III.G.	C	2	0	—	—
AMS-III.H.	B	12	2	2,023	1,012
AMS-III.I.	B	2	2	49,980	24,990
AMS-III.R.	C	1	0	—	—
Total		199	88	5,939,545	67,495

** Type of CDM project related to rural development as shown in Table 3.*
*** Of the 139 agricultural CDM projects, 51 use more than one methodology, which are listed more than once—those projects are excluded from emissions reductions calculation.*

4.4.2 Lap Vo Rice Husk Biomass Power Plant (Type C)

The project objectives are to generate electricity by utilizing rice husks generated from local husking processes and sell the generated power to the national grid in Vietnam. This is the first grid-connected rice husk power plant in Vietnam. It will apply power-generation technology and solve the environmental problem of rice husk disposal and thereby provide many benefits for the local government and people. The project will reduce GHG emissions by avoiding CO_2 emissions from the business-as-usual scenario of electricity generation from fossil-fuel-fired power plants connected to the national grid. The project also helps eliminate methane emissions from the biomass decay process when rice husks are unused and discarded (Lap Vo Rice Husk Biomass Power Plant 2009).

The project uses the AMS-I.D. methodology (grid-connected renewable electricity generation). A total of 1028 projects use this methodology, but none in the agricultural sector use it.

Although this project is categorized in the energy industries sector, it is deeply related to agricultural and rural development because the project uses rice residues as a biomass energy source. With respect to the social and economic impacts of the project, jobs are expected to be

created during the period of construction and operation of the plant. Local demand for food and supplies should promote the production of agricultural goods and commercial services in the local communities, thereby advancing economic development and improving the standard of living in the province and nearby communities.

Table 5. Examples of CDM projects related to rural development

Project title	**Hubei Eco-Farming Biogas Project Phase I**	**Lap Vo Rice Husk Biomass Power Plant**	**Plant-Oil Production for Usage in Vehicles, Paraguay**	**Small Scale Cooperative Afforestation CDM Pilot Project Activity on Private Lands Affected by Shifting Sand Dunes in Sirsa, Haryana**
Host parties	China	Vietnam	Paraguay	India
Other parties involved	Netherlands, Japan, Belgium, Canada, Denmark, Italy, Luxembourg, Norway, Spain, Sweden, Switzerland, Germany	Germany	Switzerland	n/a
Bilateral and multilateral funds	Community Development Carbon Fund (CDCF)			
Sectoral scopes	Energy industries, Agriculture	Energy industries	Transport	Afforestation and reforestation
Activity scale	Small	Small	Small	Small
Methodologies used	AMS-III.R., AMS-I.C.	AMS-I.D.	AMS-III.T.	AR-AMS0001
Emissions reductions (t CO_2 equivalent per year)	58,444	39,506	17,188	11,596
Fee level (USD)	10,188.8	6401.2	1937.6	0.0
Registration date	19 Feb. 2009	17 Aug. 2010	17 Dec. 2010	23 Mar. 2009
Crediting period	19 Feb. 2009–18 Feb 2019 (fixed)	01 Jan. 2011–31 Dec 2017 (renewable)	17 Dec. 2010–16 Dec. 2017 (renewable)	23 Mar. 2009–22 Mar. 2029 (renewable)

4.4.3 Plant-Oil Production for Usage in Vehicles, Paraguay (Type D)

The aim of this project is to substitute plant oil for diesel fuel used in transportation. Emission reductions will result from the differential GHG emissions from the use of biofuel versus the equivalent amount of substituted diesel fuel based on the relative energy content of the two fuels. Furthermore, diesel fuel is imported into Paraguay and is therefore costly. Biofuel is currently only marginally used, although Paraguayan law promotes the use of biofuels (law 2748, dated 07.10.2005). The reason for the marginal usage of biofuel is the high cost of oilseeds, which makes the production of biofuels financially unviable, and a lack of investment. Oilseeds, including castor bean, crambe, and oilseed radish, are currently produced at various locations in Paraguay, and different crops could be planted in the future (Plant-Oil Production for Usage in Vehicles, Paraguay 2010).

The project uses the AMS-III.T. methodology (plant-oil production and use for transport applications) and is categorized in the transport sector. This is the only use of this methodology in all of the CDM projects.

4.4.4 Small Scale Cooperative Afforestation CDM Pilot Project Activity on Private Lands Affected by Shifting Sand Dunes in Sirsa, Haryana (Type F)

The lands to be planted in this CDM project are located in the northeastern fringe of the Indian Thar Desert. The project area is affected by aeolian (wind-blown) sand and contains many degraded croplands, which are generally left fallow. Large areas have little or no vegetation because of frequent dust storms, and cultivation and shifting sand dunes prevent any potential natural regeneration of forest in the area. The aim of the project is to establish about 370 ha of mixed forests, using the following seven tree species: *Ailanthus excelsa*, *Acacia tortilis*, *Eucalyptus hybrida*, *Acacia nilotica*, *Dalbergia sissoo*, *Zizyphus mauritiana*, and *Prosopis cineraria* (Small Scale Cooperative Afforestation CDM Pilot Project Activity on Private Lands Affected by Shifting Sand Dunes in Sirsa, Haryana 2008).

The main expected socioeconomic benefits of the project include income generation from timber and fruit production and from the sale of carbon credits, creation of a sustainable fuel wood supply, strengthened social cohesion, improved social well-being and agricultural production, and the dissemination of technical training.

The project uses the AR-AMS0001 methodology (simplified baseline and monitoring methodologies for small-scale afforestation and reforestation project activities under the clean development mechanism implemented on grasslands or croplands) and is categorized in the afforestation and reforestation sector. The project will contribute both to mitigating climate change and combating desertification.

4.4.5 Status of CDM projects related to rural development

To date, there are no CDM projects registered in the Type A and E categories. Most CDM projects related to rural development are either Type B (manure and animal waste) or C (biomass utilization). Actual and potential projects can be placed into one of three categories. In the first category are projects that already have approved CDM methodologies that have been put to practical use, primarily Types B and C. The second category includes approved CDM methodologies, but few actual projects that make use of those methodologies. This includes the methodologies in Types

A (reduced use of nitrogen fertilizer), D (biofuel production and use), E (more energy-efficient agricultural facilities and activities), and F (afforestation and reforestation). The third category is the case in which no CDM methodology has been approved, but there is a potential to contribute to climate change mitigation. This includes methodologies for soil carbon sequestration through cropland and pasture management and management of rice fields to reduce methane emissions. Approved CDM methodologies should be developed for these cases. Promising methods of carbon sequestration have been tried in agricultural soils in Europe, including promoting the use of organic inputs on arable land, introducing perennials on arable set-aside land for conservation or production of biofuel, promoting organic farming, raising the water table in farmed peatland, and using no-till or conservation tillage practices in some areas (Freibauer et al. 2004).

5. Future perspectives of climate mitigation and CDM

My investigation of CDM projects, particularly the case studies above, revealed that current agricultural CDM projects are related to the fields of manure and animal waste and biomass utilization. These projects have the potential to promote sustainable rural development along with climate change mitigation, but the number of projects is limited. To make use of CDM projects for sustainable rural development, especially in drylands, I make the following recommendations. First, approved CDM methodologies must be developed in cropland and pasture management for soil carbon sequestration and rice field management to reduce methane emissions. Second, the use of CDM projects should be expanded to areas where a limited number of projects have thus far been conducted, particularly to reduce the use of synthetic nitrogen fertilizers, produce and use biofuels, develop more energy-efficient agricultural facilities and activities, and encourage afforestation and reforestation activities. Finally, more attention should be paid to the relationship between climate change mitigation and other issues, such as sustainable development and combating desertification. We need to seek synergies and avoid trade-offs between climate change mitigation and sustainable development as well as between climate change and desertification. (Beg et al. 2002; Smith et al. 2007).

The changing carbon cycle poses new questions for scientists (Janzen 2004). We should encourage new studies in dryland science and technology to provide scientific evidence to support agricultural functions in reducing GHG emissions by developing mitigation technologies (e.g., improved crop management and reduced fertilizer use), cost-effective and reliable GHG monitoring systems, and appropriate methodologies to assess the impact of mitigation on sustainable development.

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3.4. Managing water resources for sustainable use in Arab arid lands

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Abstract

The Arab region encompasses the largest belt of arid lands, including the driest regions on Earth. This is complicated by extreme variability of the scant rainfall in space and time. Under such conditions, proper management of the meager resources becomes essential by both water users and policy makers. This is particularly true in the case of groundwater, where modern drilling techniques of withdrawal did not consider issues of sustainability. This may be ameliorated in part by the use of advanced methods and techniques of the space age, including a variety of satellite image data. Examples are here given of the use of space images in establishing the potential of groundwater resources in the Arab region. These data include: (1) multispectral images that clearly depict surface features and allow the deduction of their geologic history and drainage patterns; (2) thermal images that show the location of rain water accumulation just below the surface, which may replenish groundwater aquifers. They are also used to identify groundwater along faults in coastal zones that can be harvested before seeping into the sea; (3) radar data that penetrate the fine-grained sand cover to reveal buried courses of ancient rivers; and (4) elevation data that depict surface water flow in the past as well as in the present. This type of information is required in a database for proper regulations by policy makers. The information would answer questions such as: What are the boundaries of each groundwater basin or aquifer? How much of the water is to be used *in situ* or transported for both agricultural and human use? What are the safe pumping rates that would assure sustainability? If knowledge-based policies are widely instituted we would assure the longevity of water resources in the Arab region as well as similar arid lands worldwide.

Introduction

The Arab region is among the driest parts of the world. The Great Sahara of North Africa, in particular, extending for nearly 6,000 km from east to west, is the driest stretch of land on Earth. Solar radiation in its eastern part is capable of evaporating 200-times the amount of rainfall (Henning and Flohn 1977). This measure of dryness, the Aridity Index, in the rest of the Arab deserts varies from 100 to 50. By way of comparison, the Aridity Index of the driest place in North America, Death Valley in California, is seven.

This hyper-arid condition necessitates dependence on groundwater resources. Countries of the Arabian Gulf region are endowed with oil resources. The latter are used in sea-water desalination for human consumption. However, agricultural activities for food and fiber production must depend on groundwater. In the meantime, increase of populations and the attendant food and fiber requirements have exasperated the situation.

Location and utilization of additional water resources have become essential in the Arab region. Some local inhabitants believe that water beneath the surface occurs as lakes or rivers underground, although it mostly exists in the pore spaces between rock grains. Types of groundwater occurrences are explained in this contribution along with the proper methodologies for locating

additional resources. Policy considerations are also enumerated along with suggestions for data collection and analysis for sustainable groundwater use.

Water covers over 70% of the Earth's surface. Salt water in the oceans and seas constitutes 97% of all water on Earth. Fresh water bodies constitute a negligible fraction of the store of sweet water in the remaining 3%. That is because polar ice masses and mountain glaciers contain nearly 70% of all fresh water. Groundwater represents the remaining 30%, which leaves less than 1% for surface water in all the rivers, fresh water lakes and swamps on Earth.

In the Arab region, groundwater is more prevalent than commonly believed, particularly in sand covered deserts, which are distant from population centers. However, it is important to note that this water accumulated during wetter climates in the geological past. Investigations in the driest region of the Great Sahara have uncovered evidence of vegetation, animal bones, and human artifacts from these wet climate episodes (e.g., Fig. 1).

Figure 1. Depictions by pre-historic humans of a variety of animals left as petroglyphs on the Gilf Kebir plateau in southwest Egypt. The most faded depiction is that of a giraffe, indicating plush vegetation. The next depictions are of an ostrich and a baboon suggesting change to a savanna like environment. The youngest illustrations are of grazing animals, indicating the lessening of the vegetation cover upon the onset of the latest dry climate episode, about 5,000 years ago.

Geological and archaeological evidence prove that the region experienced several wet climate episodes, each one lasted for thousands of years (Wendorf *et al.* 1987). The most recent wet period lasted from up to 14,000 to 5,000 years ago. The vast majority of water extracted from wells in that desert today is tens of thousands of years old (El-Baz 1988). This essentially means that the groundwater resources of the Sahara, and probably much of the rest of the Arab region, are not being replenished today. This fact has to be taken into account, because these precious resources must be properly managed to ensure sustainability.

Groundwater accumulation

Groundwater accumulates from rainfall on the surface of the Earth. The driving force for its movement is gravity, where water moves from higher to lower elevations. Water moving beneath the surface is protected from heating and evaporation by solar radiation and remains trapped

in the rock fabric for thousands of years. In its journey through the rock, water moves through primary porosity (open spaces between grains of soft sedimentary rocks) and/or secondary or induced porosity (faults and fractures in any rock type).

Any rock composed of adjoining sand grains, or sandstone, and others such as limestone that have irregular, yet connected pore spaces allow water passage. Water percolates to move from a higher to a lower place. Sandstone is usually salt free, and the confined water remains sweet for thousands of years. On the other hand, limestone rocks have soluble chemicals and the passing water dissolves the salts. In odd cases, the dissolution of salts within the host rock renders the water saltier than that of the sea.

Groundwater basins may be up to hundreds of meters in thickness. This is the case of the so-called "Nubian Aquifer" of North Africa and its equivalent in the Empty Quarter basin of the Arabian Peninsula. Here and there, such extensive, seemingly horizontal sandstone aquifer is interrupted by non-porous rock masses, including igneous and volcanic rocks.

The direction of surface runoff depends on topography; the greater the degree of tilt, the faster the water movement. The pattern may be controlled by the orientation of faults and fractures in the rock. As surface water denudes the rock to establish an easy passageway, a drainage pattern emerges (Fig. 2). The pointed tips of the often V-shaped pathway intersections indicate the direction of downward water flow. Such dry *wadi* patterns indicate the topography at the time of formation. Thus, analysis of the pattern left on the land surface by running surface water is essential to the prediction of groundwater accumulation sites.

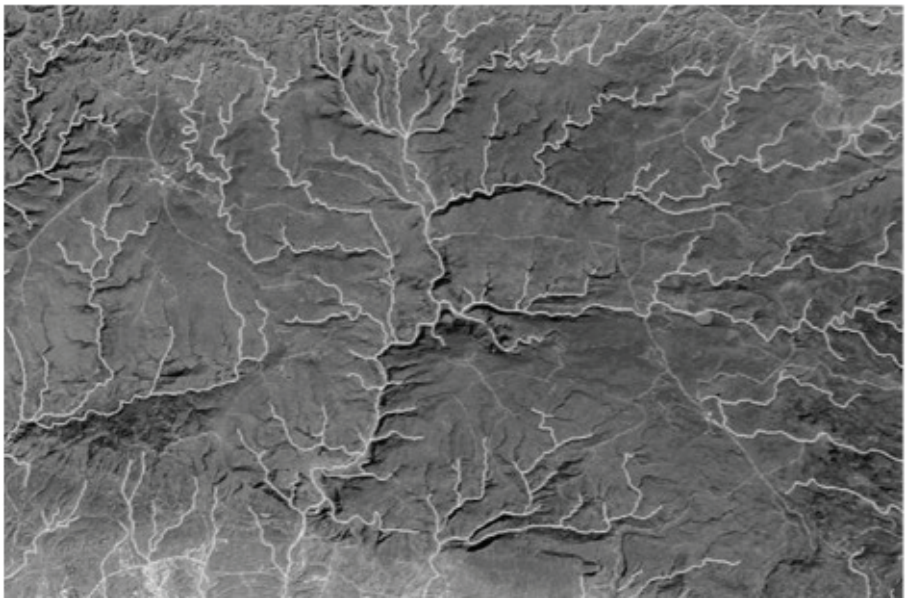

Figure 2. Landsat image of a drainage pattern in the limestone plateau of central Oman. The wadi pattern forms a typical dendritic shape. The major valley segments are oriented along the main fracture system that is oriented in a northeast-southwest direction.

In the Arab region, sparsely populated areas used to depend on water that percolated through fractures from higher topography to exit in the form of springs. These may be called *wahat* (oases) in North Africa, *oyoun* in the Middle East, and *aflaj* in southern Arabia. Such resources were sufficient for small communities in the past. The increase of populations and the resulting

water use render this impractical at present. This forced municipalities to deliver water to the numerous communities year round.

Water is known to consistently flow in fractures for extended distances. For example, *Bir Zamzam* is an open well near Mecca in the *Higaz* Mountains of western Arabia. It receives its water constantly through fractures in the host rocks. The water flows from seasonal rainfall or snowmelt on the mountain range as it has done for thousands of years. The water level in the well might increase of decrease due to fluctuations in rainfall, but the flow of its sweet and highly prized water is nearly constant.

The principle was utilized by pearl divers in the Arabian Gulf water for millennia. Prior to the discovery of oil there, the economy of the region depended on harvesting and selling Gulf pearls. Rainwater on the *Higaz* Mountains of western Arabia found its way through fractures in the rock to exit at the bottom of the Gulf, a distance of nearly 1,000 km. A pearl fishing party would send a diver carrying a rock – for fast descent – tied to a rope. The diver would seek fresh water emanating from the bottom of the high salinity Gulf water and fill a goat skin or "*girba*." When finished, the diver would give a signal using the rope to be pulled up to the vessel. The process would be repeated until the party had enough water for a peal foraging period.

No plausible explanation of the source of the fresh water springs in the bottom of the Gulf water was known. Most experts discounted the distant *Higaz* Mountains as a source. However; the theory gained support after satellite image interpretations followed by field exploration in the desert surface of Kuwait. The latter was proven to be basically a dry delta of an ancient river (El-Baz 1998). If surface water made the journey following a fracture across Arabia from west to east, then similar cracks in the subsurface would do the same. The proof was essentially the product of utilizing satellite images.

Remote Sensing

Imaging the Earth from space has progressively advanced throughout the past 45 years. Starting in the mid 1960s, photographs were obtained by astronauts of the Gemini, Apollo, Skylab, and Apollo-Soyuz missions (El-Baz 1998). They used hand-held cameras with color film, which displayed the nature and composition of the depicted features. Ancient rocks, with much iron and other dark elements appeared brown, limestone looked bright, sands appeared golden yellow, and ocean currents became discernable (Lillesand *et al.* 2004).

Detail in space images depends upon: (a) the altitude of the spacecraft; the lower the orbit, the higher the resolution, and (b) the focal length of the camera lens; the longer the length, the greater the detail. In the first satellites a whole town appeared as a dot; today a car can be clearly identified in high-resolution images. Multi-spectral satellite images, such as those of the American Landsat and the French SPOT systems, are ideal for the study of water movement on the Earth's surface (El-Baz 1998). They allow mapping and interpreting regional drainage systems and individual stream courses for drainage basin analysis.

The uniformity of drainage patterns is an indicator of rock types. For example, a branching pattern implies a homogeneous rock character with little structural control. Deviations from this pattern (by an increase in angularity, parallelism, and angle of confluence) may indicate a change in the rock type or an increase in structural control.

Fractures induce secondary porosity in any type of rock (El-Baz 2000). The resulting fracture zones store large amounts of water, usually in a network. Fracture zones may: (a) drain large areas and extend for tens of kilometers in length; (b) act as conduits to low elevation areas from mountainous regions where the recharge potential from rainfall is high; (c) connect several horizontal groundwater aquifers, increasing the volume of water; and (d) represent areas of potentially high artesian pressure where water is drained from high to low elevations and accumulates beneath the surface.

Thermal satellite image data, which indicate a difference in the temperature of desert surfaces, can be very useful in locating patters of subsurface water. Cool anomalies that appear on land in thermal images may represent water occurrences at or near the surface (Fig. 3). This is because of the latent heat content of water slows the process of absorbing and emitting radiation, so that at a given time within the diurnal heating cycle the warming of the moist soil is retarded. Similarly, cooling during the night is also slowed. Thus, moist soils possess higher thermal inertia, which shows up as a cold anomaly in the thermal data collected during daylight hours. Freshwater seeps into the coastal regions through subsurface fractures, as discussed in the case of Gulf pearl divers, may also be detected by temperature differences.

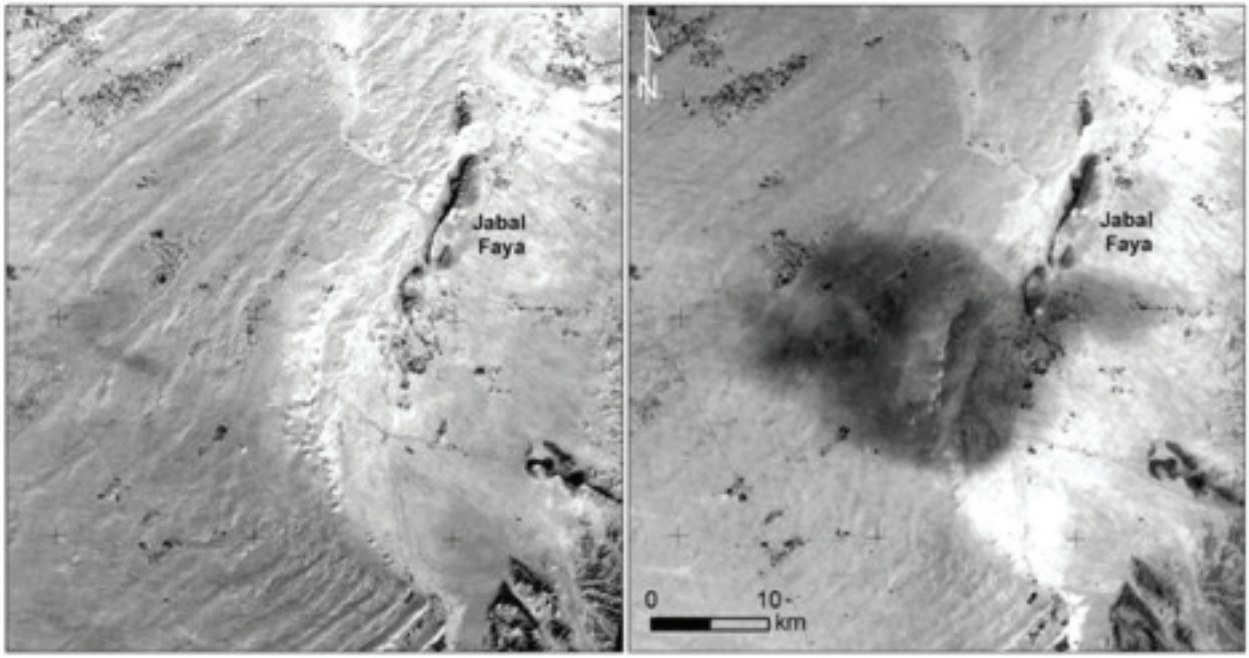

Figure 3. Before and after views of a dark (cool anomaly) in thermal images of a sandy region in the Emirate of Sharjah (UAE). The anomaly developed after rainfall on much higher topography further to the east. Water accumulation at or near the surface cooled the sand; the anomaly betrays the accumulation of groundwater in the substrate. Wells drilled in the region after the recognition of the anomaly continue to yield much sweet water.

Radar sensing from Earth orbit began with a Space Shuttle flight in 1981 (Elachi and Granger 1982). It provided the first images that showed the ability of radar waves to penetrate dry and fine-grained desert sand to reveal underlying topography. Unlike optical satellites, which sense reflected light, radar systems transmit microwave energy towards the surface and record the returned echo. Thus, a radar instrument can image the Earth, day or night, in any atmospheric condition, such as cloud cover, rain, snow, dust or haze.

In data from radar sensors bedrock surfaces and coarse deposits appear bright, because of diffuse reflection. However, smooth soils appear dark owing to reflection of the radar waves away from the receiving antenna on the spacecraft. The ability of radar waves to penetrate dry, fine-grained sand to reveal hidden topography allows unveiling ancient topography. Thus, courses of former rivers and streams give hints as to the location of groundwater accumulation sites in arid environments (Fig. 4). The principle has been put to the test in several localities in the eastern part of the Great Sahara of North Africa, as discussed below.

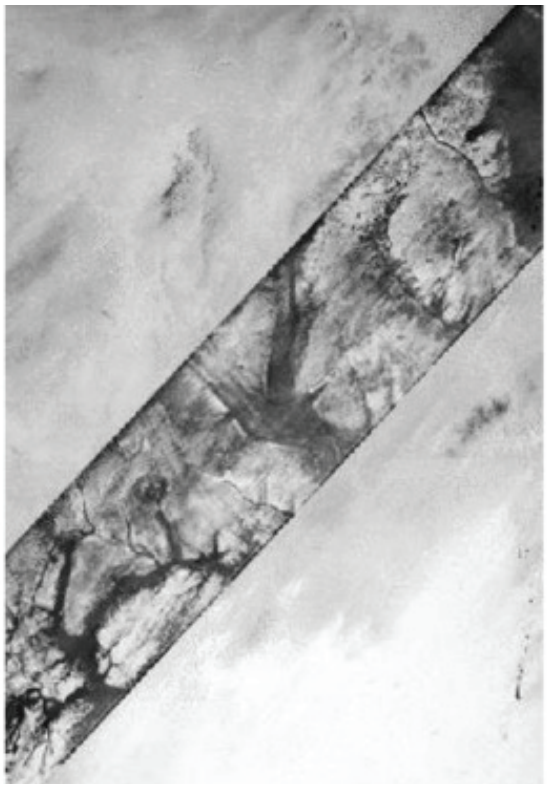

Figure 4. Shuttle Imaging Radar (SIR-A) strip superposed on Landsat image (U.S. Geological Survey, Flagstaff AZ). The radar waves penetrated the desert sand cover to reveal courses of ancient rivers and streams in an area of North Darfur in northwestern Sudan, just south of the border of Egypt.

The Shuttle Radar Topography Mission (SRTM), a joint project of NASA and National Imagery and Mapping Agency (NIMA), allows the construction of 3-D models of the terrain to show topographic variations. The digital data are available internationally at 90 m horizontal resolution and a 16 m vertical accuracy with a 90% confidence level. The void-filled seamless SRTM tiles are available, for any part of the world, from the Consortium of Space Information. These data are provided to researchers in a form that is most applicable to topographic studies of water surface flow directions, which are ideal for groundwater accumulation studies.

Saharan example

The Great Sahara constitutes the largest continuous stretch of desert on Earth, extending for nearly 6,000 km from east to west. Its hyper-arid condition necessitates complete dependence on groundwater resources for human consumption and agricultural activities. Population increase

during the last century has exasperated the situation and motivated the search for additional water resources from beneath the sands. Although the Sahara is now dry and is subject to the action of strong winds from the north, archaeological evidence indicate that it hosted much wetter climates in the past (e.g., Haynes, 1985). Surface water during past moist climates led to the formation of lakes in topographic basins (Ghoneim and El-Baz 2007).

In southwest Egypt, a 300 kilometer flat, sand-covered area straddles the border between Egypt and Sudan. This region is called the Great Salima Sand Sheet, after the Salima Oasis on its eastern border. The oasis is a prominent location along the *Darb El-Arbain* (the 40-day track) of camel caravans from Darfur in northwestern Sudan to the Nile Valley in Egypt. Many drainage lines uphill of the Great Selima Sand Sheet were revealed by SIR-C images with four major lines leading directly to it from the west (Fig. 5). The northernmost drainage system trends due east and measures 150 km in length. The longest wadi system was also very broad and is aligned in a NE-SW direction. Such broad channels usually develop under sheet flood conditions with plentiful surface water.

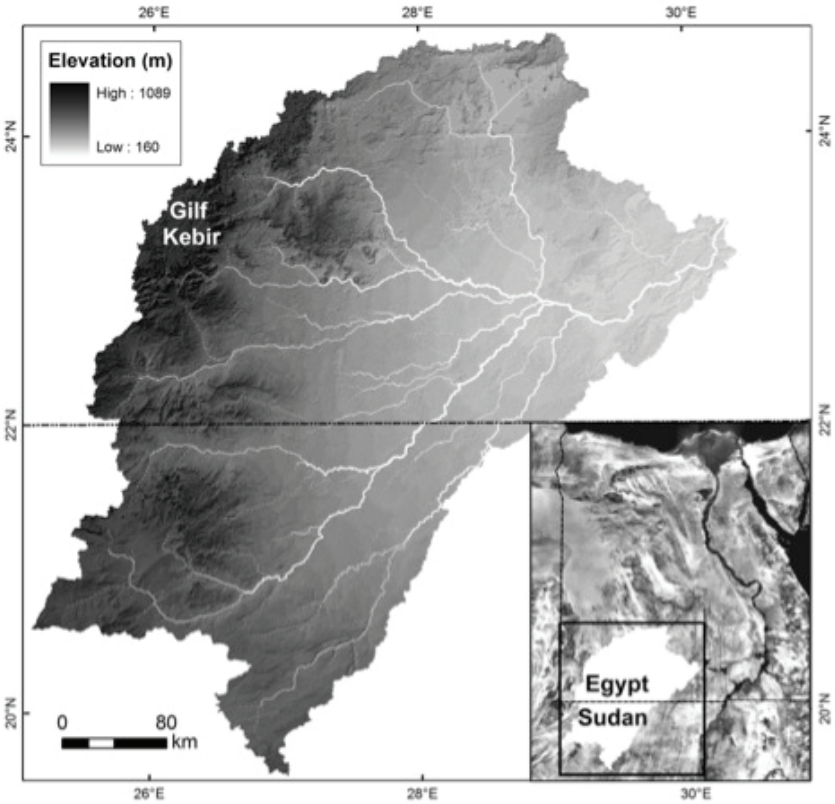

Figure 5. Numerous channels emanated from the Gilf Kebir plateau and neighboring highlands as shown by data of the Shuttle Radar Topography Mission (SRTM). All channels led to the low area toward the east, where groundwater is now being used to profitably raise wheat and other crops in the East Uweinat agricultural farms.

High-resolution, high-precision radar data show that several of these broad channels display small braided streams in their floors, indicating several episodes of water flow (Robinson *et al*. 2000). Field observations of trenches dug in May 1998 by a joint team of the Egyptian Geological Survey and Mineral Authority and the Desert Institute of Egypt indicate that moisture

begins to appear at 25 centimeters depth in the sand cover of shallow channels in the Bir Safsaf region of southern Egypt. This suggests that moisture from occasional rainstorms is carried through, and retained by, the sand fill of the palaeo-channels.

The first imaging radar data of 1981 showed courses of rivers and streams in northwestern Sudan (Fig. 4). The widest channel pointed to the northeast toward the Selima Sand Sheet region. The setting suggested that water accumulated in its eastern, lower-most area. The author made this case repeatedly, starting in 1982, to the Ministry of Agriculture and Land Reclamation of Egypt. Finally, the government of Egypt started in 1995 to drill a few exploratory wells. The latter were monitored for the next five years to assure the presence of large amounts of groundwater. Starting in 2000, plots of 10,000 acres were offered for agricultural development (Fig. 6) by private sector companies in Egypt.

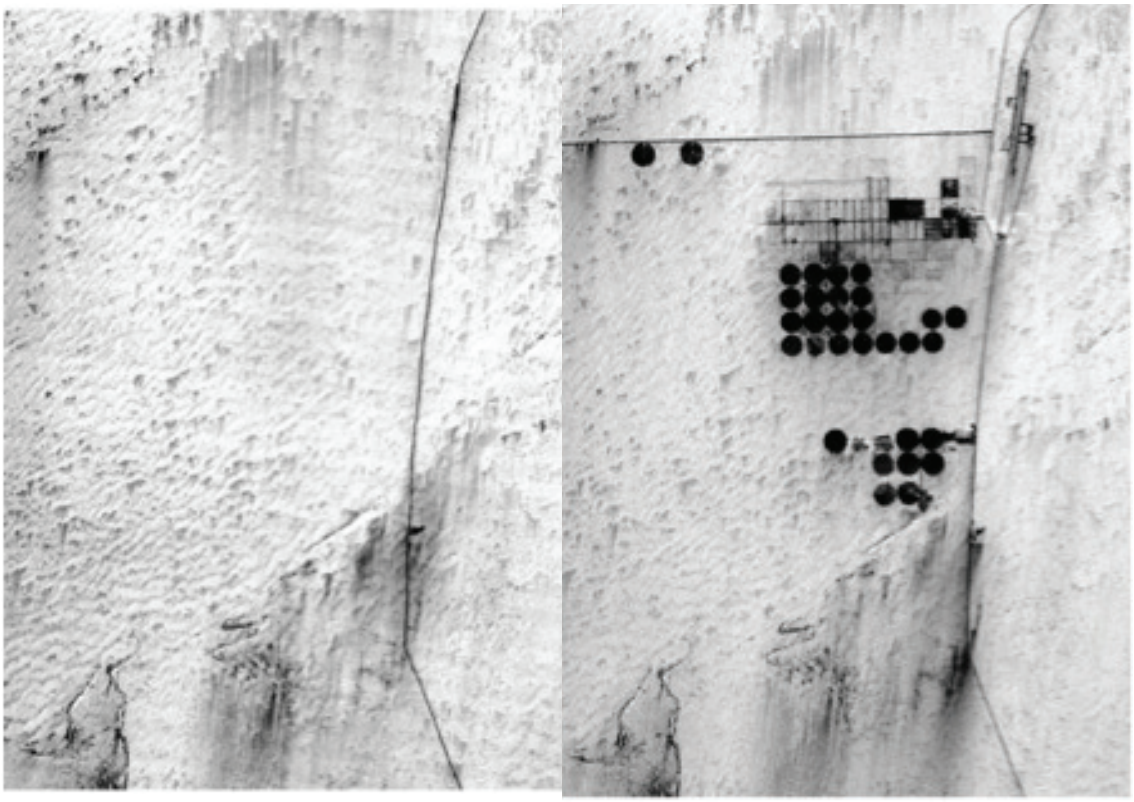

Figure 6. The East Uweinat region of southwest Egypt; left, as of 1984 only an asphalt road was paved to lead to the region. Right, in 2002 private companies began to raise cash crops using circular, spray-irrigation methods. Wheat is a major product and is utilized in bread production for populations in Aswan and neighboring towns of southern Egypt.

Today, within this "East Uweinat" region, 880 wells were drilled to water agricultural fields using circular, spray irrigation. The products include wheat, peanuts and other basic food essential crops. The wheat, in particular, has proven essential for flour production in the mills of Aswan for bread distribution in towns of southern Egypt. The proven water resources are capable of supporting agriculture over 150,000 acres for at least 100 years. This particular case emphasizes the need for a thorough study of the desert landscapes in the Arab deserts to uncover the groundwater potential for the benefit of its people.

Sustainability considerations

Extensive regions of the Arab deserts have not been explored for their groundwater potential. This includes the extensive, sand covered plains of the Great Sahara and the Empty Quarter of Arabia. In the meantime, it was recently realized that desert sands were rounded, transported and deposited by running surface water in depressions forming lakes (El-Baz 1988). The last of the wet phases ended about 5,000 years ago. During dry phases, like the present one, the wind acts on the sand deposits to shape desert dunes. This suggests that sand covered expanses might be underlain by much groundwater that would have accumulated in depressions during wet phases. However, this implies that the resources are not being replenished and would run out by constant extraction.

Regulations for sustainable use of these resources belong to the policy domain, where government bodies must collect and analyze the required data to control groundwater use. It is also essential that attention of policy makers should be sustained in the long term, because data collection and evaluation require much time. For this reason, it is instructive to consider major issues that require institutional regulation by policy makers. Detailed mapping is required to establish the boundaries of each groundwater basin or aquifer using all available space images and field-collected data. This is to be followed by exploration wells to establish the depth of the groundwater level. In many cases the water exists in several levels beneath the ground surface. The sampling must include measuring the salinity of various levels of the located aquifers.

In addition, modeling is required to establish how much water is contained in each aquifer. In some cases, over-pumping draws water from saline sources to contaminate sweet water horizons. The modeling is essential to establish the safe pumping rates that would assure sustainability. A glaring example of over-pumping with little or no regulation is that of *Al Qaseem* region in central Saudi Arabia. In this case, unregulated extraction of groundwater for wheat production in the 1980s and 1990s resulted in exhausting the resource and the abandonment of numerous fields.

It is essential that regulations take into account that such resources are of "fossil water." They accumulated during wet climate episodes that lasted for thousands of years in the geological past. Replenishment may occur in minor locations along the few mountain ranges, while the open desert very rarely receives any rainfall to replenish the groundwater below. From a policy regulation point of view this groundwater must be considered a finite resource that will run out, after a given period of time.

Regulations are also necessary to establish the proper use of the water. In some cases, it is best to use the water for *in situ* agriculture, such as in southwest Egypt. In others, the water is transported to where populations reside, as in the case of the Great Man Made River Project of Libya. Where groundwater aquifers extend beyond national boundaries regulations are required for equitable use of the resource. Examples include the aquifers of the Jordan River system of Palestine, Jordan and Israel, and the *Hamad* basin of Syria, Jordan, Israel and Palestine.

Conclusion

The literature on groundwater resources in the Arab region indicates that: (a) vast areas have not yet been studied or explored; (b) current water scarcity will be further exacerbated by the rapid population growth and increasing water usage; (c) some productive aquifers are being

over-drilled and over-pumped with little regulation to assure their sustainability; and (d) aquifers shared by multiple nations have not been quantified for equitable use.

It is proposed to initiate a major study of the Arab deserts with the purpose of identifying regions of potential groundwater accumulation. Available data must be collected for each country or region; using only part might be misleading. The data should be processed, analyzed, correlated and updated in a geographic information system (GIS) database. In adjacent countries, the database should be freely exchanged for planning equitable use of the resource.

The data collection is required for all regions where water might be extracted for human consumption, agricultural or industrial uses. The required data include geo-coded locations of the wells, their depth and type of host rock; water salinity; and pumping rates, along with historical illustrations of changes to water levels in space and time. All such data are essential for the proper assessment of the actively mined resources and the establishment of a proper water extraction rate to assure the longevity of a given aquifer.

Therefore, it is concluded that groundwater resources of the Arab region require detailed study and data collection using advanced methodologies. Such methods have been tested and proven in other parts of the world. It is also evident that the use of groundwater requires better and more thoughtful regulations by policy makers. Neither the detailed studies nor the thoughtful regulations would be accomplished without sustained, long-term attention by policy makers. Throughout the region, concerted efforts and plans are required at the present time to ameliorate severe shortages of water in the future.

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Plenary Session 4

4.1. Assessment of losses for managing calamities and risks in dryland livelihoods

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Abstract

Dryland livelihoods with resource poor base are complex, diverse, uncertain, vulnerable, risk/ distress prone and under invested. Climate change, especially in extreme weather events, is further compounding risks and investment decisions of policy makers and farmers. Potentials of latest technologies are not being fully realized due to lack of extension, adaptations, mitigation and adequate safety nets. The traditional assessments and relief measures for extreme weather events and disasters generally serviced by Revenue Departments based on field surveys are time consuming, subjective, arbitrary and do not focus on enhancing productivity, production, efficiency, income and livelihoods. The century old relief system of India of food for work, arranging fodder, feed and cattle camp was augmented by crop insurance, initially in cash crops since 1972 and further extended to loanee farmers. Weather-based insurance products with settlement of claims within weeks are being pilot tested by bankers and insurance companies. Assessment of losses to livestock, perennial crops, horticulture, natural resources and environmental externalities are more complicated for designing risk management. The governments, bankers and insurance companies require weather indices based ready reckoners for arriving at premium rates and claims at smaller spatial scales. This requires research on losses triggering threshold and rates due to abiotic or biotic stresses during different phases of growth of annual crops, perennials, livestock etc. Internalization of RS, GIS, GPS, modeling of crop growth, modern communication tools and almost real time exchange of information including mobile phones has been argued in this paper for quick assessment of losses and prompt relief. Rural employment guarantee scheme of payments of about US$ 8.8 billion per annum through banks and post offices since 2006 for rainwater management, land development and other tangible assets is quite progressive risk management strategy. Revisiting of traditional safety nets and harmonization with technological development is also called upon.

Introduction

Extreme climatic events severely affect dryland livelihoods through losses in production, farm and non-farm income, as these are unpredictable. Dryland/rainfed agriculture has a very important role to play in the food security, livelihoods and economy of developing world. India ranks first among the dryland/ rainfed countries in the world in terms of area, but ranks among the lowest in rainfed productivity (1t/ha). About 60 per cent of Indian agriculture is rain dependent and extremely vulnerable to climate. It contributes 40 per cent to the total food production and supports 40 per cent of human and 60 per cent of cattle population (CRIDA 2007). Dryland

ecologies in India cover about 87 per cent area of each of coarse cereals and pulses, 77 per cent oilseeds, 66 per cent cotton and 50 per cent cereals. Dryland areas are home to majority of rural poor, vulnerable, marginal and small holders.

Dryland livelihoods with poor resource base are complex, diverse, uncertain, risk/distress prone, under invested and volatile. Climate change and climatic variability, especially extreme weather events, is further compounding risks and investment decisions of policy makers and farmers in the vulnerable situation.

In the absence of formal risk sharing mechanism, small and marginal farmers with limited risk bearing resilience, rely on traditional safety nets to deal with production as well as farm income risks. In a few cases where farmers took to capital or inputs intensive diversification to cash crops like Bt cotton in drylands, recurrent droughts and crop failures have led them to incur debt and in some cases to take extreme steps of committing suicides (Kumar and Bhat 2007).

Analysis of crop loss data (1985-2002) in India by Parchure (2002) has revealed that more than 70 per cent of the crop loss is a result of drought and about 20 per cent due to excess rainfall. Analysis of Crop Insurance Programme in India between 1985 and 2003 reveals that rainfall accounted for about 95 per cent claims; 85 per cent due to rainfall deficit and 10 per cent due to excess rainfall (DAC 2004). The major element of risk in dryland agriculture therefore comes from the uncertainty in rainfall. The dryland ecosystem is less resilient on account of degraded ecological (natural resource) systems and poor socio-economic status.

About 20 per cent of the around 121 million farmers of India avail crop loans from financial institutions and only three fourth are insured, while remaining are either self financing or seek finance from informal institutions (Raju and Chand 2009). The institutional loanees are compulsorily insured, whereas non-loanee farmers constitute only about 15 per cent of the total farmers covered under insurance schemes in India. This clearly indicates a huge gap for coverage of farming community under agricultural insurance for risk management.

Agricultural risk management strategies seek effective mechanism of safety nets, building resilience, minimize prices volatility and reduce vulnerability through biophysical measures. Potentials of latest technologies are not being fully realized due to lack of adoption and adequate safety nets. It has also been argued by Jodha (1981) that farmers' own risk management measures in dryland farming in semiarid tropics in India are not only costly but also relatively ineffective in reducing risk, and adjusting to drought and scarcity conditions.

The traditional relief measures for extreme calamities and disasters, generally serviced by Revenue Departments based on field surveys, are time consuming, subjective, arbitrary and do not focus on enhancing productivity, production, efficiency, income and livelihoods. Implementation of risk management measures requires timely assessment of losses at disaggregated smaller spatial scales like that of villages.

The paper discusses estimation of losses for effective management of risks including insurance, loan waiver, loss compensation, safety nets and relief schemes in catalyzing adoption of potential technologies, investments, and inclusive economic growth for improved dryland livelihoods. Internalization of RS, GIS, GPS, modeling of crop growth, and IT enabled communication tools has been suggested for quick assessment of losses and early settlement of claims and provision of other relief measures.

Traditional methods of loss assessment

Conventional procedures of collecting crop statistics

The historic references to generation of crop statistics in India date back to Kautilya's *Artha Shastra* in the 4th Century B.C. During the Moghul period, during the 16th Century, it was a part of the revenue administration. The great famine of 1860 emphasized the need for more statistical information. Systematic generation of agricultural statistics began as early as 1884 with the assessment of wheat yields and the land utilization statistics (Singh and Rai 2005). Collection of crop statistics for oilseeds, rice, cotton, jute, indigo and sugarcane was added to the list by 1900. Currently, the crop statistics cover 52 food crops and 16 non-food crops. Directorate of Economics and Statistics (DES) in the Ministry of Agriculture is the nodal agency for maintaining agricultural statistics at the national level.

Assessment of losses, both for relief and insurance claims, are based on the traditional system of field survey, popularly called *Girdawari (field to field visit)/ annawari/ (valuation at the scale of 0-16)/ paisewari (valuation at 0-100 scale)* for area under crops and its status. The crop area statistics is collected by the village level revenue official called *Patwari* (village accountant) and recorded in standard village register based on land revenue system. Area estimates from these surveys have to be displayed publically for any objections/corrections by the public and then pass through a hierarchy of aggregation at village, *taluka* (sub-district unit), district (county) and state level. This contributes to a delay in compilation of loss estimates. States follow different nested sampling procedures to assess losses, such as 20 percent sampling on rotation basis, *ad hoc* surveys, multi season full enumeration approach, etc. for area statistics.

Yield estimates of major crops are obtained through analysis of crop cutting experiments (CCEs) conducted under scientifically designed General Crop Estimation Surveys (GCES). Product of area under crop and yield estimates provides information about production and loss in production. National Sample Survey Organization (NSSO) coordinates and provides necessary guidance for crop estimation surveys to all the states. The sampling design for general crop estimation survey is a multistage stratified random sampling with administrative units and sub-units of *tehsils/ talukas*/blocks, villages, fields within a village, and experimental plot of specified size within a field as the ultimate sampling units. Information on crop-wise productivity and loss is provided at administrative units of *taluka/tehsil*/block/district level in standard forms. Final figures for monsoon season *(kharif)* crops are available only in December, while those for winter season *(rabi)* crops in March/April.

Special field surveys

Special field surveys are also conducted in unusual situation of loss due to severe drought, flood, etc. to undertake quick assessment of agricultural losses. For example, during the drought of 2002 when significant area could not be even sown due to 51% rainfall deficiency in July, the procedure of estimating losses by crop cutting became meaningless (Rathore 2002). In such situations, the normal practice of the past is waived off and the states may assess damages to farmers/families on the basis of 'eye-estimation' for declaring drought and providing relief. In such special situations, Government of India deputes special multi-disciplinary teams to conduct field visits of affected areas to assess requirement for relief and financial assistance from National Calamity Contingency Fund (NCCF). Finance Commission of India provides budget for NCCF and funds remain with district (county) administration for ensuring immediate relief.

Limitations and constraints

In spite of established procedures and wide coverage, the existing system of agricultural statistics, has inherent limitations in the matter of providing an objective and timely relief. The present system of crop statistics and information is cumbersome, time consuming, subjective, and delays reporting. It has rigidity of definition, non-sampling errors, inadequacy for forecasting and non responsiveness to dynamic changes. It is also vulnerable to political considerations, biased at times. It is constrained to provide quick response and relief, whereas, management of risks in dryland livelihoods, characterized by higher degree of uncertainty or risks, requires quick, objective and effective means of estimating losses for implementing relief and safety net schemes.

Relief measures and safety nets

Conventional relief measures

A number of conventional relief measures are immediately put in place to mitigate the hardships of distressed farmers, because of the loss of their livelihoods, as a partial and temporary relief. Some of the usual relief measures include food for work, release of food grains from Public Distribution System (PDS), employment through cash wages, gratuitous assistance, relief through tax wavers and concessions, suspension or reduction of land taxes, rescheduling of crop loans, subventions in interest, scaling down or waiving of accumulated agricultural debts, input subsidy to compensate losses, and direct relief from Calamity Relief Fund. Some US $ 15 billion of accumulated agricultural debts were waived off in 2008).

Income or loss of a farmer is a product of production and market prices. Minimum support price (MSP) takes care of price volatility and is used as a measure of income stability. However, it is inadequately implemented for most of the dryland crops in most of the states. MSP should be enlarged to cover dryland crops and commodities as a measure of safety net against market risk. The recent opportunities like contract farming, PPP business models with buy back arrangements, etc., when implemented with proper safeguards, may also provide some safety against farm income and market risks.

Recent flagship scheme for guaranteed employment, relief and safety nets

Economic restructuring, inclusive development and revamped governance have evolved innovative, equitable and transparent flagship scheme in India, under what is called Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA). This gives legal guarantee to provide at least 100 person-days of employment to a rural family every year in rural area. The Act also seeks to strengthen natural resource base and create durable assets in rural areas to build production and livelihood support system. Weekly wages are generated by software and payments made through banks and details of beneficiaries are uploaded on web site in public domain, as a measure of transparency.

In the last five years it has generated 7.77 billion person-days employment since its notification in 2006, with 50 per cent going to women. Of the total expenditure of US $ 21 billion, 68 per cent has been spent on wages and rest on material and other components, with more than 50 per cent on rain water conservation. Works of MGNREGA, when properly orchestrated to support and strengthen development of dryland areas provided robust safety net.

Insurance schemes for agricultural risk minimization in India

Crop insurance scheme on 'individual' approach for the first time was initiated in 1972 in a predominantly dryland crop of cotton (Hybrid 4) in Gujarat and later extended to groundnut, wheat and potato and in other states. Pilot Crop Insurance Scheme (PCIS), based on 'homogeneous area' with coverage against decline in crop yield below the threshold level, covering food crops, oilseeds, cotton and potato for loanee farmers on voluntary basis was operational between 1979-1984. This was expanded to Comprehensive Crop Insurance Sheme (CCIS) and became compulsory for loanee farmers between 1985-1999 (DAC 2004; Raju and Chand 2009). Based on the experience of Experimental Crop Insurance Scheme during winter season (*rabi*) of 1997-98, the National Agricultural Insurance Scheme (NAIS) was started in India from the winter season of 1999-2000. In view of shortcomings and challenges with yield- indices based insurance products, India started piloting weather (rainfall)-index based insurance since 2003, starting with a private bank ICICI Lombard, followed by IFFCO-Tokio and public sector Agricultural Insurance Company (AIC).

Yield index based crop insurance-NAIS: The yield based crop insurance, popularly known as National Agricultural Insurance Scheme (NAIS), is administered by Agricultural Insurance Company (AIC) insuring about 25 million farmers annually covering an area of over 35 million ha (Rao 2010). All farmers including sharecroppers and tenant farmers growing listed crops in notified areas are eligible for coverage. The scheme is compulsory for loanee farmers and voluntary for non-loanee farmers, and available for almost all seasonal and annual crops for which historical yield data of past 10 years are available at appropriate administrative (sub-block/block or county) level. The minimum sum insured for loanee is the amount of loan availed, further extendable up to 150% of average yield. While for non-loanee, it can be up to value of 150% of average yield. The scheme covers losses from sowing to harvesting, and operates on 'area approach' for widespread calamities, and 'individual approach' for localized calamities such as hailstorm, landslide, cyclone, etc. Low, medium and high risk levels of indemnity (90, 80 and 60 percent) are available. Despite high claim ratio and low premium rates, the scheme is falling short of expectations of farmers and has low acceptability. It suffers from some key problems including basis risk because of too large insurance unit, delay in receiving estimates of yield loss leading to delayed settlement of indemnities, non-coverage of unsown area, pre-sowing and post harvest losses, huge infrastructure and manpower required to estimate yield through crop cutting experiments, no claim bonus, higher indemnity level for low risk, concerns for considering past 3-5 years for assessing threshold yield (triggers), moral hazard, and huge administrative cost .

Weather index based insurance: Several weather-based insurance derivatives have been piloted in India since 2003, starting with a private bank ICICI Lombard, in technical collaboration with World Bank, for groundnut and castor farmers of drylands of Mahboobnagar district in Andhra Pradesh. IFCCO-Tokio, a joint venture insurance company, piloted rainfall insurance scheme-called *Baarish Bima* (rainfall insurance) in 2004-05 in the states of Andhra Pradesh, Karnataka and Gujarat, for predominantly dryland areas. AIC, also launched rainfall insurance (*Varsha Bima*) targeting three risks namely, inadequate rainfall over the entire cropping cycle; inadequate rainfall during critical stages of crop development; and sowing failure due to inadequate rainfall at the beginning of the season. The scheme was further fine tuned in 2004-05 and extended to more areas. Weather Based Crop Insurance Scheme (WBCIS) of AIC, with the support of Government of India, was implemented on a pilot basis in selected areas of Karnataka state in monsoon season of 2007, covering eight rainfed crops (Nair 2010; Raju and Chand 2009). Weather-based insurance schemes are presently being offered by both the public and private sector insurance companies for different crops in selected areas of the country.

Weather index measures a specific weather variable; rainfall, temperature, relative humidity, etc., and pays indemnities based on the realization of the index such as rainfall (that proxies the loss in yield owing to the adverse weather incidence) rather than based on estimates of actual yield losses experienced by the insured. The product specifies a threshold that establishes the range of values over which indemnity payments are made. It operates on the concept of 'Area Approach' i.e., for the purpose of compensation (as also in NAIS), and this 'Reference Unit Area (RUA)' deemed to be a homogeneous unit of insurance, is linked to a Reference Weather Station (RWS) and on the basis of its current weather data, claims are processed. All the insured farmers of a particular insured crop in that area will be deemed to be on par in the assessment of claims. The scheme is compulsory for the loanee farmers and voluntary for non-loanee farmers. The premium rates depend on the 'expected loss', and it could vary with each RUA and each crop. However, the premium rates are capped for the cultivator; and the premium (rates) beyond the cap are shared equally by the Central and concerned State government. As a result of this, the premium payable by the farmer is affordable.

One of the key advantages of the weather-index based crop insurance is the use of independently verified, objectively measured and publicly available weather data (rainfall, temperature) as trigger events to 'proxy' for crop yields in compensating the farmers for deemed crop losses. This not only makes the indemnity payouts faster (within a fortnight or so after indemnity period compared to 6-12 months in conventional insurance), but also the insurance is more transparent, less costly due to reduced transaction costs of yield estimation and field visits, and less susceptible to moral hazard. This has expanded the domain of crop insurance scheme in India as this can also be provided for crops that do not have adequate historical yield data and also for horticulture crops. The scheme covers over 35 crops and is piloted in only about 10 per cent of the areas in the country (Rao 2010). The scheme has insured about 2.15 million farmers covering approximately 29,000 ha for an insured value of around US $ 1.1 billion till *kharif* season of 2009, with a quantum jump of almost 600 per cent during *kharif* season of 2009 alone over the previous year (Nair 2010). Wheat, chick peas, mustard, paddy, green gram, barley and groundnut account for more than 80 per cent of the coverage under weather-based insurance, with Rajasthan state (predominantly dryland) accounting for almost half of the total area, liability and premium, followed by Bihar, Karnataka, Gujarat and Orissa.

There are some weaknesses and limitations with weather-index based insurance that limit its scaling up. First, the concern of high basis risk due to wide variability of index value within the RUA of a representative weather station, arising from insufficient network and spread of weather stations. In a recent study, over 80 per cent of the respondents indicated that they were not satisfied with weather station density or location of weather station. AIC has estimated the requirement of about 8,000 weather stations and 32,000 rain gauges across the country to effectively use weather insurance as an important risk mitigation tool (Rao 2010). For effective delivery and scaling up of the weather-index based insurance products network of rain gauge stations will need to be expanded so as to ensure that every village *Panchayat* (elected body) has a truly representative rain gauge station. The second challenge is to design a crop and/or area specific proxy weather risk trigger (index) with predictive capability to realistically measure crop losses, with well researched and calibrated threshold levels of triggers considering critical crop growth stages. Thirdly, there is reluctance of buying weather insurance due to lack of understanding of highly technical and complicated claim structure by farmers. A successful introduction would require a significant sensitization and educational effort. Lack of sufficient awareness and understanding of the product specificities could prevent farmers from buying otherwise attractive products.

Modified National Agricultural Insurance Scheme

Some of the above issues of yield based insurance have now been addressed including participation of select private sector insurance companies in the Modified National Agricultural Insurance Scheme (MNAIS) to be implemented in 50 districts from the winter season of 2010 on a pilot basis for two years. The scheme will cover cereals, millets and pulses, oilseeds and annual commercial horticultural crops; loanee farmers (compulsory) and non loanee farmers (voluntary); indemnity amount (maximum 25 percent) for prevented sowing /planting risk with the village *panchayat* (elected body) as unit area of insurance and the threshold yield based on average yield data of preceding 10 years excluding years of calamity. The government subsidy will range from 40 percent to 75 percent depending upon the premium slabs, to be shared equally by the Centre and the States.

DHAN Foundation, an Indian NGO, has piloted Mutual Crop Insurance (MCI) in six locations to address the crop risks of small holder rainfed/dryland farmers (Karthikeyan 2010). The learning experience of four years of the project has demonstrated that MCI is better than individual conventional crop insurance due to its customized nature, dynamic design, awareness generation, and motivating farmers for collective and individual actions. It is designed and managed by the wiser farmers of the insured farming community, nominated as members of the Mutual Insurance Committee. However, the success of MCI depends on effective community organization, insurance education, design of customized products and reinsurance support.

Revisiting traditional safety nets

Agro-forestry (trees) is relatively resilient to abiotic stresses because of the extensive root system of the tree component and better adaptation to stresses. Similarly, livestock can out migrate from, or fodder brought in from elsewhere in, the stess affected area to avoid risks. The animals could also be liquidated during weather abnormalities and sale proceeds used for sustaining livelihood (Samra 2006). However, improved technologies and better marketing are called upon to keep pace with the better R & D. Animals lose their fertility due to lack of green fodder and poor nutrition in drought years, during heat and cold wave conditions. It takes 2-3 year to restore their fertility and losses have to be estimated and spread over years accordingly.

Perennial crops, plantations and fruit trees follow different pathways of loss. In coconut, stress before pollination results in productivity losses in the same year. If stress occurs after pollination, part of the yield losses may extend to second year. Different kind of effect may appear in other perennials, fruit trees and plantation crops.

Non-agriculture activities like arts, craft, skills and employment elsewhere can moderate distress of calamities. However, enhanced opportunities in modern infrastructure development and housing with the new materials and construction, would necessitate re-skilling of the people to catch up with development dynamics. Old arts, crafts and skills are losing demand and income generation potentials. The capacities of artisans will have to be upgraded for harnessing emerging opportunities of reducing vulnerability.

Integrating advances in RS, GIS, GPS, modeling and IT

Crop growth and productivity are determined by a large number of spatially varying weather, soil and management variables. Continuous advancement in Remote Sensing (RS) has improved timely, accurate and synoptic coverage of crops and also assessing crop vigour at a range of

spatial and temporal scales. RS data on crop environment, crop distribution, phenology and leaf area index can be coupled to crop simulation models in a number of ways to estimate crop yield and yield loss. Crop simulation models (CSM) that have been successful in field-scale applications are being adapted in a GIS framework to model and monitor crop growth with remote sensing inputs. An integration of the five technologies, viz., crop simulation models, RS data, GIS, GPS and mobile enabled services, provides an excellent solution to monitoring and modelling of crop at a range of spatial and temporal scales.

In order to strengthen generation of agricultural statistics in India, a RS based nation-wide project called **C**rop **A**creage and **P**roduction **E**stimation (**CAPE),** at the behest of Ministry of Agriculture, Government of India, was launched in 1988 in collaboration with Department of Space (DoS) to provide district- and state-level pre-harvest acreage and production forecasts. Production forecast of eight crops was made using multi-band RS data along with ancillary ground and weather data.

In order to make forecasts of desired coverage, accuracy and timeliness, FASAL (**F**orecasting **A**gricultural output using **S**pace, **A**gro-meteorology and **L**and-based observations), was conceptualized to integrate inputs from diverse sources and made operational in August 2006. FASAL seeks to strengthen the current capabilities of early and in-season crop estimation capabilities from econometric and weather-based techniques with RS applications. Mid-season assessments can be supplemented with multi-temporal coarse resolution data based analysis. In the later half of crop growth period, direct contribution of RS in the form of acreage estimates and yield forecasts would be available. National Agricultural Drought Assessment and Monitoring System (NADAMS) of National Remote Sensing Centre (NRSC) is another major national level initiative for agricultural drought assessment using AWiFS/WiFS derived normalized difference vegetation index (NDVI). Integration of these efforts to facilitate crop insurance and nation-wide operationalization of such projects need a dedicated institutional arrangement.

Use of CERES-Wheat model included in Decision Support System for Agro-technology Transfer (DSSAT) for regional wheat yield prediction has been demonstrated in India by Nain *et al.* (2004). Infocrop, a dynamic crop simulation model of Aggarwal *et al.* (2006), has been used for the assessment of effect of weather, variety, pests, soil and management practices on crop growth and yield. Sehgal *et al.* (2001) developed a prototype Crop Growth Monitoring System (CGMS) for wheat using WTGROWS simulation model in a GIS environment for generating daily crop growth maps and predicting district-wise grain yield using RS-based wheat input maps. Integration of diverse inputs and models would require that either a model is embedded in GIS or a GIS system is included in a modeling system. This allows automatic use of relational database and statistical packages. Integration of promising crop simulation models with RS and GIS is yet to be given due emphasis in improving design and implementation of risk management interventions including crop insurance especially for dryland crops.

Major potential and challenge is now to innovatively integrate use of crop simulation and RS in a GIS together with AWS-derived weather data for near real time simulation of yield assessment and yield forecasts, and link this with GPS and mobile telephone to not only design the insurance products, but also enhance its efficiency and delivery at the smaller spatial scales of village elected body (*panchayats)*, and its reach to small and marginal farmers. For instance, partnership between United Agri Product (UAP) insurance and telecom operator Safaricom has led to a low cost innovative mobile phone enabled index (weather) based crop insurance in Kenya and some other African Countries. Farmers can buy their insurance from agro-dealers, who immediately

can register the policy with Insurance Company over the mobile data network, and farmers can receive policy confirmation via a text message. Payouts are triggered by the index system tied to local weather condition. Data is transmitted to a central server over Safaricom's 3G data network. When data from a particular station indicates the extreme conditions (trigger event), all farmers registered with that station automatically receive payouts directly via mobile money transfer service. Transfer of premium to UAP and the payouts to farmers using data network claims to have reduced cost of each transaction to less than the price of a SMS message (http://www.sciencedaily.com/2010/03).

Such approach should be innovatively pilot tested in drylands of India using vast network of mobile telephony to protect farmers against the farming risks, where conventional crop insurance requiring field inspections and field visits is far too expensive for small and marginal farmers. Comprehensive and innovative contracts may be evolved for 'total and diversified dryland livelihood portfolio (crop, livestock, horticulture)' involving provisions for credit, insurance, health check-ups, extension and buy-back for risk management. This will go a long way in not only protecting them against agricultural risk, but also encouraging them to make investments in dryland farming interventions to enhance productivity and livelihood.

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Plenary Session 5

5.1. Promoting sustainable desert development to mitigate global warming effects in Egypt

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Abstract

The world in the 21st century is facing a number of challenges due to both environmental and economic factors. On the one hand, the tremendous increase in the burning of fossil fuel in developed and some developing countries has resulted in the release of huge amounts of CO2 in the atmosphere, which has been considered a major cause of the climate change phenomena. On the other hand, the depletion of oil reserves as well as its increasing prices has prompted some countries to convert food grains into biofuels or ethanol which may restrict their exports of grain; thus causing a major problem for countries which do not enjoy food sufficiency. These changes in environmental and socio- economic conditions can be dealt with by ensuring the sustainable development of desert lands based on a holistic approach where agricultural, technological, socio-economic and environmental concepts are implemented. One of the expected global warming effects on Egypt is the sinking of parts of the delta leading to the loss of agricultural, industrial, housing and domestic facilities. Those living, cultivating and operating the activities on this land may have to migrate to new areas. With the overpopulated delta and Nile valley, sustainable desert development is the solution. For this to be achieved, it is necessary to save enough water from our present share from the Nile and other sources through increasing water use efficiency in the irrigation and cultivating systems of the delta and the valley by:1) decreasing water losses through water conveyance and distribution systems,2) changing the present flood irrigation system to more appropriate techniques leading to the use of lower quantities of water, and 3) promoting regulations that would encourage farmers to use less amounts of water through proper choice of crops and /or evading high water delivery cost. For this to be achieved, it is proposed to create viable multipurpose communities based on a particular water basin serving reclaimed agricultural desert land, industrial and agro industrial as well as urban activities which would cover the needs of those migrating from the sinking parts of the delta as well as others. Holding companies will be created; representing the delta migrants, unemployed graduates, small farm owners, business owners and other investors and players of the multipurpose community. Each holding company and its specialized divisions must work together to ensure the successful development and sustainability of the multipurpose community based on promoting use of solar and wind sources of energy and treated organic domestic & agricultural waste to produce needed energy as well as promoting appropriate technological systems for agricultural, industrial& domestic needs resulting in decreasing CO_2 evolution . The Sinai desert is the ideal location for the above mentioned multipurpose communities which are to be operated by holding companies.

Introduction

The world in the 21st century is facing a number of challenges due to both environmental and economic factors. On the one hand, the tremendous increase in the burning of fossil fuel in

developed and some developing countries has resulted in the release of huge amounts of CO_2 in the atmosphere, which has been considered a major cause of the climate change phenomena. On the other hand, the depletion of oil reserves as well as increasing oil prices has prompted some countries to convert food grains into biofuels, restricting their exports of grain and thus causing a major problem for countries which do not enjoy food sufficiency. These changes in environmental and socio- economic conditions can be dealt with by ensuring the sustainable development of desert lands based on a holistic approach where agricultural, technological, socio- economic and environmental concepts are implemented.

Climate change refers to any significant change in measures of climate (such as temperature, precipitation, or wind) lasting for an extended period (decades or longer) (see http:/gov/climate change/basicinfo.html). Climate change may result from: (a) natural factors, such as changes in the sun's intensity or slow changes in the Earth's orbit around the sun; (b) natural processes within the climate system (e.g. changes in ocean circulation); and (c) human activities that change the atmosphere's composition (e.g. through burning fossil fuels) and land surface (e.g. deforestation, reforestation, urbanization, desertification, etc.). Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human induced. In common usage, global warming often refers to the warming that can occur as a result of increased emissions of greenhouse gases from human activities

For over the past 200 years, the burning of fossil fuels, such as coal and oil, and deforestation have caused the concentrations of heat-trapping "greenhouse gases" to increase significantly in our atmosphere. These gases prevent heat from escaping to space. Greenhouse gases are necessary to life as we know it, because they keep the planet's surface warmer than it otherwise would be. But, as the concentrations of these gases continue to increase in the atmosphere, the Earth's temperature is climbing above past levels. According to NASA data, the Earth's average surface temperature has increased by about 0.74±0.18 C° in the last 100 years. The eight warmest years on record (since 1850) have all occurred since 1998, with the warmest year being 2005. Most of the warming in recent decades is very likely the result from human activities. Other aspects of the climate are also changing such as rainfall patterns, snow and ice cover, and sea level.

Climate change affects people, plants, and animals. Scientists are working to better understand future climate change and how the effects will vary by region and over time. Scientists have observed that some changes are already occurring. Observed effects include sea level rise, shrinking glaciers, changes in the range and distribution of plants and animals, trees blooming earlier, lengthening of growing seasons, ice on rivers and lakes freezing later and breaking up earlier, and thawing of permafrost. Another key issue being studied is how societies and the Earth's environment will adapt to or cope with climate change.

Reducing the amount of future climate change is called mitigation of climate change. The IPCC (Intergovernmental Panel on Climate Change) defines mitigation as activities that reduce greenhouse gas (GHG) emissions, or enhance the capacity of carbon sinks to absorb GHGs from the atmosphere. Many countries, both developing and developed, are aiming to use cleaner, less polluting, technologies. Use of these technologies aids mitigation and could result in substantial reductions in CO_2 emissions. Policies include targets for emissions reductions, increased use of renewable energy, and increased energy efficiency. Studies indicate substantial potential for future reductions in emissions. Since even in the most optimistic scenario, fossil fuels are going

to be used for years to come, mitigation may also involve carbon capture and storage, a process that traps CO_2 produced by factories and gas or coal power stations and then stores it , usually underground.

Other policy responses include adaptation to climate change. Adaptation to climate change may be planned, e.g., by local or national government, or spontaneous, i.e., done privately without government intervention. The ability to adapt is closely linked to social and economic development. Even societies with high capacities to adapt are still vulnerable to climate change. Planned adaptation is already occurring on a limited basis. The barriers, limits, and costs of future adaptation are not fully understood.

Greenhouse gas emissions, global warming and Egyptian Delta

Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. Global atmospheric concentrations of CO_2, methane (CH4) and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. Egypt is expected to suffer from global warming through Nile water possible decrease or increase, rising sea water levels, soil salinity and rising level of ground water near sea shores, as well as sand storms, etc. The Mediterranean coast of Egypt which borders the Egyptian delta is expected to be strongly affected from global warming since this coast is originally of low level compared to sea level and is harboring a number of important cities such as Alexandria, Rosetta and Port Said. Figure 1 shows the average increase in sea level based on earth & satellite measurements for the period 1994 to 2006 which shows that the average increase in global sea level is about 3.00mm per year.

Figure 2 gives the topography of the Egyptian Delta which shows contour lines for different high and low levels of the delta. The areas showing hatching are the parts of the delta which are currently under sea level. They are currently protected from sea by sand dunes or walls built to prevent sea water from reaching there. Rising of sea water level by about 50 cm will result in Alexandria in the loss of number of touristic coasts as well as agricultural and industrial activities, resulting in the loss of about 194000 employment opportunities (151000 industrial, 34000 touristic and 9000 agricultural), which in turn would result in the migration of about 1.5 million persons from Alexandria and its neighboring areas.

While some scientists and enginers propose diferent engineering means to protect our shores, I would like to consider an additional alternative which would not only help to face this expected calamity ,but will also help to solve problems caused by our continous population expansion: Let us go to the desert…. but do it properly!

Biofuels

Biofuels are gaining increased public and scientific attention, driven by factors such as oil price spikes, the need for increased energy security, and concern over greenhouse gas emissions from fossil fuels. Bioethanol is an alcohol made by fermenting the sugar components of plant materials and it is made mostly from sugar and starch crops. With advanced technology being developed, cellulosic biomass, such as trees and grasses, are also used as feedstocks for ethanol production.

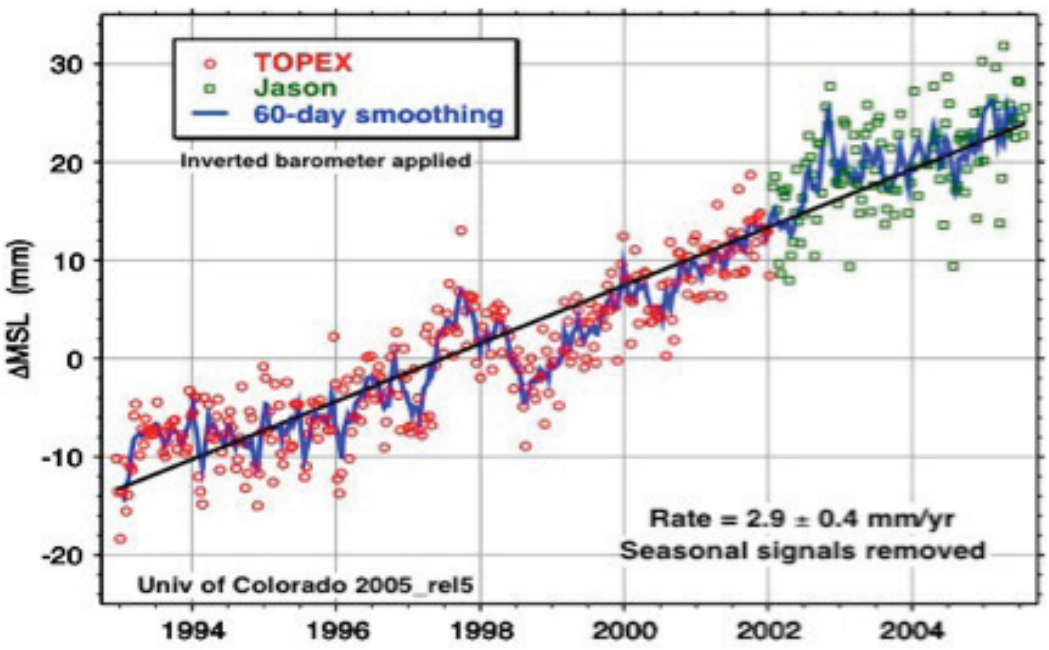

Figure 1. Average sea level elevation based on terrestrial and satellite measurements.

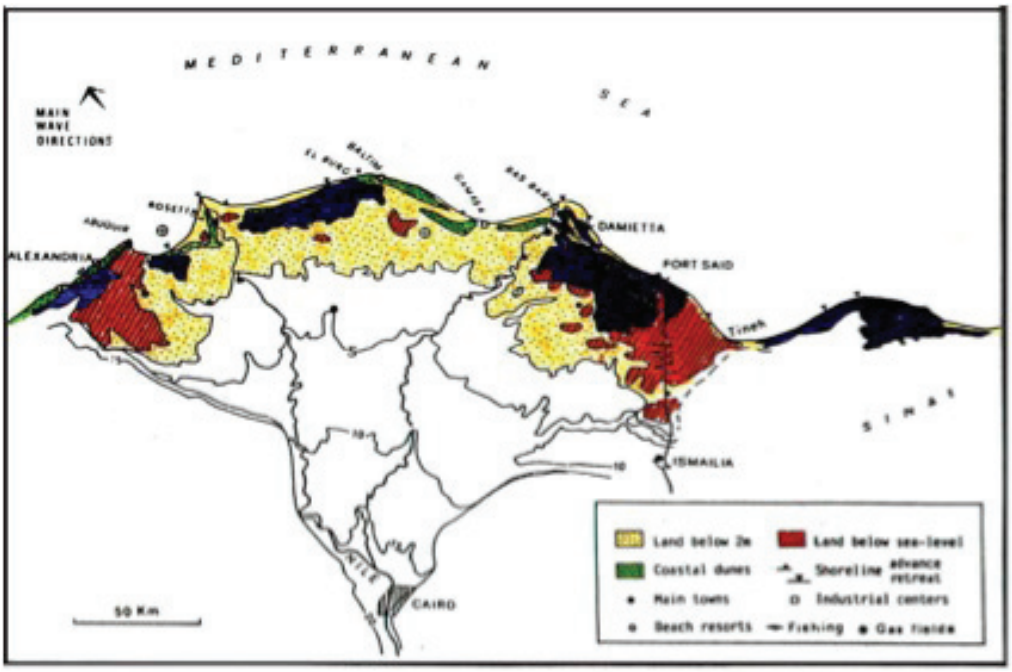

Figure 2. Topography of the Egyptian Delta.

Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bioethanol is widely used in the USA and in Brazil. Biodiesel is made from vegetable oils, animal fats or recycled greases. It is the most common biofuel in Europe.

The basic feedstocks for the production of first generation biofuels are often seeds or grains such as sunflower seeds, which are pressed to yield vegetable oil that can be used in biodiesel, or wheat, which yields starch that is fermented into bioethanol. These feedstocks could instead enter the animal or human food chain. As the global population is increasing, the need for adding them to the food chain has risen and their use in producing biofuels has been criticised for diverting food away from the human food chain, leading to food shortages and price rises.

Ethanol fuel is the most common biofuel worldwide, particularly in Brazil. The ethanol fuel production methods include enzyme digestion (to release sugars from stored starch), fermentation of the sugars, distillation and drying. The distillation process requires significant energy input for heat. Ethanol can be used in petrol engines as a replacement for gasoline; it can be mixed with gasoline to any percentage. Most existing car petrol engines can run on blends of up to 15% bioethanol with petroleum/gasoline. An advantage of ethanol (CH3CH2OH) is that it has a higher octane rating than ethanol-free gasoline available at roadside gas stations which allows an increase of an engine's compression ratio for increased thermal efficiency. There is controversy and political speculation surrounding first-generation biofuels due to the agricultural, economic, and social implications associated with the potential expansion of biofuel production.

Research in China indicates that the demand for bio-fuel feedstock such as maize, sugarcane, and cassava will significantly increase due to the expansion of biofuel production; the increased demand for feedstock will lead prices for such grain to significantly increase. A similar study examining a potential increase in ethanol production capacity in the United States also predicts an upward trend in agricultural prices as a direct effect of expanding domestic biofuel production. Expanding biofuel production is also projected to have an effect on livestock prices. A study done in China predicted that increased maize prices, due to biofuel expansion, will indirectly cause the prices of livestock production to increase due to the heavy reliance on maize for animal feed.

Increased agricultural prices of corn and other sugar containing crops will also provide incentives for farmers to stray away from producing other less profitable grains, causing a shift in the crop production structure, leading to a decrease in agricultural diversity subsequently diverting food away from the human food chain. As an example, in order for the United States to meet the biofuel target introduced in the U.S. Energy Independence and Security Act, 40% of the land that is currently devoted to corn production would have to be converted to biofuel feedstock production. Shifts in crop production and the changes in world price of agricultural commodities due to the expansion of the biofuel market are expected to have global impacts on consumers.

Individuals who are food insecure will be more heavily impacted by the increase in world prices; food price volatility has the largest impact on the extremely poor, those who spend 55-75% of their income on food.Accordingly, the tendency to convert corn and other plant material to biofuels by some will result in decreasing export of grains thus causing a major problem for countries (such as Egypt) which currently do not enjoy wheat sufficiency. In order to overcome this situation , let us go to the desert…but do it properly!

Sustainable development of desert lands

Egypt's water resources based on current agreements range from a total of 66.6 billion cubic meters in 2002/2003 to 73.06 billion cubic meters in 2008/2009. This includes Egypt's present share from the Nile, ground water from the valley and delta, treated agricultural waste water, treated municipal sewage, rain and floods and sea water desalination (Table1).

These amounts are distributed between agricultural use (from 57.8 to 60.5 billion m³/year), to domestic, industrial and other uses (Table2). In addition, it should be stipulated that the individual annual share of current and expected available water has decreased from 2604 m³/year in 1947 to 860 m³/year in 2003 and expected to come down to 582m³/year with increasing population (Table 3).

Table 1. Water Resources in Egypt (billion cubic meters / year)

Source	2002 /3	2003/4	2004/5	2005/6	2006/7	2007/8	2008/9
Share from Nile water	55.5	55.5	55.5	55.5	55.5	55.5	55.5
Ground Water	5	5	5.5	5.9	6.2	6.6	6.6
Treated agricultural waste	4.4	4.8	5.1	5.3	5.9	6.7	7.8
Treated municipal waste	0.7	0.8	0.9	1.1	1.3	1.55	1.8
Rain and floods	1	1.1	1.1	1.1	1.3	1.3	1.3
Sea water desalination	0	0	0	0.06	0.06	0.06	0.06
Total	66.6	67.2	68.1	68.96	70.26	71.71	73.06

As shown in Table 4, population in Egypt has increased from 9.7 million in 1897 to 80 million in 2009. Although, the area of cultivated land was gradually increased from 4.9 million feddans in 1897 to about 8.5 million in 2009, the individual share decreased from 0.5 feddan to 0.1 feddan per person (Goueli 2002).

Table 2. Water consumption (billion cubic meters / year)

Sector	2002/3	2003/4	2004/5	2005/6	2006/7	2007/8	2008/9
Agriculture	57.8	58.1	58.5	59	59.3	60	60.5
Evaporation losses	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Domestic uses	5.4	5.7	6.05	6.5	7.5	8.2	9
Industry	1.1	1.1	1.15	1.15	1.15	1.2	1.25
River navigation	0.2	0.2	0.3	0.2	0.2	0.2	0.2
Total	66.6	67.2	68.1	68.95	70.25	71.7	73.05

Table 3. Average individual's share of water (past, present & future)

Year	Average individual's share of water (m^3/year)	% Change compared to 1947
1947	2604 (plentiful water)	--
1960	1893	27.3
1970	1713 (water sufficiency)	34.2
1986	1138	56.3
1996	936 (water scarcity)	64.1
2003	860	67.0
(expected) 2025	582 (water poverty)	77.6

However, it should be emphasized that in addition to increasing population which by necessity would increase the need for additional water availability, two major factors should also be taken into consideration: (a) The expected effect of global warming on the intensity of rain fall on the Nile valley, which would affect the share of Egypt from the Nile water; and (b) The present disagreement with the Nile water countries which claim that Egypt is currently taking more than its fair share (55.5 billion cubic meters). This state of affairs should warn us not to anticipate an increase in our present share from the Nile water, while making sure that we will be careful in utilizing every drop we get in the most efficient and useful application.

Table 4. Change in population , agricultural land area since 1897

Year	Population (millions)	Area of agricultural land (m. feddans)	Individuals share (feddans)
1897	9.7	4.90	0.5
1966	33.2	6.00	0.20
1970	38.2	6.12	0.18
1990	55.0	7.20	0.13
2004	71.0	7.80	0.11
2008	78.6	8.43	0.10
2009	80.0	8.50	0.10

In order to deal with the above expected problems of decreasing water availability (caused by global warming and/or disagreements with Nile valley countries), and the need for additional habitable land (caused by increasing population and sinking parts of the delta land used for domestic, agricultural and industrial activities), the author proposes that the sustainable development of desert lands is the solution, provided that we save enough water from our present share from the Nile and other sources through increasing water use efficiency in the irrigation and cultivating systems of the delta and the valley by:1) decreasing water losses through water conveyance and distribution systems,2) changing the present flood irrigation system to more appropriate techniques leading to the use of lower quantities of water, and 3) promoting regulations that would encourage farmers to use less amounts of water through proper choice of crops and /or evading high water delivery cost. This requires coordinated efforts in many disciplines related to the natural resources, technological aspects, and community aspects appropriate for the specific desert area. This integrated approach (Bishay 1993) is the basis for different types of desert development systems.

The integrated approach

In 1979, the author had the honor of founding the AUC Desert Development Center (DDC). In addition to adopting a systems approach integrating biological, technological and community aspects of desert development, we followed the following concepts: a) advocating that a desert should be treated as a desert (no outside manure or silt added to the soil), b) desert development should be based on a balance of appropriate indigenous methods with modern technologies, c) any trials for improving productivity should be environmentally compatible with desert conditions and economically replicable under prevailing social and technical constraints, d) the use of solar water heaters, photovoltaics, and passive solar architecture as well as wind energy and biogas should be promoted ,and e) applying sprinkler and drip irrigation techniques should be used instead of flood irrigation, whenever possible, in order to ensure rationalization of use of good quality irrigation water and enhance efficiency. Now, more than thirty years later, I am still a believer of this AUC/ DDC approach!!

Strategies for sustainable development for Egypt

In 1990 a task force sponsored by the United Nations Development Programme (UNDP) and coordinated by the author, was assigned to propose strategies for sustainable development for Egypt (Bishay 1992). Sustainable development, or environmentally sound development, indicates that environment and development are closely linked and are mutually supportive. In other words, there will be no sustained development or meaningful growth without a clear commitment at the same time to preserve the environment and promote the rational use of resources. Sustainable development argues that “real” improvement cannot occur unless the strategies being formulated and implemented are ecologically sustainable over the long term, are consistent with social values and institutions, and encourage public participation in the development process. The primary objective is to provide lasting and secure livelihoods that minimize resource depletion, environmental degradation, cultural disruption, and socio-economic instability through a dynamic and adaptive process of trade-offs.

Figure 3 was developed by the author (Bishay 2007) based on the findings of the UNDP Task Force. According to this figure, in order to achieve sustainable development (and self reliance), a balance should be reached between economic development, human development, resource management, and environmental protection. This is a dynamic system which would require

appropriate management (especially under micro/ macro crisis conditions), necessary finances, and research and development with emphasis on optimization between ecological and economic dimensions of development. Public participation (social and political), necessary infrastructure and supporting services are of utmost importance in implementing the different strategies proposed for achieving sustainable development. These strategies were grouped into four sets: (a) public policy and legislation; (b) information management, monitoring and public awareness; (c) technical support (training; research and development); and (d) institutional and international cooperation.

Figure 3. Parameters for Sustainable Development.

Proposed implementation scenario for sustainable desert development

To achieve sustainable desert development i.e. desert development for our future generations, we have to work with the boundaries of water scarcity, energy limitation, and population increase (Bishay 1996). We also have to consider three additional main factors:

1) The possible effect of global warming on the loss of parts of the delta.
2) Problems facing graduates (allocated 5-6 feddans each) and small farmers.These problems include marketing, inputs, appropriate technology, credit facilities, etc.

Lack of coordination between different players in a certain region, including industry, agriculture &domestic activities with emphasis on water management i.e. lack of integrated water management within a certain basin.

In order to solve the above mentioned problems, it is proposed to create viable multipurpose communities based on a particular water basin. These communities would cover reclaimed agricultural desert land, industrial and agro- industrial as well as urban activities to cover the needs of those migrating from the sinking parts of the delta as well as young men and women who are looking for work or better working conditions. In other words, we would have rural, industrial and urban communities intermingled together in such a way that they would benefit from each other economically, socially and environmentally.

To achieve the above, it is proposed to create holding companies, which would represent the delta migrants as well as unemployed graduates, small farm owners, business owners and other investors and players in the area. Each holding company and its specialized divisions must work towards supporting and developing the proposed multipurpose communities.

Mission, activities and structure of Holding Company

The mission of the Holding Company is to help in solving the problems of the delta migrants, unemployed graduates or those allocated 5-6 feddan and small investors, to develop and support proposed multipurpose communities, and to work towards achieving sustainable development for the zone through promoting use of solar and wind sources as well as treated organic domestic and agricultural waste to produce needed energy. In addition, it will ensure:

a) Environmental Protection against all types of pollution (air, water, soil, noise, visual etc…).

b) Community development (providing necessary services and amenities, education, health, employment, etc…) with emphasis on public participation, financial, and technological activities.

c) Proper planning and management of financial resources and providing credit services to delta migrants, small investors and graduates, purchasing inputs, marketing and/or processing of agricultural products.

d) Initiate and support different area activities (agriculture, industry, agro- industry, renewable energy, tourism, mining and urban activities).

e) Research and Development efforts to achieve optimum management of resources, pollution control, integrated management of natural, human & historical resources.

Proposed activities of the Holding Company will be:

a) Ensure implementation of integrated water management to promote water use based on appropriate technological systems for agricultural (irrigation &choice of crops), industrial and domestic needs.

b) Facilitate and minimize cost of procurement of inputs.

c) Optimize quality and quantity of products.

d) Offer financial facilities and technical knowhow.

e) Help in processing and marketing of different products.

f) Provide management support.

g) Promote general services for the community.

h) Assist in solving unemployment problems, and alleviating poverty.

The type and number of specialized companies belonging to the holding company will vary from one zone to another depending on location, availability of water, soil, raw materials and current as well as proposed activities e.g. agricultural, educational, agro- industry, mining, industrial, tourism and housing. Also, specialized companies may be established gradually, giving priorities to those pertaining to the most needed activity. Each specialized company will be represented in the Board of Directors of the Holding Company. Also, delta migrants, small investors, and graduates will be represented in relevant specialized companies as well as in the holding company.

The administrative structure of the Holding Company would comprise the Chairman, a Board of Directors, a Director General and a Head for each of the Divisions (Business, Planning, Services, Evaluation and Follow-up; and R & D). The office of the Director General will be responsible for (a) coordinating among the five divisions, (b) coordinating between the Holding Company and the different specialized companies, and (c) reporting to the Board of Directors. The Heads of Divisions can deal directly with specialized companies in matters concerning the division's field of activity. The Divisions would be divided into departments. As an example, the Business Division would have a "Financial Department" and a "Personnel Department"; the Planning Division a "Technical Department" and an "Economic Department"; the Services Division seven or more departments: 1) Infrastructure 2) Water 3) Energy 4) Land 5) Housing 6) Education 7) Health, etc.

Capital investment will be as follows:

Holding Company (distribution among share holders): 25 %(graduates and small investors in the zone).35 % (GOE +Delta migrants), 25 % (specialized companies in the zone), 15 % (Others e.g. banks, insurance companies).

Specialized Companies (distribution among share holders)**:** 20 % (Staff& Labor), 29 % (Open Shares), 51% (Holding Company).

Steps and time schedule for implementation will be as follows:

a) Scenario to be presented to GOE and approval and/ or modification to be secured.
b) Selected desert zones to be identified, based on water resources sharing as well as the Ministry of Planning sectoral zones proposed earlier by the UNDP sponsored project. Concerned Ministries to be involved are: Ministries of Planning, Water Resources, Agriculture, Industry, Environment, Petroleum, Housing, Local Administration and Scientific Research.
c) Conduct feasibility study for the above mentioned identified zone.
d) Take necessary steps towards formulation of the Board of Directors of the Holding Company.
e) Specialized companies to work in the identified zone and other share holders are then invited to participate.

Financing for Holding Company

The studies preceding formation of the Holding Company could be sponsored by one of the international agencies interested in environment and development or by the Ministry of International Cooperation. The paid capital of the Holding Company would be provided by the different partners, based on the number of shares they would own. However, some mechanism must be formulated to enable delta migrants, graduates and small investors to pay for their shares. A loan from the Social Fund may be one possible alternative.

Conclusions

Egypt may have to face problems caused by: 1) decreasing water availability (caused by global warming and /or disagreements with Nile Valley countries), 2) decreasing availability of fossil fuel, and 3) the need for additional habitable land (due to increasing population and sinking parts of the delta land currently used for domestic, agricultural and industrial activities). In order to

solve the above mentioned problems, it is proposed to create viable multipurpose communities based on a particular water basin. These communities would be associated with reclaimed desert land for agriculture, industrial and agro- industrial as well as urban activities covering the needs of the migrants as well as young men and women who are looking for work or better working conditions.

To achieve the above, it is proposed to create holding companies, which would represent the delta migrants as well as unemployed graduates, small farm owners, small business owners and other investors and players in the area. Each holding company and its specialized divisions must work towards supporting and developing the proposed multipurpose communities based on promoting use of solar and wind sources of energy and treated organic domestic and agricultural waste to produce needed energy as well as promoting appropriate technological systems for agricultural, industrial & domestic needs resulting in decreasing CO_2 evolution. It is also imperative that the holding company would take necessary actions to save enough water from our present share from the Nile and other sources through increasing water use efficiency in the irrigation and cultivating systems of the delta and the valley by:1) decreasing water losses from water conveyance and distribution systems; 2) changing the present flood irrigation system to more appropriate techniques (drip, sprinkler…etc) leading to the use of lower quantities of water; and 3) promoting regulations that would encourage farmers to use less amounts of water through proper choice of crops and /or evading high water delivery cost.

The Sinai desert is the ideal location for the above mentioned multipurpose communities which are to be operated by holding companies. This important step would also help to solve the problem of continuous increasing population which needs more land for agricultural, industrial and residential activities. Furthermore, populating this location is the most critically needed for defending Egypt against criminal and strategic infiltration.

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5.2. Influence of climate change on agriculture and natural resources of Kyrgyzstan

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Abstract

An examination of the average annual temperature in Kyrgyzstan in the last 100 years shows that it increased in the 20th century by 1.6° C, and it is considerably above the global warming of about 0.6° C. The greatest warming was observed in the winter (2.6 ° C) and the least in the summer (1.2° C) season. By 2100, it is expected that the increase in average annual temperature might range from 2.5 to 3° C. At the same time there will be also an increase in the annual precipitation by 10-15 percent in comparison with the average for 1961-1990. However, it will still lead to increase in the dryness of the climate as slight increase in precipitations will not be able to compensate the effect of rise in air temperature. Thus the area and volume of mountain glaciers will sharply be reduced, which will lead to reduction of discharge in the rivers feeding the most habitable and economically important valleys in the country, Chuj, Fergana, Talas and Issyk-Kul. A severe shortage of drinking and irrigation water would be the main threat to the stability in the Central Asia by 2050. Under such a situation the agriculture in the drought afflicted Central Asia, which is mainly dependent on irrigation, will be severely affected causing the problem of food insecurity as in this strategic region about 90 percent of consumed fresh water is used in agriculture.

Introduction

Kyrgyzstan is a mountainous country, where 94 percent of territory is occupied by Central Tjan-Shan and Pamiro-Alaj ridges. Therefore a strong influence is rendered by mountain relief and height on the country climate. To reach a polar climate zones of Kyrgyzstan, it is enough to pass only 40 kilometers from capital Bishkek (the height 750) to upper places of Ala-Archa and to rise 3500 meters above sea level. Thus, in our mountainous country the width and longitude do not influence the climate as is the case in Russia, but height and relief or vertical zonality has great influence. Here climate changes will be expressed in valleys in one way, and at the mountain top absolutely differently.

Climate change

If we take last 2 periods, namely 1931-1960 and 1961-1990, the average annual temperature in Kyrgyzstan in the last 100 years showed an increase in the 20th century by 1.6° C, and it is considerably higher than the global warming, which is about 0.6 ° C. The greatest warming was observed in the winter (2.6 ° C), and the least in the summer (1.2° C) season, thus, the winters have become relatively warmer in comparison with the summer months. The climate in Kyrgyzstan has therefore gradually become warmer from the beginning of the 20th century. Statistical calculations show that temperature rise was beyond its natural fluctuations and the climate warming is steadily taking place in republic territory.

The precipitations in the 20th century has slightly increased in Kyrgyzstan - by 23 mm or 6 percent from long-term average. However in all climatic zones of Kyrgyzstan, except internal Tjan-Shan, which occupies a considerable part of country territory, precipitation increased from 1-2 to 20-30 percent.

The quantity of runoffs is increasing now in the republic. It might appear currently as a positive phenomenon. However, if one considers the reasons of increase in the runoff, the phenomenon does not remain positive because this increase is connected with thawing of glaciers. The number of mountain glaciers in Kyrgyzstan in 1965-1974 was 7628 with a total area of 8107 km^2; there are now only 5237 glaciers with the area of 6336 km^2. If the trend continues, because of global warming, there will certainly be a severe water shortage problem developing in the future. River's runoffs will increase approximately during 15-20 years. Decrease of the river's runoff, which are feeding the most habitable and economically important valleys as Chuj, Talas, Fergana and Issyk-Kul, is especially dangerous. The same problem is likely to be encountered in the near future in all the countries of Central Asia. A severe shortage of drinking and irrigation water would be the main threat to the stability and live in the Central Asia by 2050.

Climate change and agriculture in Kyrgyzstan

Under such a situation the agriculture in the drought afflicted Central Asia mainly dependent on irrigation will be severely affected causing the problem of food security as in this strategic region about 90 percent of consumed fresh water it is used in agriculture. Already today it is possible to notice the decrease of cereal crops productivity because of climatic zones changes due to warming. The negative factor is a rise in the air temperature in hot region.

In this scenario, the main scientific challenge is breeding drought and heat tolerant agricultural crop varieties adapted to new specific conditions. In this regard the necessary research work is already started in Kyrgyzstan.

Due to global climate warming in the foreseeable future we should master mountain valleys – "Syrts". Our people will be compelled to come back to mountains where mainly the animals (sheep, horses and yaks) are raised. If the global warming tendency will continue and climatic zones will move upwards the extreme mountain areas in the future will become softer for live.

The contribution of Kyrgyzstan to emission of greenhouse gases, and thus global warming, is not much. Firstly, the territorial area of the republic is not great; secondly, the industry is not so developed, and thirdly the electric power development is based basically on hydro-electric engineering that does not give big emissions of greenhouse gases. However, according to new information on climate change, Kyrgyzstan takes a leading place in the vulnerability index among the Central Asian countries because it is the most mountainous country with high unpredictability regarding its weather conditions.

5.3. Resilience and adaptation strategies to climate change, IFAD's work in drylands

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Abstract

The International Fund for Agricultural Development (IFAD) is an international financial institution and specialized United Nations agency dedicated to supporting poor rural women and men in developing countries to achieve higher incomes and improved food security. IFAD operates through grant and loan instruments to finance agricultural and rural development programs and projects. Promoting resilience of small farmers to climate change is at the center of these efforts. IFAD is increasingly becoming "climate smart" by continuing to prioritize and mainstream adaptation into its operations as expressed in its new Climate Change Strategy that was approved by the IFAD Executive Board in April 2010. IFAD's operations in drylands are highly relevant to this vision and to the implementation of the UN Framework Convention on Climate Change which recognizes the adverse effects of climate change on these particular ecosystems. Degradation of land reduces the land's resilience to climate variation and increases the vulnerability of poor communities to the harmful effects of climate change and their ability to adapt. From 1999 to 2005, IFAD committed approximately USD 2-billion to programs and projects related to objectives of the UN Convention to Combat Desertification. IFAD's efforts primarily support four types of adaptation activities: (i) diversifying livelihoods to reduce risk; (ii) improving agricultural techniques and technologies; (iii) strengthening community-based natural resource management; and (iv) preparing for risk and coping with disaster. Africa, a severely affected continent in terms of poverty, desertification, and climate change is discussed using IFAD project efforts in Mauritania (Sustainable Oasis Development Project) and Sudan (Gash Sustainable Livelihoods Regeneration Project). The conclusion addresses (i) tools and approaches for adaptation mainstreaming at the national and grassroots levels; (ii) Climate smart investment and climate proofing of rural development projects; and (iii) Partnerships diversification and knowledge management.

Introduction: IFAD and Climate Change

The International Fund for Agricultural Development (IFAD) is an international financial institution and specialized United Nations agency dedicated to supporting poor rural women and men in developing countries to achieve higher incomes and improved food security. IFAD operates through grant and loan instruments to finance agricultural and rural development programs and projects.

The urgency of the international response to climate change has given a new place to drylands in terms of vulnerability to predicted climate change impacts and potential contribution to climate change adaptation and mitigation. In addition, there is growing recognition of the importance of dryland ecosystem services in supporting food security and other needs of dryland and non-dryland populations. IFAD is increasingly becoming "climate smart" by continuing to

mainstream resilience and climate adaptation measures into its operations as expressed in its new Climate Change Strategy (IFAD 2010). IFAD's operations in drylands are highly relevant to this vision and to the implementation of the UN Framework Convention on Climate Change which recognizes the adverse effects of climate change on these particular ecosystems. Degradation of land reduces the land's resilience to climate variation and increases the vulnerability of poor communities to the harmful effects of climate change and their ability to adapt. The adverse effects of climate change can further erode the quality of the natural resource base that the poor depend on and reinforce conditions of poverty. Therefore, climate change severely impacts livelihoods of the poor and may force drastic changes on livelihood strategies. This is especially true in drylands that are home to a very large share of the world's poor. Within the framework of the Millennium Development Goals (MDGs), the right of poor people to development is an international obligation. The achievement of MDGs targets cannot be met, nor can sustainable ecosystem management be achieved, unless drylands are brought back into the mainstream of global development.

IFAD's continuing commitment towards bringing drylands into the mainstream of global development is illustrated in the approximately USD 2-billion IFAD had committed from 1999 to 2005 to programs and projects related to objectives of the UN Convention to Combat Desertification in which sustainable land management interventions were used in arid, semi-arid, and dry sub-humid areas inhabited by the poor for livelihoods enhancement (IFAD and Global Mechanism of the UNCCD 2005). IFAD primarily support four types of adaptation activities: (i) diversifying livelihoods to reduce risk; (ii) improving agricultural techniques and technologies; (iii) strengthening community-based natural resource management; and (iv) preparing for risk and coping with disaster (IFAD 2008). On a broader level, IFAD has promoted climate-oriented approaches to development, including participatory approaches, holistic approaches such as the sustainable livelihoods framework, gender mainstreaming, and vulnerability assessment and targeting (Urquhart 2008). (See general examples in ***Table-1*** in Annex). IFAD has also supported research institutes and other bodies to develop and disseminate technology in order to address climate variability.

Africa – a continent severely affected by poverty, desertification, and climate change and their overlapping dimensions, and which IFAD has targeted as a development priority – is discussed below using IFAD development efforts in Mauritania (Oasis Sustainable Development Project) and Sudan (Gash Sustainable Livelihoods Regeneration Project).

Mauritania's Oasis Sustainable Development Program (OSDP)

Mauritiania lies entirely within the arid region: The Saharan desert covers three-quarters of Mauritania while a quarter of the country is a Sahelian zone. The effects of climate change, including variable rainfall patterns and recurring droughts, adversely affect the country's drylands area and aggravate the process of desertification. Decreased productivity of the soil as well as adverse effects on the water supply caused by both natural and anthropogenic factors are harming ecosystem balance and threatening environmental services and functions that are critical to livelihoods (Islamic Republic of Mauritania 2004). Mauritania's problems demonstrate the cause and effect factors of the poverty-environment nexus that contributes to increased poverty and a severely degraded environment. Focusing on this critical nexus, IFAD, in partnership with its co-financiers, aims to promote sustainable land management (SLM) and relevant interventions to reduce Mauritania's land degradation problems while simultaneously reducing poverty and vulnerability to climate variations. Mauritania's oasis communities will be

able to improve their livelihoods, strengthen the environment (land and water resources) in which they inhabit and enhance their resilience and adaptive capacity to the effects of climate change.

Towards those ends, the OSDP started implementation in 2004. The total cost of the program amounts to approximately USD 35 million with the IFAD loan amounting to USD 11.4 million on highly concessional terms. The Global Environment Facility (GEF) is co-financing the project. The Arab Fund for Economic and Social Development (AESD) is participating by doing a parallel project with a small management unit attached to the OSDP. The Government of Mauritania and the beneficiaries also have their respective contributions (IFAD 2003a).

OSDP overview of beneficiaries and key issues

The target beneficiaries of OSDP are 95 oasis communities, most of whom live in poverty and have limited access to basic social services. Most households are poor because of their limited access to productive assets and extremely harsh environmental conditions in which they have to survive. Several droughts in the last 30 years have reduced water availability for irrigation. Furthermore, cultivated area has been reduced under flood recession and dry farming, with the combined effect of smaller livestock herds and overall lower productivity. Lack of market access, small size of most oases, and lack of transparent infrastructure hamper the potential for diversification and intensification of agricultural production (IFAD 2003a).

OSDP and climate change adaptation and vulnerability

The following are examples (IFAD 2003a) of development interventions in OSDP that address climate change adaptation and vulnerability while improving livelihoods of oasis communities. Though the project did not specifically focus on climate change adaptation, the activities nonetheless served to fulfill its essential functions (see Figure 1).

Improved production systems: By improving production systems and minimizing damage to land and water resources, OSDP investments enhance resilience to future climate change impacts by: developing and disseminating water saving and management techniques; identifying and disseminating improved farming practices for date palms and other oasis crops using an ecosystem approach; disseminating improved natural resources management (NRM) practices in peripheral oasis areas, including systems for improved water management and practices for efficient water use such as water control procedures; and mainstreaming the famer extension system using Moroccan and Mauritanian farmers. Specific measures that contribute to community resilience and climate change adaptation are: seed banks for agricultural diversification; drip irrigation; rehabilitation of wells and dune fixation.

In addition, an entire sub-component of OSDP focuses on *NRM and environmental protection* in which training and technical support are provided for the following areas: improved NRM practices in oasis border areas; water harvesting technologies and techniques for deterring dune encroachment. The GEF contributes by further strengthening SLM practices, mainly through bolstering capacity and institutional build-up as well as up-scaling of best SLM practices.

Market access: Strengthening production and enabling diversification of crops allows oases communities to market their production, benefit from returns, allow for alternative income-generating enterprises, develop market chains for diversified livelihood strategies, and enable more sustainable business and production while increasing food security. This collectively

strengthens the livelihood assets base and abilities of communities to be more resilient to extreme climatic events. OSDP establishes market information systems for major oases products (dates, meat, some vegetables), and support systems for improved marketing. This includes on-demand training for beneficiary groups in marketing and improved technologies for conservation and processing of agriculture products. Basic social and economic infrastructure, including rural roads that link oases communities to markets, is established to facilitate and enable market access.

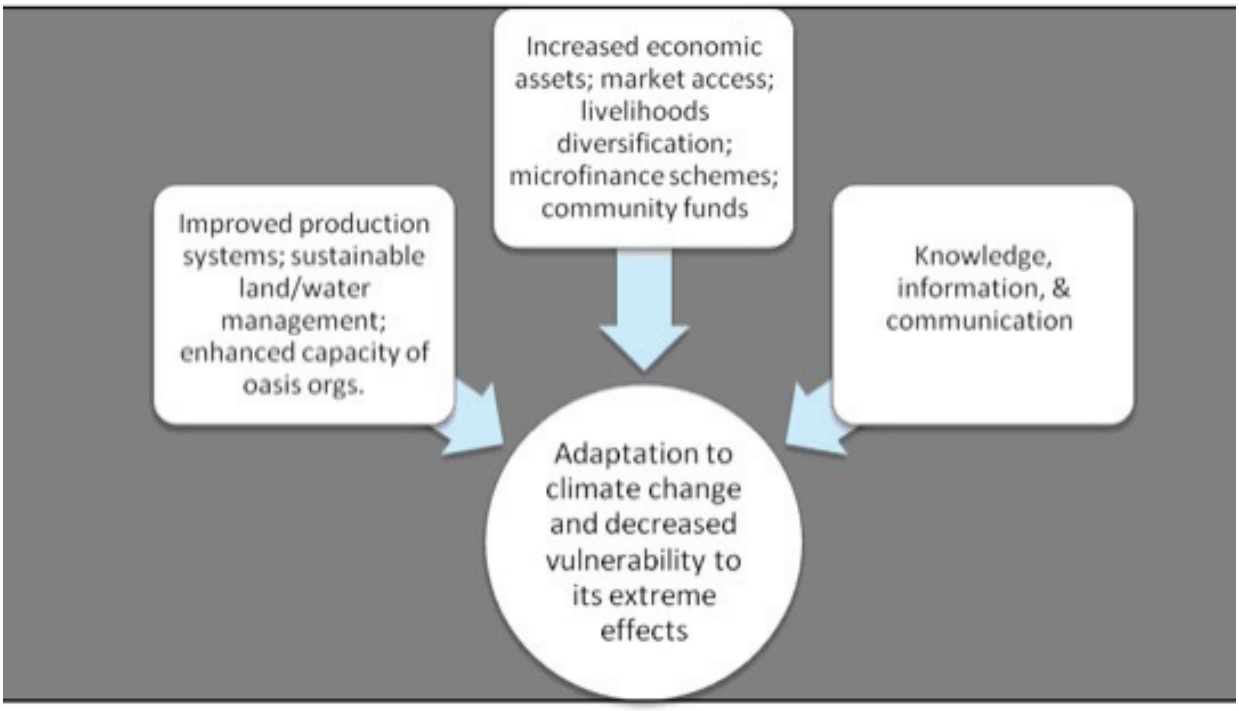

Figure 1. IFAD's Oasis Sustainable Development Programme in Mauritania enables poor rural communities to adapt to climate change and become less vulnerable to its adverse effects.

***Microfinance schemes and community investment fund*:** Towards further strengthening the economic assets base, abilities of communities, and their economic diversification prospects that renders them less vulnerable to harmful climatic impacts, OSDP supports the consolidation of existing oasis credit associations (OCAs), establishment of new OCAs, and development of a network of microfinance institutions in the oasis areas. Furthermore, a *community investment fund* to support eligible community investments has been considered. Investments include *inter alia* water mobilization infrastructure; collective water lifting and distribution systems and dune protection measures.

Knowledge, information, and communication: Enabling poor oasis communities to have knowledge and information through transparent and effective communication makes them less susceptible to natural shocks, including those that are climate-induced. In addition to essential knowledge derived from marketing support systems, as stated above, OSDP supports policy dialogue; assists in establishing platforms for collaboration among various local development actors, and facilitates information and knowledge exchange through rural radio.

In addition, OSDP has enhanced capacity-building of oasis organizations, including oasis participatory development associations, other grass-roots organizations – including women's cooperatives, economic interest groups, farmer organizations and youth associations – and

communes involved in programme implementation. Increased knowledge, information, and communication enable more transparency among relevant stakeholders, empower local communities to work to the full extent of their capabilities, maximize assets, reduce risk, and strengthen their overall understanding of threats and opportunities. This collectively renders them less vulnerable to the adverse effects of climate change and allows them to adapt to these effects.

Gash Sustainable Livelihoods Regeneration Project (GSLR)

The main source of livelihood for Sudan's rural inhabitants is agriculture which is the main activity for approximately 60 percent and 90 percent of the population in northern and southern parts of the country respectively (IFAD 2009). Small-scale farmers predominantly inhabit Sudan's agriculture sector and normally live in chronic poverty. They depend on rain-fed and traditional practices which make famers vulnerable to climate variability as past droughts have demonstrated (Republic of the Sudan 2007).

Conflicts and drought have especially increased the population of communities in the Gash Dye area in eastern Sudan where they seasonally depend on water to irrigate and cultivate crops. The need to sustain livelihoods by poor communities has caused immense pressure on the limited natural resources base (land and water) and increased competition and conflict among community members. The GSLR is one of IFAD's major efforts to address these environmental threats while simultaneously improving the livelihoods of poor rural farmers in the country, contributing to better resilience to climate variability (IFAD 2003b).

Towards achieving that objective, GSLRP started implementation in 2004. The total cost of the GSLR project is USD 39 million with the IFAD loan amounting to USD 24.9 million on highly concessional terms. The purpose of the project is to ensure the efficient, equitable and sustainable operation of the Gash Flood Irrigation Scheme and the integration of the scheme into the local economy to improve livelihoods (IFAD 2003b).

GSLRP overview of beneficiaries and key issues

The estimated population of the project area is 87,000 households. About 30,000 tenant farmers will benefit from secure and equitable access to irrigated landholdings and an additional 10,000 landless households will gain legally recognized and secure access to irrigated land. Moreover, approximately 27,000 non-tenant households will benefit from improved infrastructure for livestock production (fodder availability, veterinary services, restocking efforts) and non-farm income-generating activities. Livelihoods in the Gash Delta have been adversely affected due to managerial, institutional, and policy factors – the root causes of impoverishment of communities. Among the main factors leading to impoverishment are:
(a) No agreed approach and plan for development in the region which has led to *ad hoc* use of resources and investments;
(b) unpredictable local and extra-local resource allocation, including inequitable patronage systems;
(c) lack of transparency in the management of Gash area resources and investments;
(d) frequent exemption from or non-payment of services charges, such as water rates; weakening of traditional solidarity and social support mechanisms;
(e) relatively harsh and fragile agro-ecology and the cumulative degradation of the natural resource base which exacerbates the problems (IFAD 2003b).

GSLRP and climate change adaptation and vulnerability

The following are examples of how GSLRP contributes to climate change adaptation and decreases vulnerability of communities to the effects of climate change. The activities below did not focus specifically on climate change adaptation, but fulfill its essential functions as explained below:

Spate irrigation rehabilitation, animal production, and rangeland management: Spate irrigation was promoted through this project and plays an adaptation role to climate change as it adapts to a wide range of effects from climate variability. For example, the spate irrigation system can be used to prevent the degradation of a ephemeral river system in extreme flood events. Farmers who depend on the irrigation system can manipulate the conditions of sedimentation and scour processes by deepening the head reach of a flood channel to attract a larger flood, or block a flood channel to force the river bed level to rise. Farmers can mold such an irrigation system to produce optimal results for production and strengthen their livelihoods (van Steenbergen et al. 2008).

Productivity of crop and rangelands is promoted by soil and water conservation investment and improved institutions. The latter includes tenant selection and registration; establishment of tenancy rights to secure viable landholdings; and formation of Water User Associations (WUAs). WUAs enter into service provision contracts for delivery of water for irrigation, and allow access to various land development initiatives, including de-siltation of canals; land leveling; mesquite clearance and improvement of water intake of irrigation units (IFAD 2003b). Access to water is a crucial element for adaptation to climate change in this project area.

In addition, rehabilitation works are promoted, including river training and reconstruction of the water reticulation network, canals and access roads. Improved cultivation through efficient and equitable irrigation, animal production, and rangeland management will increase economic assets and capabilities of the poor, enable diversification of livelihoods, and alleviate social tensions in the community, all of which contribute to resilience to the effects of climate change. River training activities and other rehabilitation works enable adaptation to climate change through prevention of flood damage, higher retention of water and its use, and prevention of erosion in the riverbed and riverbanks (Urquhart 2008).

Sustainable Livelihoods Approach (SLA)**:** The SLA approach focuses on strengths, vulnerabilities, and livelihood strategies, and enables understanding of the socio-economic aspects of vulnerability, including climate risks, which allows for effective adaptation planning and resilience measures. Sustainable management of environmental assets, including the maintenance of functioning ecosystem services, serves as a buffer against climate change and is itself a critical form of adaptation. SLA's *holistic* approach takes into account the contextual and systematic factors that contribute to poverty and its effects on various types of capital (human, natural, social, physical, financial) that the poor depend on for livelihoods. The following were learned through the SLA that contribute to climate change adaptation and resilience measures for the rural poor: water requirements and grazing areas; allocation of land for irrigation; dual importance of livestock and crop production; the role of women; and internal and external relationships and inter-crossing dimension.

Financial services and marketing**:** Financial services and marketing allow Gash communities to market production, benefit from returns, allow for alternative income-generating enterprises, develop market chains for diversified livelihood strategies, and enable more sustainable

business and production. This collectively strengthens the livelihood assets base and abilities of communities to be more resilient to extreme climatic events. Economic diversification drives poor people to increasingly participate in markets. Investment of time and labour in alternative livelihood options can provide an escape from the potentially dire consequences of extreme events and climatic fluctuations.

Community development, capacity-building and women empowerment: This includes improving of existing water facilities and transferring of management of these facilities to water management communities. Moreover, it prioritizes women integration in strategic alliances with local leaders to promote social and economic benefits, will train the most vulnerable women various social and economic skills, and encourage their representation in community development committees. Gender mainstreaming and building women capacity enhances their economic assets and capabilities and renders them less vulnerable to the adverse effects of climate change.

Conclusion and way forward

Climate change and livelihoods are linked together in interactive ways through mediating factors such as access to land, water and grazing, income diversification and gender empowerment. These factors have prime importance in configuring the 'platform' on which adaptation is constructed – particularly in drylands. IFAD projects focus on strengthening the knowledge base; valuing and sustaining dryland ecosystem services; promoting public and private investment in drylands; improving access to profitable markets; and prioritising rights, reform, risk and resilience for poor rural communities. IFAD will continue to fulfill its mandate of improving livelihoods of smallholders in poverty-stricken countries by enhancing the natural resources base they depend on.

New tools and approaches will be used to make interventions more climate-proof, including climate-related information to smallholders, financial services programs that ensure affordable weather index-based insurance, and the continual use of participatory and vulnerability mapping techniques to assist smallholders improve community-adaptation efforts, make them less vulnerable to extreme climatic effect, and increase their resilience to these effects. Efficient irrigation systems, improved water management and harvesting techniques, and sustainable use of ground water are effective adaptation measures that help to build smallholder resilience, particularly in drylands.

In addition, the piloting and scaling up of new technologies and modifications to farming practices will contribute as climate adaptive measures. Climate smart investment and climate proofing will continue to be considered in IFAD rural development efforts. Moreover, a holistic approach to program development will continue to be used, while risks and opportunities related to climate change will be assessed in the context of poverty alleviation (IFAD 2010).

Partnerships diversification and knowledge management with bilateral and multilateral institutions, research institutions, civil society organizations and private sector (especially famers and rural producers' organizations) will continue to be essential for sharing of knowledge, including best practices, and to enable optimal targeting of smallholders to alleviate poverty, promote livelihoods, and decrease pressure on the natural resources base they rely on (IFAD 2010).

Lastly, IFAD projects will provide greater support to natural resources management components of its projects and programs, and will continue to incorporate disaster risk management strategies

into its development efforts for optimal results in combating poverty and increasing the resilience of the rural poor to the effects of climate change (IFAD 2010).

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Annex

Table1. General technical examples of adaptation and co-benefits from mitigation in agriculture that strengthen the resilience of rural poor communities and enable them to adapt to the effects of climate change.

Intervention	Climate Adaptation Linkages
Sustainable Livelihoods Approach *(SLA)*	• Focuses on strengths, vulnerabilities, and livelihood strategies, and enables understanding of the socio-economic aspects of vulnerability, including climate risks, which allows for effective adaptation planning and resilience measures. • Sustainable management of environmental assets, including the maintenance of functioning ecosystem services, serves as a buffer against climate change and is itself a critical form of adaptation. • This *holistic* approach takes into account the contextual and systematic factors that contribute to poverty and its effects on various types of capital (human, natural, social, physical, financial) that the poor depend on for livelihoods.
Spate irrigation	• Spate irrigation plays an adaptation role to climate change as it adapts to a wide range of effects from climate variability. For example, the spate irrigation system can be used to prevent the degradation of an ephemeral river system in extreme flood events. Farmers who depend on the irrigation system can manipulate conditions of sedimentation and scour processes by deepening the head reach of a flood channel to attract a larger flood, or block a flood channel to force the river bed level to rise. Farmers can mold such an irrigation system to produce optimal results for production and strengthen their livelihoods and becoming more resilient to the effects of climate change.
Financial services and markets	• Allows poor communities to market production, benefit from returns, allow for alternative income-generating enterprises, develop market chains for diversified livelihood strategies, and enable more sustainable business and production. This collectively strengthens the livelihood assets base and abilities of communities to be more resilient to extreme climatic events. • Economic diversification drives poor people to increasingly participate in markets. Investment of time and labour in alternative livelihood options can provide an escape from the potentially dire consequences of extreme events and climatic fluctuations.
Capacity building	• Environmental planning at local level and training such as river training activities and other rehabilitation works that enable adaptation to climate change through prevention of flood damage, higher retention of water and its use, and prevention of erosion in the riverbed and riverbanks. Special emphasis is placed on women empowerment and gender mainstreaming.

Intervention	Climate Adaptation Linkages
Rangelands and pasture management	• Managing grazing systems and grazing intensity, fire management and pasture rehabilitation, mobility, water points and corridors, crop-livestock conflict management.
Livestock management	• Modifying herd composition: varied species/breeds; adapting grazing management practices to increase soil carbon. Reducing greenhouse gas emissions from livestock by improving animal nutrition, breed selection and manure management.
Disaster Preparedness	• Improving risk management and preparedness – e.g. better agro-meteorological warning systems, drought contingency plans, response to flooding, awareness-raising, weather-indexed risk insurance.
Sustainable land and crop management	• Applying conservation agriculture – minimum disturbance of soil, in combination with maintenance of year-round soil cover plus crop rotation, preferably with inclusion of leguminous crops to boost soil nitrogen. • Adopting new crops, crop rotation and/or crop varieties, adjusting the time of planting/harvesting; introducing integrated soil-fertility management systems that cater to the nutritional needs of the crop without polluting the environment; and integrated water-management practices. • Soil and water conservation. • Perennial or deep root crop systems.

Plenary Session 6

6.1. The Red Sea Project, an integrated sea water agriculture system

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Abstract

Meeting the food, feed, fiber and fuel needs of a still-growing global population in a changing climate is one of the great challenges of the 21st century. The initial effects of climate change, a still-expanding human population of growing affluence, overexploitation of ocean fisheries and the new and growing demand for biofuels call for new approaches. Integrated aquaculture and agriculture systems, both fresh-water and saline, offer the opportunity to optimize nutrient cycling and minimize ecological impacts. New Nile Co combines Egypt's abundant resources of desert land, seawater and labor to address many national and global challenges—such as freshwater scarcity, food shortages, arable land depletion, unemployment and urban congestion—through the development and operation of Egypt's first commercial scale Integrated Seawater Agriculture System (ISAS) project, NNC Red Sea ("Red Sea Project"). ISAS is a completely closed loop, fully integrated system that combines untreated seawater with arid, desert lands to facilitate the practice of aquaculture and agriculture, yielding both biofuels and food. Simply put, a series of manmade seawater rivers and canals are used for aquaculture operations, the effluent from which is then used as a natural fertilizer for halophyte-based (i.e. naturally salt tolerant plants such as salicornia and mangroves) agriculture operations. Collectively, these interdependent aquaculture and agriculture operations yield biofuels (liquid and solid), seafood (fish and shrimp) and a host of co-products including biomass, protein meal, animal feed and salt. Working together with the Ministry of Agriculture and the Governorate of the Red Sea, New Nile Co has selected a site located west of Gebel El Zeit for the project. The Project details are presented in the paper.

1. Introduction

This conference has focused our minds sharply on the changing climate. Arguably the biggest challenge of the 21st century is to produce sufficient food for a still growing and increasingly affluent human population – without destroying what is left of Earth's rich biological heritage.

Concerns about food security are as old as mankind, of course. Thomas Malthus' eloquent 1798 Essay on Population crystalized the dilemma for modern times. Malthus argued that humanity was doomed to poverty and famine because the human population grew exponentially, while mankind's ability to produce food could only increase at a linear rate. Curiously, it was at about the same time at the turn of the 19th century that science entered agriculture in earnest. Over the subsequent two centuries, scientific and technological advances drove extraordinary increases in agricultural productivity.

When Malthus penned his essay in 1798, the human population of the world was about a billion. Science-based agriculture supported a tripling of the global population by the middle of the 20th century and another doubling in the second half of the century. Population experts tell us it's likely that another roughly 3 billion people will be added to the planet's population before it stops growing. It is a sobering fact that the amount of arable land has not changed appreciably for more than half a century, even as the population doubled. But the development of an agriculture sufficient to feed and clothe the world's current population of 7 billion has extracted an extraordinary toll on biodiversity.

The global food price crisis of 2008 was a harbinger of things to come. Continuing growth of the human population and its increasing demand for meat, diversion of grains to biofuel production, three decades of declining investment in agricultural research, combined with widespread drought triggered a sudden upward spiral in the cost of the basic staple grains that feed humanity and its animals.

It is our growing conviction that we will have to do nothing less than reinvent agriculture in the 21st century. We must reduce agriculture's ecological footprint, decrease agriculture's use of fresh water, reduce agricultural pollution of air, land and water, and adapt crops to a hotter and -- in many populous places -- a drier world. And oh and by the way, we need to do this while doubling the food supply and powering our cars with biofuels.

We have both the knowledge base and the technical toolkit to tackle these daunting challenges in the face of a shifting climate. The late 20th century witnessed a genetic revolution with the invention of recombinant DNA technology, the explosion of genome sequencing, and the development of techniques for the reintroduction of individual genes into plants and animals. Today, it is possible to use these techniques to modify crop plants and animals very precisely, adding, subtracting or precisely changing well-characterized genes. These techniques will allow us to improve our existing livestock and animals and our growing knowledge base will allow us to domesticate more stress-tolerant microorganisms, plants and animals much more rapidly than the tens of thousands of years it took to create our current ones.

But the greater challenge to agriculture is to use land we now consider useless and water we now consider unusable, all powered by sun and wind -- and advances in science and engineering. Aquaculture is part of the answer, but as practiced in many places today, aquaculture exacerbates nutrient pollution of water. In the larger scheme of things, we need to view agriculture as a "system" that encompasses ecology, hydrology, and energy, not just food production. The New Nile Project promises to be the first truly large-scale effort to establish an integrated desert aquaculture and agriculture system based entirely on seawater to produce food, feed, fiber and fuel.

In the twenty-first century, Egypt is faced with an incredible array of challenges which, if not addressed, will create unnecessary and avoidable catastrophic risk. Fresh water scarcity, food shortages, arable land depletion, staggering unemployment, population explosion and urban congestion are but a few of these challenges. On the global stage, there are equally grand challenges such as global warming, sea level rise and the production of sustainable biofuels. For some, such as the authors of this document, addressing these seemingly overwhelming issues has become a raison d'être. New Nile Co, a company under formation, combines Egypt's abundant resources of desert land, seawater and labor to address many of these national and global challenges through the development and operation of Egypt's first commercial scale Integrated Seawater Agriculture System (ISAS) project along the Red Sea ("Red Sea Project").

2. Integrated Seawater Agriculture System (ISAS)

ISAS is unlike any traditional biofuel production systems that utilize freshwater and arable land, displacing food products in favor of biofuels. Rather, an ISAS is a completely closed loop, fully integrated system that combines untreated seawater with arid, desert lands to facilitate the practice of aquaculture and agriculture, yielding both biofuels and food. In a generic ISAS operation, seawater is pumped from the sea via canals (and ultimately new seawater rivers), flowing through an aquaculture system in which fish and other seafood are produced using quality assured and monitored procedures. The seawater effluent from this operation is high in nutrients and is used to irrigate and fertilize mangrove forests and meadows of salicornia, a valuable oil seed and straw crop. The salicornia is harvested as an annual crop and oil pressed from its seed. The oil is transformed into liquid fuels, while the seed meal becomes feed for the aquaculture crops and other animals. The straw may be used for fiberboard, ruminant feed, liquid biofuel or as a solid biofuel for power generation or cement production. The mangrove trees clean and stabilize the marine / terrestrial interface, restore critical habitat, provide long term carbon sequestration and contribute to animal feeds and solid biofuels. This nutrient-flow system also can provide revenue generating co-products such as sea-cucumbers, bi-valves, macro-algae, artemia and salt.

The comprehensive, integrated system is the basis for economic, environmental and social benefits. The whole system is built on non-arable and freshwater starved land, obviating competition with food production.

The ISAS technology has been designed and prototyped for over thirty years by Global Seawater, Inc. and The Seawater Foundation on two sites: Seawater Farms Eritrea, in Eritrea, East Africa; and Bahia Kino, Sonora, Mexico. In addition, it is endorsed by leading scientific authorities including the Dr. Nina Fedoroff, the US Secretary of State's Science & Technology Adviser as well as President-Elect of the American Association for the Advancement of Science.

Core principle of ISAS: The core principle of the system is that no nutrient escapes the system. Thus nutrient-laden seawater flows sequentially from extremely wasteful units (aquaculture ponds with 30% nutrient use efficiency), to less wasteful units (salicornia fields with 65% nutrient use efficiency), finally to scavenging nutrient filters (mangrove stands with 90% nutrient use efficiency) and final to salt production fields. Organic sediments in seawater channels are regularly dredged and transferred to salicornia fields for fertilization, carbon sequestration, and soil conditioning.

Key components of ISAS: An ISAS project is essentially an agriculture project combining untreated seawater and arid, non-agricultural grade land to produce multiple end products including biofuel and food. The key components of an ISAS project are:

- **Seawater:** A manmade seawater river enables seawater to flow from the sea into the project area to be pumped onto the land for agricultural irrigation and other applications;
- **Land:** Large tracts of low lying uninhabited, arid desert land (e.g. 50,000 to 60,000 ha of non-agricultural grade land) located inland, which will become productive through the farming of halophytes (seawater tolerant plants) and practicing aquaculture;
- **Labor:** A sizable workforce of skilled, semi-skilled and unskilled labor required to operate the project, which in turn will generate considerable infrastructure and support services needs.

Key units of ISAS: An ISAS project has multiple production units developed in a phased approach, with each production unit designed to be scalable as the operations expand. The key

units of an ISAS project include:

- **Production units:** Units will include shrimp ponds, fish ponds, salicornia plantations (a highly desirable biofuel feedstock), mangrove forests, small livestock feedlots, salt lakes and algae ponds (future production).
- **Processing facilities:** Units will be required for the processing, packaging and distribution of the ISAS project's primary products of liquid and solid biofuels, seafood and ancillary co-products of meat and dairy, animal feed, protein meal, fertilizer, hides, industrial salt and building materials.
- **Project infrastructure:** This will include administrative, accommodation, medical, recreational, educational (vocational), religious, R&D, storage, power generation (including renewable), desalination (if required) and roads.

3. The Red Sea Project

3.1. The site

Since January 2009, New Nile Co has worked diligently to identify and assess potential sites along the Mediterranean and Red Sea coastlines for its ISAS project. The list of criteria used to assess each and every potential site was exhaustive, exceeding thirty factors including elevation, topography, meteorology, water and soil salinity, human and wildlife presence, ownership and proximity to sea, towns and infrastructure. Working together with the Ministry of Agriculture, the Governorate of the Red Sea and the National Center for Planning State Land Uses ("NCPSLU"), New Nile Co selected a site located west of Gebel El Zeit, in between the Red Sea cities of Hurghada and Ras Ghareb. The Red Sea Project will commence with an initial phase of 20,000 hectares, and eventually encompass 50,000 hectares (~123,000 fedan); land which would otherwise sit idle given its arid nature, existing nearby Oil & Gas facilities and the Gebel El Zeit mountain chain which obstructs views to the Red Sea.

3.2. The seawater river system

At the heart of an Integrated Seawater Agriculture System (ISAS) project is a seawater river system that brings untreated seawater on to land for productive purposes. These nutrient-laden rivers meander purposely through aquaculture, agriculture and other environmentally enhancing – and revenue generating - venues. In the Red Sea Project, the entire river system will be about 160 km long and will flow inland from two constructed inlets on the Red Sea, located at each end of the site, approximately 17 km apart. These two water sources, providing untreated seawater directly to the project production components, will be supplemented by a few on-shore wells strategically located to provide naturally filtered seawater for specific, exacting uses.
The water employed in the system is segregated into three categories, according to quality and intended use. Seawater coming directly onto the site, unaltered, is termed 'Red' and is used as supply water for aquaculture and various ecological production activities. Seawater derived from on-shore wells is defined as 'Blue' and, being naturally filtered and purified by the soil, is applied to specific sensitive uses such as hatchery functions and algae production. Finally, seawater identified as 'Yellow' is water that is obtained from original 'Red' quality, but run through a series of constructed gravel / sand filters, also for use in aquaculture components. Crucial to the integrity of project productivity, these three grades of seawater are carefully managed to meet the biological needs of the various organisms of the system's production components. Collectively, it is anticipated that the system capacity will be approximately 13 meters^3 / second.

The seawater rivers will be placed at three elevations, along the 10, 20, and 30 meter contours. At sea level, near the river inlets, there will be locks and the first series of pumps to raise the seawater (and alternative-fueled or non- motorized crafts) to an elevation of 10 meters. The supply river at this level provides seawater for the shrimp and fish ponds, as well as related aquaculture components including algae, sea urchins and bi-valves. After being fortified by the nutrient-rich effluent of the shrimp and fish excrement, the water is again pumped up to rivers and lakes at 20 and 30 meter contours that also contain productive components. From there, the water flows by gravity to irrigate lush fields of salicornia and mangroves, while working its way back down to constructed, ecologically rich wetlands. Adjacent to the wetlands, some water is retained in shallow basins, to grow brine shrimp and *D. salina*, a red algae used as a feed for brine shrimp, before moving on to the final activity, salt crystallization. Eventually, many weeks or months later, having been biologically cleaned as it is filtered through the soil, part of the seawater makes its way back down to the Red Sea water table.

Fresh water supplies for the project will be transported to the site, obtained from wells, and retained in constructed basins filled by storm water run-off. This latter source will be enhanced through the creation of 'fresh water lenses', made possible by the intentional placement of underlying, denser, seawater stores. Once used, fresh water effluent will be captured and treated for further reuse through de-centralized on-site, natural-based reclamation systems. This replicable reuse regime will re-process approximately 90% of the freshwater used at the project. Other effluent sources, such as sewerage, will be treated through the use of seawater, further reducing fresh water consumption.

3.3. Products and markets

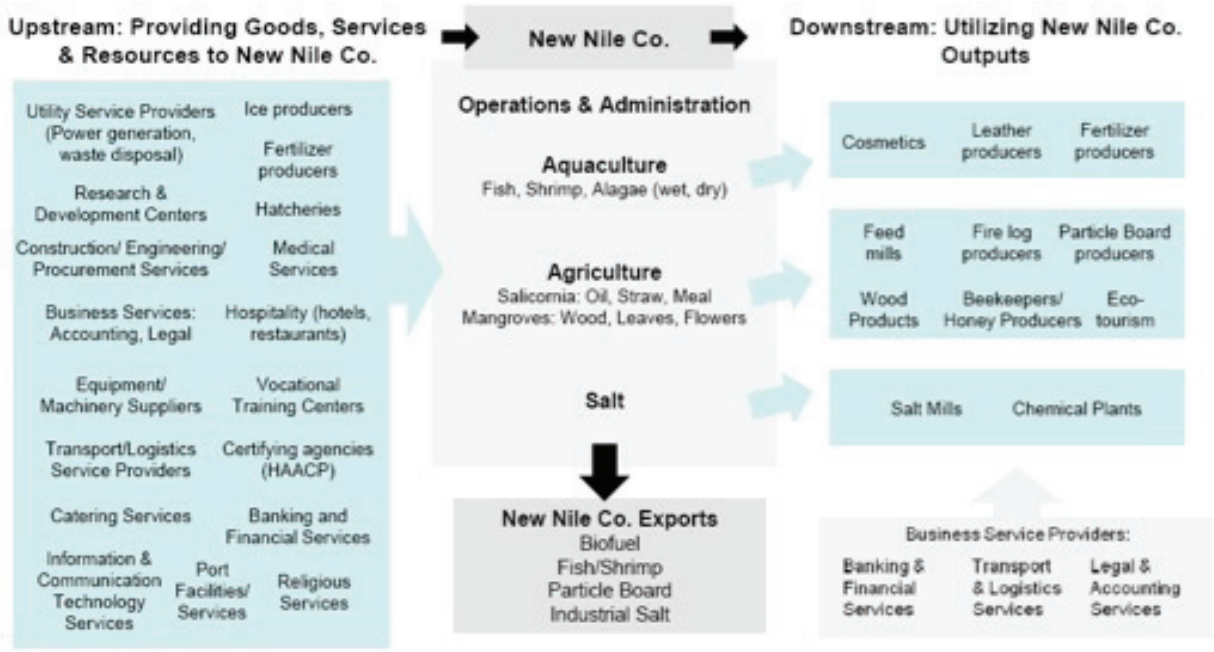
Upon completion, the Red Sea Project will yield hundreds of thousands of tons of biofuels and food products annually. The Red Sea Project's biofuels will be targeting the international aviation and vehicles markets, both of which are presently subject to extensive regulations mandating the use of blended fuels (e.g. EU Renewable Energy Directive). Moreover, boasting a population exceeding 80 Million, the region's largest, and with ever-increasing food demands, Egypt is one of Africa's biggest producers, importers and consumers of seafood and offers a local, sustainable market to ensure the financial success of the Red Sea Project's aquaculture operations.

3.4. Socio-economic benefits of Red Sea Project

Increased employment opportunities: The Red Sea Project will generate direct employment opportunities at the project site for approximately 6,500 people. It is expected that these employees will be recruited from Ras Ghareb and Hurghada as well as from greater Egypt. The Red Sea Project does not expect to establish human settlement at the project site through construction of accommodation for employees, but rather facilitate commuting from Ras Ghareb and Hurghada.

Economic diversification and indirect employment: The Red Sea Project will generate opportunities for new and existing businesses to provide goods and services required for its operations, as well as inputs for downstream enterprise. The diversification of the local economy through such upstream and downstream linkages is expected to lead to positive economic impacts in terms of a 'multiplier effect' on employment, estimated at a factor of 10 for a total of 65,000 jobs indirectly supported by the Red Sea Project.

Increased access to education: The Red Sea Project will require human resources with specialized skills to meet operational requirements. Where this specialized skill is not available,



the Red Sea Project will support vocational training to develop the necessary human resources. In 2005/2006 there were 16 vocational training centers reported in Red Sea Governorate, which trained a total of 629 individuals according to the Red Sea Governorate Information Report 2008. These centers largely impart tourism-oriented training to meet current market demand for these vocational skills. The Red Sea Project will generate demand for different sets of vocational skills, and will incentivize private sector training providers to offer a greater range of vocational training to meet this demand. Diversifying the skills of the work force will be beneficial to the Red Sea Project, as well as for the general economic diversification of the area's economy as an improved and diversified labor force attracts other investors. In addition, the Red Sea Project may support additional education and training initiatives as part of the project's Corporate Social Responsibility component, ranging from primary and secondary education to business development and management training.

Increased exports: The Red Sea Project expects to generate exports through international marketing of fish and shrimp, particleboard, biofuel and salt. Such an increase in exports will lead to greater macroeconomic stability. The precise nature of exports and contribution to the Egyptian economy will be more fully explored in the Feasibility Study.

3.5. Government and academia support

It is precisely these positive socio-economic impacts that have endeared New Nile Co to national and international governments, academia and media. In addition to the Ministry of Agriculture, Governorate of the Red Sea and NCPSLU, New Nile Co has enjoyed the active support of the highest levels of the Ministry of Trade & Industry, the Ministry of Higher Education & Scientific Research, the National Research Center (NRC), Agricultural Research Center (ARC), the General Authority For Investment (GAFI) and the American University in Cairo (AUC). New Nile Co has also concluded long term cooperation agreements with both the ARC and AUC and has a further cooperation agreement underway with the NRC and King Abdullah University of Science and Technology.

3.6. News and media support

In addition, due to its innovative and unique approach to producing both biofuels, New Nile Co and the Red Sea Project have been featured in various energy, technology and financial conferences including the United States Trade & Development Agency's (USTDA) MENA Power 2010, the Ministry of Higher Education & Scientific Research's International Workshop on Industrial Biotechnology and Euromoney Egypt 2010 as well in numerous regional and international publications such as Alternative Energy Africa, Biofuels International and Build Green. Moreover, New Nile Co was voted amongst Biofuels Digest's Top 30 Transformative Technologies 2010.

3.7. The sponsors of the project

Bringing together the requisite financial, technological, planning and political forces to transform New Nile Co and its Red Sea Project from a concept into reality are the company sponsors: Energy Allied International, a world class projects development firm, and the Seawater Foundation, which, with Global Seawater, Inc., are the world's leaders in seawater-based agriculture and Integrated Seawater Agriculture Systems. With the assistance of water technologies consulting firm H2O Futures, agricultural consultants Key Development Services, and the New York, Houston and London offices of Gensler, the world's largest architectural design firm, New Nile Co is poised to bring about an agricultural revolution to the great nation of Egypt.

6.2. Competence of alien genetic resources for wheat breeding in drylands

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Abstract

While the world population is rapidly increasing, the gain in the annual cereal production is slowing at rates far from keeping pace with the expanding population. Despite the great success of the traditional breeding in increasing the yield and overall per capita cereal production, solving the global food crises by only conventional breeding is becoming more difficult. There is an urgent need for new ideas and technologies to be exploited and adopted.

A breakthrough might be achieved through marker-assisted selection based on genome sequencing information, discovery of excellent genes and their transformation, and/or hunting, integrating and utilizing novel traits present in the cereal wild species that have not been used in the past. We have crossed wheat with several wild species and developed wheat lines with alien chromosomes or genomes. Additionally, we have built a valuable collection of lines that had been developed by other researchers. We analyzed several of these lines for various aspects and dug out novel traits such as fertilizer-use efficiency, high yield potential, high mineral contents, drought tolerance, good bread-making-quality and disease resistance. Our efforts are expanding to introduce chromosomes from more distantly related species such as pearl millet into wheat. This presentation reviews the recent status of wide crossing in wheat based on our studies and discusses the appropriateness of this strategy for wheat breeding for dryland development.

Present status of breeding methods to improve drought tolerance

As the world population rapidly increases, the growth in annual cereal production is slowing, and is far from keeping pace with the expanding population. Despite great successes of traditional plant breeding in increasing crop yield per unit area, solving the global food crisis using conventional breeding alone is becoming more difficult. There is an urgent need for new ideas and technologies to be exploited and adopted. A breakthrough may be achieved through: 1) marker assisted selection (MAS) based on genome sequencing information, 2) discovery of desirable genes for transformation, and 3) finding, integrating and utilizing novel traits present in wild cereal species that have not been domesticated. These new strategies should be efficiently adopted in cereal breeding programs for drought tolerance. MAS is an effective tool when the number of genes for a desired trait is limited, and the contribution of each gene is large. However, most of the drought tolerance related characters are inherited quantitatively through a number of genes with smaller individual contributions. Thus, MAS is of limited use for improving drought tolerance unless a major drought tolerance gene is discovered.

A breakthrough for breeding drought tolerant crops may be achieved through the discovery of novel genes in the gene pool of non-crop species. If such a gene is discovered in a species related to cereals, it may be transferred to the cereals via wide hybridization. Alternatively, if a desirable gene is found in the genome of a more distantly related organism, it can be cloned and then transformed into the crop species. The merit of genetic transformation in crop improvement is

its potential to introduce any gene from any organism into crops. Indeed, the genes responsible for glyphosate herbicide resistance and insect resistance (Bt toxin), the most widely used crop transgenes in the world, originated in bacteria. Public acceptance for the application of genetic transformation to staple foods, however, is very low. Among several arguments against this technique, one of note is that transformation is just a technique and required that genes applicable for transformation be discovered. After the complete sequencing of the genomes of *Arabidopsis*, rice and several other plant species, encyclopedic studies involving all genes, proteins or metabolites has become the trend of plant science research. Enormous analytical projects have been carried out to uncover all information possible for several plant species. However, if we consider the potentially useful genes necessary for breeding through transformation, the source of such genes may not be in these well studied plants. Desirable genes might be present in the genomes of any plant, animal, and fungal and bacterial species. We therefore need to take a broad approach to finding important phenomena that may be applicable to crop breeding. Another problem for transformation that remains to be solved is that the technique is genotype specific. This is especially true in wheat, where only a limited number of cultivars are amenable to transformation. One of the benefits of transformation is the ability to change a particular trait without altering the genetic background of the transformed cultivar. Protocols that are applicable to any wheat cultivar must therefore be developed.

Suitability of genes from cereal relatives

Genes in species related to cereals might be of value to address the problem of global food shortage. Over the 10,000 year history of agriculture, humans have developed many crops. However, the genetic variation within these crops is very limited compared to the total variation present in their relatives. For example, humans first domesticated tetraploid wheat from the wild species, *Triticum dicoccoides*. The cultivated form, *Triticum dicoccum*, then naturally crossed with a wild species, *Aegilops tauschii*, and hexaploid wheat, which was to become the common bread wheat that is distributed throughout the world, was produced. All of the present day bread wheat cultivars are the descendant of this one, or of several, interspecific hybrids. Wheat belongs to the taxonomic group termed the Triticeae tribe. In this tribe there are more than 300 species that are distributed across all continents except Antarctica. However, only a few species of wheat, barley and rye are used by humans as food. Most of the genetic resources of tribe Triticeae have never been used in the history of agriculture, though most of the species are able to be crossed with wheat. Many wild species in tribe Triticeae inhabit harsh environments in cold, humid, saline and dry regions, where wheat cannot survive. Some genes, mainly disease resistant genes, have been used in wheat breeding; however, these constitute a very small portion of the useful genes present in tribe Triticeae.

We have crossed wheat with a variety of wild species and also produced chromosome addition wheat lines. These lines are called disomic alien chromosome addition lines (DALs) and contain a pair of chromosomes from a related species. In addition, we have studied other DALs produced by researchers from other institutions. These materials have been used to analyze specific characters present in the alien species in the genetic background of wheat, on a large scale. We named this library of stock lines the Tottori Alien Chromosome Bank of Wheat (TACBOW). The morphologies of the DALs in TACBOW are the same as for wheat, with few, if any, modifications. Detailed analyses may reveal unique characters present in the alien species. We have already reported that several DALs in TACBOW produce unique seed storage proteins (Garg et al. 2010). The seeds of wild species are very small, and thus it is difficult to analyze flour characteristics. However, DALs allowed us to characterize the effect of wild genes on dough quality in detail, because the DAL kernels were similar to those of wheat.

Another important characteristic discovered using DALs is fertilizer use efficiency. A DAL containing a chromosome of *Leymus racemosus* was found to secrete an unidentified substance(s) from the roots that inhibits the growth of nitrobacteria. Thus, this line uses nitrogen fertilizer more efficiently than standard wheat cultivars, and in addition, inhibits emission of nitrous oxide (N_2O), which is known to be a more potent greenhouse gas than CO_2 (Subbarao et al. 2007). Recently, we found that several DALs have high phosphorus uptake and phosphorus use efficiency (Wang et al. submitted). Since phosphorus resources are predicted to have depleted by the end of this century, the variation introduced from wild species will be useful for wheat breeding programs. As shown by these examples, the genetic diversity of alien species is a gold mine for human crop breeding and food production.

Populations to exploit the abundant variation of *Aegilops tauschii*

The introduction of desirable genes into common wheat by chromosome addition usually involves a challenging cytogenetic technique. However, in the case of *Ae. tauschii*, this technique is unnecessary because meiotic recombination occurs due to both species having the common D genome. *Ae. tauschii* (genome DD) is usually first crossed with tetraploid durum wheat (genomes AABB), and plants with the same genomes as bread wheat (AABBDD) are produced. These hybrid plants with AABBDD genomes are called synthetic wheat and are used in breeding programs. However, it is not very easy for wheat breeders to evaluate the agronomic traits of synthetic wheat, because one third of the genes in the synthetic wheat originate from the wild *Ae. tauschii*. Therefore, the synthetic wheat produced directly from durum wheat and *Ae. tauschii* (called 'primary synthetic'), is crossed with a leading cultivar, and the resulting F_1 hybrids or the further back-crossed BC_1F_1 plants are self-pollinated several times. The segregating lines, called 'synthetic derivatives', are then used and evaluated for desired characters.

Inagaki et al. (2010) identified a drought tolerant genotype in the synthetic derivatives of cultivar 'Cham 6'. This line holds potential to be successfully used in a drought tolerance breeding program. The synthetic derivatives have a similar morphology to Cham 6, because theoretically only 1/12 of the genes are those of *Ae. tauschii*. We were able to confirm the locations of *Ae. tauschii* chromosomes in this drought tolerant synthetic derivative (Itami et al. unpublished).

One problem with synthetic derivatives, however, is that a single synthetic derivative consists of a series of lines, and it is difficult to incorporate numerous series of synthetic derivatives into a breeding program. In order to utilize the wide variation within the gene pool of *Ae. tauschii*, many series of synthetic derivatives must be incorporated effectively. Thus, the present method is efficient only when the target character can be pre-evaluated in *Ae. tauschii* itself. However, even if evaluation in *Ae. tauschii* is possible, the performance of the *Ae. tauschii* character may not be exhibited in the synthetic derivatives, due to differences in the morphology and ploidy of *Ae. tauschii* and bread wheat. We found large variation in drought tolerance related traits in a large number of *Ae. tauschii* accessions. However, the performance of these traits was not exhibited in the synthetic derivatives (Sohail et al. 2010). Indeed, some unexpected synthetic wheat lines showed better performance than the lines expected to perform well based on the evaluation in *Ae. tauschii*. This indicates that we need to evaluate drought tolerance in synthetic wheat rather than in *Ae. tauschii*. However, the morphology of the primary synthetics is still different from that of bread wheat, and it takes time to generate synthetic derivatives from a selected primary synthetic.

Here, we propose the generation of a population for the efficient selection of desirable traits, which includes large genetic variation from *Ae. tauschii*. The population is named Multiple

Synthetic Derivatives (MSD) (Fig. 1). To produce the MSD population, numerous strains of synthetic wheat are independently crossed twice with a leading cultivar in a target region, generating a large number of BC_1F_1 seeds. For example, if 50 primary synthetic wheat accessions are available, one of the spikes of each accession is crossed with the target cultivar. Spikes of one or a few plants of each F_1 hybrid are then back-crossed with the same leading cultivar, and about 100 BC_1F_1 seeds are obtained from each plant. An equivalent number of the BC_1F_1 seeds from each F_1 are combined, and a bulked population is produced. This population is grown in good field conditions, to increase the seed number. Since 3/4 of the genomes of the BC_1F_1 plants are of the leading cultivar and 2/3 of the remaining 1/4 is durum wheat (11/12 of the genome in total is from cultivated wheat), the morphology of the plants is much more consistent than for the primary synthetic wheat accessions. The seed from BC_1F_2 or BC_1F_3 progeny generated to increase seed number are sown in stressed conditions and tolerant plants are screened and then selected, or seed is naturally increased under stress conditions. Through this process, several tolerant genotypes derived from the 50 accessions of *Ae. tauschii* will be selected, and the genotypes will simultaneously be fixed. The selected genotypes will then lined be for pedigree selection, or alternatively, the population is propagated through several generations for bulk selection. Once the MSD population is produced, this can also be used as the initial source for other desired characters.

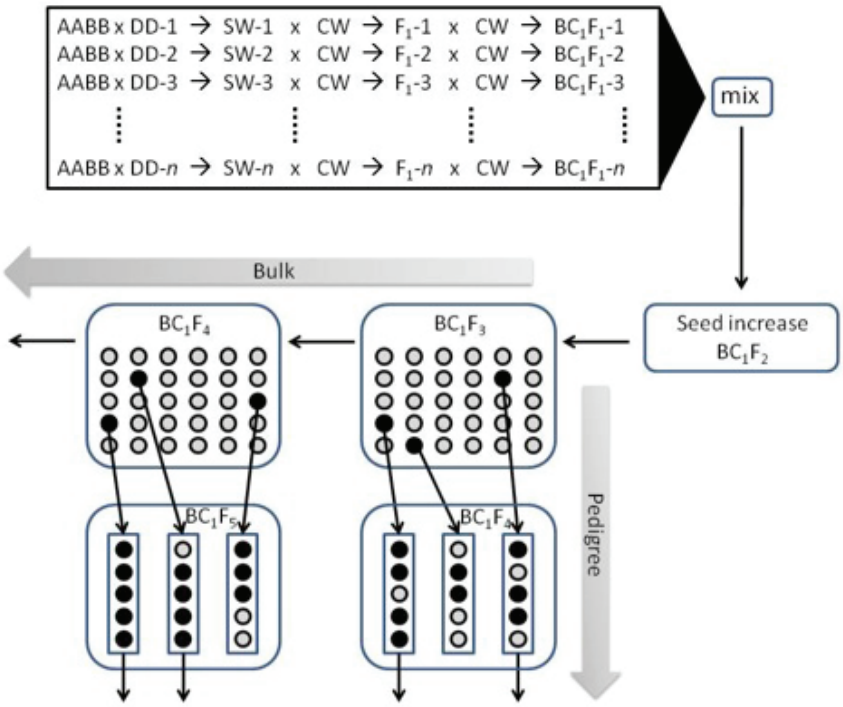

Figure 1. Multiple Synthetic Derivatives (MSD) wheat population with variation from many accession of Aegilops tauschii. AABB, durum wheat cultivar; DD-1 to DD-n, Ae. tauschii accessions; CW, a leading cultivar of common wheat from a target region; SW-1 to SW-n, synthetic wheat lines.

At present, wheat breeding primarily occurs through pedigree selection or bulk selection. In other words, these conventional breeding methods essentially involve the process of creating new genotypes by recombination of genes present in either of the parents. Thus, even when using synthetic wheat, the synthetic wheat lines must be well evaluated. However, as mentioned above, it is difficult to assess the performance of genes of interest in the primary synthetic wheat, because

the morphology differs greatly from that of the leading cultivars. In contrast, the morphology of plants in the MSD population is similar to the common cultivars, despite containing variation from many accessions of *Ae. tauschii*. In addition, the morphology of MSD plants is more consistent than for the bulked primary synthetic accessions, making trait selection easier. The traits present in the MSD population could certainly be used for breeding programs, and the plants may also be released as new cultivars without further crossing. Numerous molecular markers are available that can reveal the pedigree of the selected plants, if necessary

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6.3. Adapting *Pongamia pinnata* to dry area environments for bio-fuel production

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Abstract

Use of biofuels to supplement and eventually replace the petro-based fuels is considered as an important mitigation strategy for retarding the process of climate change. However, the production of feedlot for biofuels should not compete with production of food. The biofuel plants should therefore be able to grow on lands which are marginal for sustained food production. *Pongamia pinnata* is a leguminous tree species that grows under tropical conditions and is capable of providing good quality oil for biodiesel production. It grows under humid and sub-humid conditions but there are possibilities of adapting the species to marginal agroecological conditions of semiarid tropics. Studies were carried out in the glass house conditions to test the possibility of raising the seedlings of this species on dune soils at the Arid Land Research Center of the Tottori University, Japan using irrigation water high in salt content or boron content. Results showed that the seedlings of the Indian ecotype used in the study were able to withstand irrigation with marginal quality waters for several weeks without showing any reduction in growth. However, prolonged irrigation resulted in the development of symptoms of toxicity on old leaves, which eventually dropped off. Nevertheless, the apical growth continued. When the soil was leached with water simulating the rainfall common in the semiarid tropics, the plants showed quick recovery. The results suggest that the species can be grown on degraded land under semiarid environments when irrigated with marginal quality water during the dry season. There is thus a possibility of enhancing adaptation of this species to marginal environments in the semiarid topics.

Introduction

Increasing demand for energy, rising prices of fossil fuel for generating energy, monopoly of a few countries on fossil fuel's supply and growing threat of climate change and environmental degradation because of the greenhouse gas emissions with its use have necessitated the search for green renewable sources of energy. In the face of global warming, the fuel needed is that which has low carbon footprint. The first generation biofuels, based on oilpalm, soybean, corn, sugar crops, etc., are not that carbon efficient and the use of these food crops as feed stock for biofuel production compromises global food supply in a world where the demand continues to grow. Oil-bearing shrubs and trees such as *Jatropha curcas L.* (*Euphorbiaceae*) and *Pongamia pinnata* (L.) Pierre (*Papilionoideae,* the tribe *Millettieae)* are important in this regard, particularly because they are reported to be able to grow on lands that are marginal and degraded so that their cultivation would not compete with important food, feed and fiber crops for land.

Pongamia pinnata (L.) Pierre is a medium-size tree species. It is indigenous to the Indian subcontinent and south-east Asia (Myanmar, Malaysia and Indonesia) where it has historically been used as a source of traditional medicines, besides serving as a source of green manure

(Muthukumar and Udaiyan 2002), animal fodder, timber and fuel (Scott et al. 2008; Mukta and Sreevalli 2010). The synonyms of *Pongamia pinnata* (L.) Pierre are *P. pinnata* Merr., *Pongamia glabra* Vent., *Derris indica* (Lam) Bennett and *Millettia novo-guineensis* Kane & Hat. The plant is commonly called as karanja, karum, kanji, pongam, poonga-oil-tree and Indian-beech. It has been introduced to several countries outside of Indian subcontinent and south-east Asia having humid tropical lowlands as well as parts of Australia, New Zealand and the United States (Scott et al. 2008). An annual minimum rainfall between 500-800 mm is needed for the tree to grow well with a further requirement for irrigation during the establishment stage. Night-time temperatures appear critical in regulating Pongamia phenology: plants do not develop new leaves in spring until minimum temperatures are consistently greater than 15°C, and at least six months of minimum temperatures > 15°C are required for production. The maximum temperatures in the area in which Pongamia occurs in India range from 27 - 38°C (Mutka & Sreevalli 2010).

Being a member of family *Leguminoceae,* Pongamia is able to procure its own nitrogen from the atmosphere by symbiosis with appropriate legume bacteria (rhizobia belonging to the *Bradyrhizobium* tribe , Scott et al. 2008). Thus it needs no nitrogenous fertilizers. Its seed contains 30 to 40% oil. The oil is rich in C18:1 fatty acid (oleic acid; 50-55%) and has low palmitic and stearic acid (10-25%) making it useful for the manufacture of biodiesel (FAME), especially when considering a B20 to B50 blend. The composition of seed oil and properties of FAME meet North America and European industry standards, particularly for tropical and some temperate regions.

When Pongamia is used for biofuel, the only thing removed in the harvest from the system are the fatty acids and all other nutrients can be recycled back in the system. Thus, Pongamia can permit sustainable production of biofuel in an agroforestry system. That is the reason as to why Pongamia is being promoted to produce biofuel feed stock on marginal land in India (Kesari and Rangan 2010) and there is growing interest for similar use in Australia (Kazakoff et al. 2011; Scott et al. 2008)

Pongamia has not traditionally been established in plantations even in India where the species is native. Only small lots can be found on degraded land, along roadsides and river embankments, and in open farmland and there has to date been very little systematic collection and processing of seeds (Kesari and Rangan 2010). No wonder, little information was available on its production technology and genetic improvement in the past. These areas are however now receiving increasing attention (Kesari and Rangan 2010; Pandey et al. 2010; Sunil et al. 2009).

An important and critical stage in successfully raising a Pongamia plantation is the early establishment of seedlings under the marginal quality of land and water. In many areas where the rainfall is low and seasonal, irrigation would be needed before the start of rainy season to get the seedlings of Pongamia established. And the quality of irrigation water in some of these marginal growing conditions might also be marginal – saline or rich in boron content. Information on the effect of marginal quality water on germination and early seedling growth of Pongamia is rather limited (Patil et al. 1996; Tomar and Gupta 1985).

Such information would be essential to grow the species in arid and semiarid areas where salinity is common, water is scarce and the quality of irrigation water is often marginal. Hence, experiments were conducted under controlled environmental conditions at the Arid Land Research Center of the University of Tottori in Japan to develop some of this information. The results of these studies are presented in this paper.

Response of Pongamia seedlings to irrigation with marginal quality water

Water available for irrigation in many areas is generally of marginal quality—brackish or rich in B content. We investigated the ability of the Pongamia seedlings to grow when irrigated with saline water (containing 50 and 100mM NaCl in tap water of EC 0.098d Sm-1) or tap water enriched in B (content 6 mg L-1 as H3BO3). The study was preliminary and constrained by limited number of seeds available for getting seedlings.

Material and method

Seeds of an Indian accession were sown on 16 October 2008 in small plastic pots containing soil + peat moss mixture in a biohazard room (25°C temp and 35-38% RH). They germinated in 15 days. Seedlings were transplanted in 1/5000A Wagner pots containing a mixture of 60% dune sand+40% peat moss (vol. basis) and a compound (15-15-15) granular fertilizer to provide 50 kg of N, P and K each per ha. Pots were irrigated with tap water to saturation, allowed to drain and weighed to determine the water content at field capacity (FC). They were then irrigated regularly with tap water each time when about 60% of FC water was exhausted by evapotranspiration. Every 15 days, plants were also given liquid fertilizer (HYPNeX, 6-10-5). Plants were allowed to grow till 2 March (106 days after transplanting, DAT). Nine pots were selected for testing three levels of salinity in irrigation water (tap water, S0; 50mM NaCl, S1; and 100mM NaCl; respective EC values being 0.09, 4.9 and 9.8dSm^{-1}), in three replications. Another set of two pots was used to test the possibility of irrigation with B-rich irrigation water, which was started on 16 March (120 DAT).

Results

1. Response of Pongamia saplings to irrigation with saline water

By the end of March, i.e. after 3-weeks of saline water irrigation, there was a tendency for the S2 plants to start dropping lower leaves while no apparent symptoms of salt toxicity were visible. By mid April, the lower leaves of S2 and some S1 plants started showing toxicity symptoms on lower leaves. The symptoms became more conspicuous by 24 April (159DAT) although the apical growth continued. At this stage, irrigation with saline water was stopped and all pots were irrigated with tap water from then on. Thus the plants received saline irrigation for 68 days (Table 1).

Table 1. Amount of NaCl added per pot during irrigation with saline water

Treatment	Amount of NaCl (g/pot)	
	Average	SE
S0	0	0
S1	15.118	±0.203
S2	29.169	±0.425

In spite of the stoppage of saline irrigation, the symptoms of salt toxicity started becoming more conspicuous because of the presence of salt in the pot (Photo 1 and 2). Hence on 23 May (83

days after the start of and 30 days after the end of saline irrigation; 189 DAT) all the pots were leached with 1000 ml of tap water in two splits and the EC of the leachate determined using HORIBA ES-51 Electrical Conductivity Meter (Horiba Ltd., Japan). This would simulate a total of 50mm of rainfall, which is expected to occur at the end of the dry season under the semiarid tropic situations of India. The EC increased as the level of salinity in irrigation water increased and the EC of the first leachate was higher than of the second leachate (Figure 1).

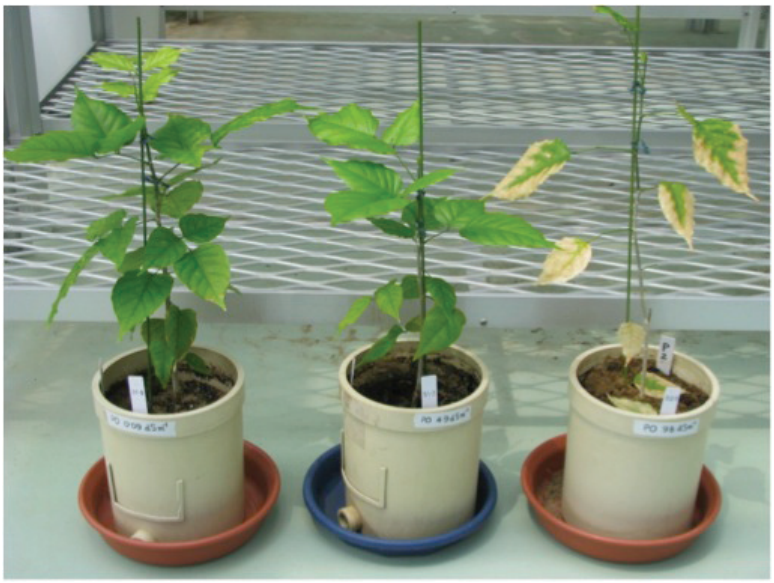

Photo 1. Effect of salinity on plant growth of P. pinnata on 23 May 2009.

Photo 2. Symptoms of salinity toxicity on the leaflets of P. pinnata on 23 May 2009.

After leaching, the plants were regularly irrigated with tap water as was the case before the start of salinity treatments and they were also given liquid fertilizer every 8-10 days.

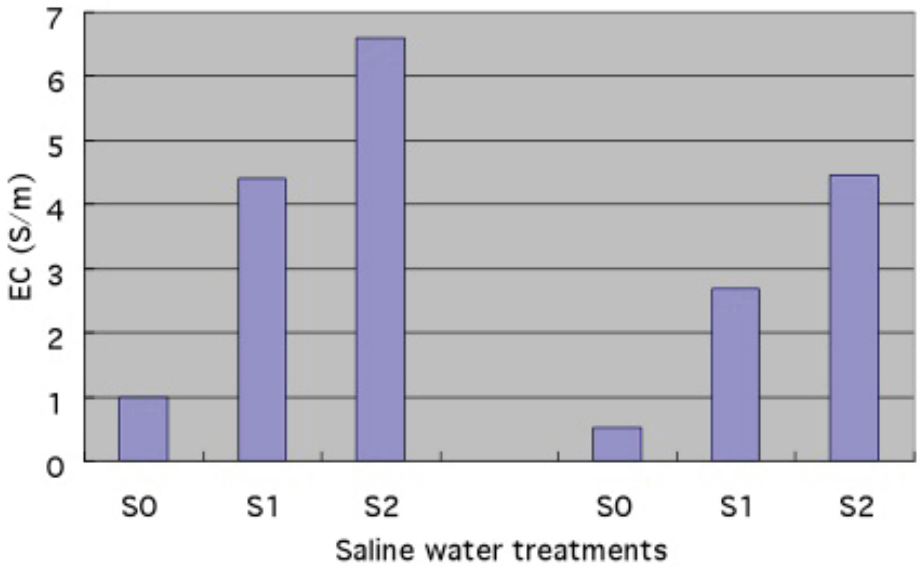

Figure 1. EC of the first and second leachate (with 500 ml of tap water each time) as affected by saline irrigation treatments.

The total consumptive use of water from 2 March up to the 15 June was higher in S0 as compared to S1 and S2 (Table 2). The latter two treatments had nearly identical values. There were little differences in the cumulative consumptive water use between S0 and the other two treatments in the period after the stoppage of saline irrigation (Table 2).

Table 2. Consumptive use of water (ml/pot) under different saline water irrigation

Treat-ment	March to 2 June 15		April to 24 June 15	
	Average	SE	Average	SE
S0	10318	±900.3	3970	±171.6
S1	8963	±238.9	3789	±175.9
S2	8927	±183.9	3936	±145.8

The adverse effect of salinity on growth gradually started becoming conspicuous as the plant grew and by 23 May, the number of green leaves significantly decreased by salinity treatment (Figure 2). In fact the adverse effect was more conspicuous on the number of leaflets as recorded on 23 May (Table 3). Individual ones started dropping off as the symptoms of toxicity got accentuated. The stem girth measured on 23 May was also reduced because of the salinity treatment (Tables 3).

Table 3. Number of leaflets per plant and stem girth as affected by saline water irrigation

Treatment	Leaflets/plant		Stem girth (mm)	
	23-May	21-Jul	23-May	21-Jul
S0	21.6 ± 3.48	27.3 ± 6.4	7.0 ± 0.28	7.4 + 0.77
S1	17.5 ± 2.96	21.0 ± 10.5	6.0 ± 0.28	6.6 ± 0.48
S2	3.3 ± 1.66	15.7 ± 2.0	5.0 + 0.00	6.0 ± 0.45

Table 4. Photosynthetic rate(PR), stomatal conductance (SC), intercellular CO_2 concentration (CC) and transpiration rate (TR) of upper-most fully expanded leaf of P. pinnata on 9 April 2009.

Treatments	PR (μmol CO_2 m^{-2} s^{-1})			SC (mol H_2O m^{-2} s^{-1})			CC (μmol CO_2 mol air^{-1})			TR (mmol H_2O m^{-2} s^{-1})		
S0	4.8	±	1.7	0.075	±	0.019	173.3	±	15.9	2.18	±	0.45
S1	5.9	±	0.7	0.055	±	0.013	83.6	±	25.2	1.70	±	0.37
S2	4.0	±	1.5	0.031	±	0.011	68.0	±	25.7	1.01	±	0.35
Ave ±SE (n=3)												

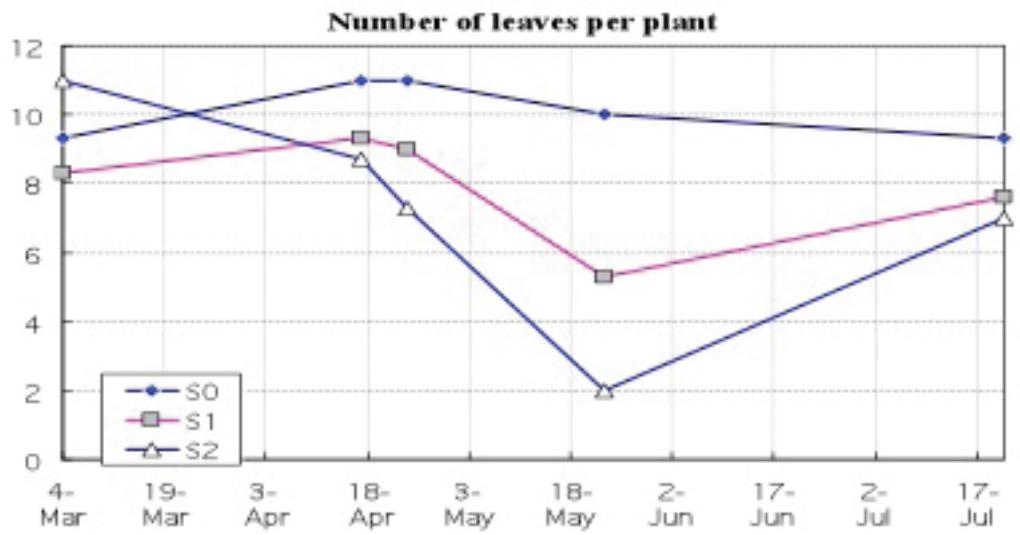

Figure 2. Number of green leaves per plant as affected by saline water irrigation

The photosynthetic rate and other gaseous exchange parameters (Table 4) were measured on 9 April using LI-6400 Portable Photosynthesis Measurement System (LI-COR). Although the stomatal conductance, transpiration rate and intercellular CO_2 concentration were decreased as the level of salinity increased, there was no major effect on the rate of photosynthesis, which in general was low.

The plants started recovering after leaching and by 15th June the recovery was almost complete (Photo 3); and by 21 July there were little differences to be seen (Photo 4).

The results show that Pongamia saplings were able to withstand irrigation with saline water of as high a concentration as 100mM NaCl for nearly two months and salinity for nearly three months, and in this period they never ceased their apical growth. The plants were apparently able to restrict the salt toxicity to lower leaves, which eventually dropped off, and the apex continued to grow resulting in appearance of new leaves.

Photo 3. Effect of salinity on plant growth of P. pinnata on 15 June 2009

Photo 4. Effect of salinity treatment on plant growth of P. pinnata on 21 July 2009

2. Response of Pongamia saplings to irrigation with water rich in Boron content

Only two plants (P8 and P11) were used for this study because limitation of seedlings. Of these, one showed little growth with time while the other showed continuous growth in terms of number of green leaves (Figure 3). Irrigation with B-rich water was given from 16 March to 24 April and the amount of water and B received by the two treatments is shown in Table 5.

Table 5. Amount of Boron containing water (6mg B / L) and B (mg) added per pot from 16 March to 24 April 2009)

Plant No.	Water (ml)	Boron (mg/pot)
P8	3081	18.5
P11	3787	22.7

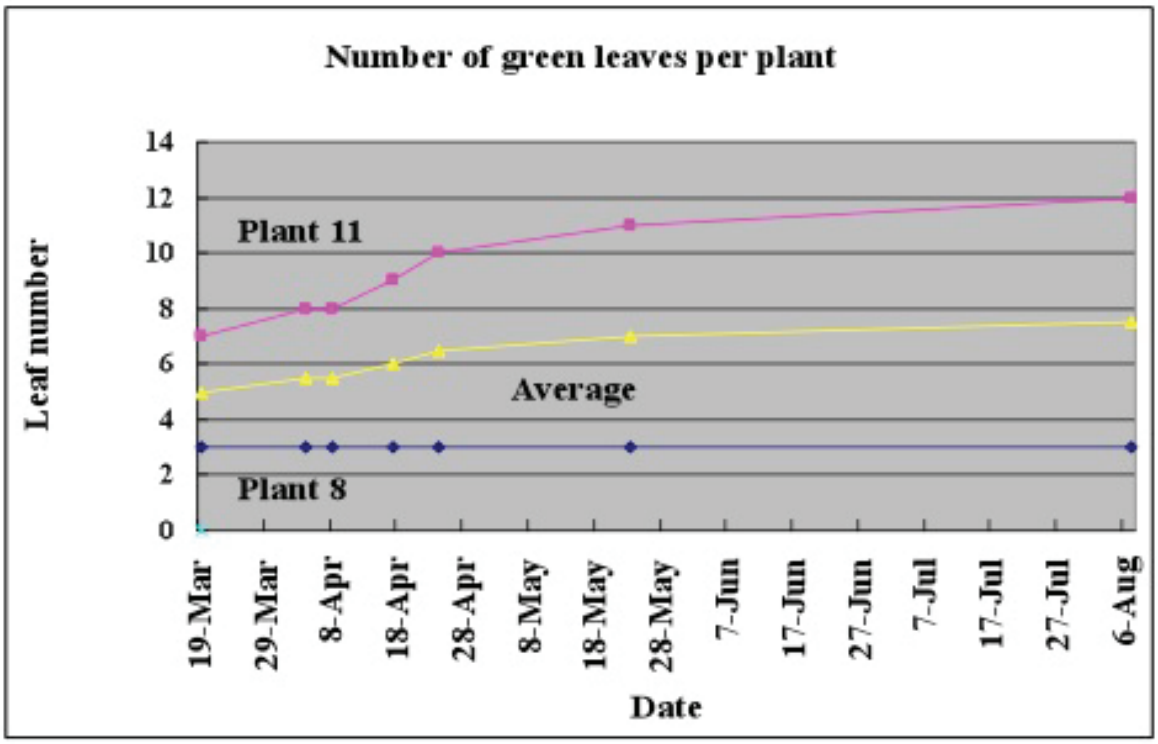

Figure 3. Number of green leaves of two P. pinnata irrigated with B-rich water from March 16 till April 24, 2009, and with tap water thereafter. Pots were leached with 1500 ml of tap water on 15 June 2009 when B-toxicity became very conspicuous.

There was no apparent symptom of B toxicity up to 24 April (38 days after the start of treatment) although lower leaves senesced and dropped, while the apex continued differentiating in to new leaves thus allowing the number of green leaves to gradually increase. On 1 May (44 days after the start of treatment), the irrigation with B-rich water was stopped. Instead, the plants were irrigated with tap water. On 23 May (67 days after the start of treatment and 23 days after the stoppage of the treatment) the plants started showing symptoms of B toxicity by drying of the tips of lower leaves, and the laminar tissues where the veins ended, although the apex continued to grow. On 15th June (46 days after the stoppage of treatment), when toxicity on the lower leaves became very conspicuous (Photo 5), the pots were leached with 1500 ml of tap water.

The plants continued to show increased toxicity on older leaves till 25 July (Photo 6) because of the B accumulated in these leaves but also made new growth. The older leaves were detached and photographed (Photo 7). By early August, the plants showed complete recovery (Photo 8).

Photo 5. Effect of boron on P. pinnata on 15 June 2009 (46 days after stoppage of irrigation with B-rich water).

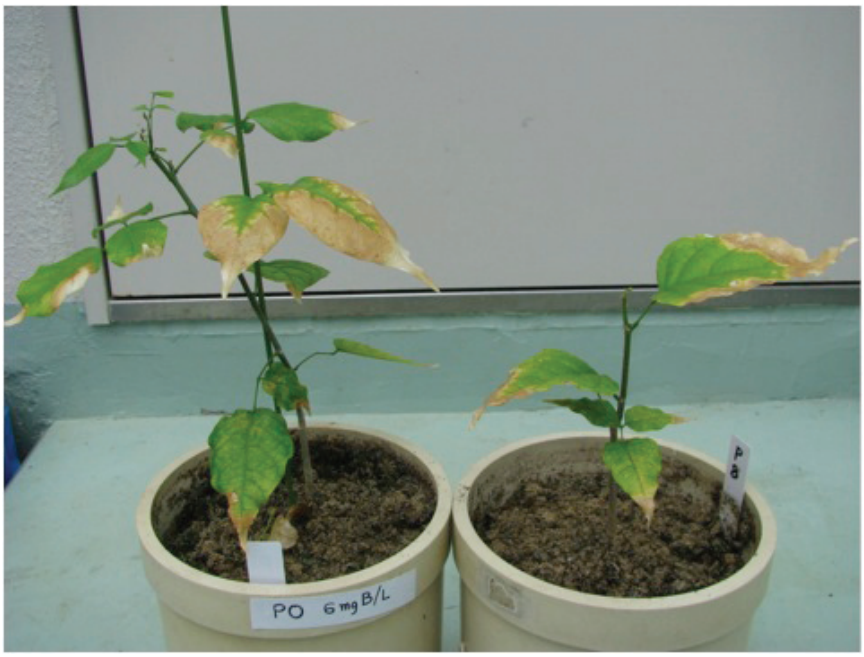

Photo 6. Effect of boron on P. pinnata on 21 July 2009 (82 days after stoppage of irrigation with B-rich water, and 36 days after leaching of the profile).

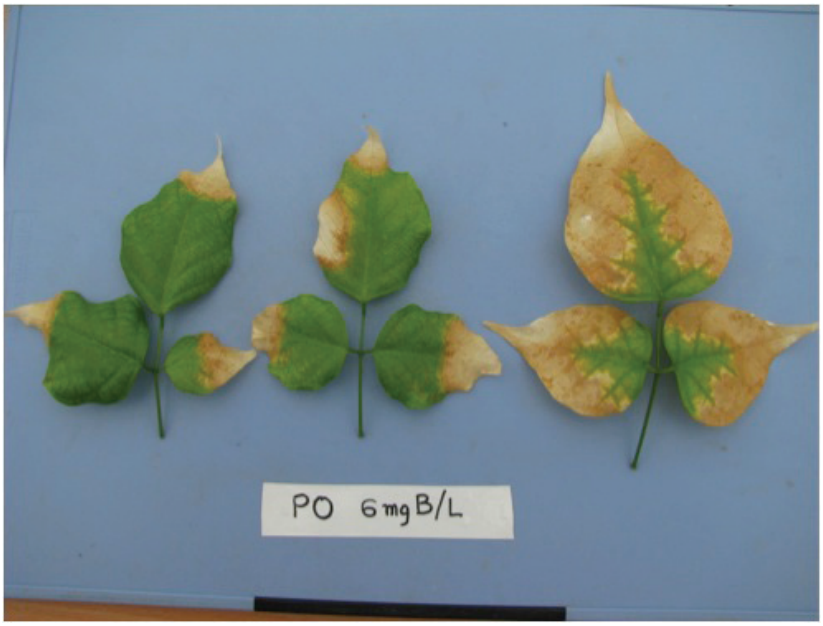

Photo 7. Symptoms of boron toxicity on the leaflets of P. pinnata on 25 July 2009.

Photo 8. Condition of P. pinnata plant on 7 August 2009 (52 days after leaching of the profile).

The saplings of Pongamia were able to withstand very high level of B (6mg/L) in the irrigation water for nearly 38 days, and tolerated high B content in the rhizosphere for more than two months. They showed phytotoxicity on older leaves, which dropped off, while the apex continued to differentiate new leaves. When the B stress was relieved by leaching the soil with tap water, the plants started showing recovery. Thus, this plant can be irrigated with water of high B content during the dry season if the excess of B accumulated is washed off from the soil profile in the subsequent rainy season.

Conclusion

Preliminary pot studies using marginal quality water (high in salinity or boron content) for irrigation have shown that the seedlings can survive when exposed to high salt or B content in the rhizosphere for a period of nearly two months and would recuperate if the stress was relieved by leaching the profile with sweet water. Such a situation can occur with the onset of monsoon in the semiarid tropic region in India. Hence, the survival of the seedlings of Pongamia can be assured in the pre-monsoon dry season by providing them irrigation with marginal quality water. This information is of value in adapting the plant to dry marginal lands.

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Concurrent Session Presentations

Theme 1: Assessment of climatic change in arid lands

1. Relationship between AVHRR NDVI and precipitation in northern China

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Abstract

Water is a primary resource limiting terrestrial biological activity, particularly in arid and semi-arid regions. This study focuses on the temporal and spatial variation between vegetation green biomass and precipitation parameters (annual precipitation AP, annual efficient precipitation AE), annual precipitation uniformity APU and growing season precipitation GSP) in northern China. The relationship between vegetation and precipitation was investigated with Normalized Difference Vegetation Index (NDVI) images (1982–2006) derived from the Advanced Very High Resolution Radiometer (AVHRR), and precipitation data from 297 weather stations throughout northern China. Results indicate vegetation green biomass increased linearly ($P<0.001$) through both AP and AEP gradient, but increased nonlinearly through APU gradient. There are 82, 78 and 33 stations of 297 with positive linear relationship ($P<0.05$) between NDVI and AEP, AP and GSP respectively and 50 stations with negative linear relationship ($P<0.05$) between NDVI and APU. Moreover, most stations with NDVI significantly linearly related to precipitation parameters are distributed within the 200-400mm annual precipitation isoline. Our results confirm the lag effect of precipitation on vegetation and also help understand the tendency and spatial pattern of vegetation response to climate change.

1. Introduction

Precipitation is the main limiting factor of primary production in arid and semiarid zones (Noy Meir 1973). Mean aboveground net primary production (ANPP) of widely different arid and semiarid systems is strongly correlated with mean annual precipitation (Sneva and Hyder 1962; Noy Meir 1973; Lauenroth 1979; McNaughton 1985; Le Houerou et al. 1988; Sala et al. 1988; Paruelo et al. 1999). The relationship of ANPP with mean annual precipitation was derived from long-term averages for many sites distributed across precipitation gradients (spatial model) (Wiegand et al. 2004). However, temporal models relating time series of ANPP and annual precipitation for single sites show much lower slopes and regression coefficients than spatial models (Smoliak 1986; Le Houerou et al. 1988; Lauenroth and Sala 1992; Briggs and Knapp 1995; Jobbágy et al. 2002). Lauenroth and Sala (1992) explored the relationship between annual ANPP and precipitation across a 52-year series in a single shortgrass steppe site and showed that the dispersion of the data around the temporal model was larger than the dispersion of data around the regional model (precipitation accounted for 39% of the variability in ANPP among years, contrasting with 90% for the regional model).

A critical limitation to study temporal dynamics of ANPP and its relationship with precipitation is the lack of long-term data (Jobbágy et al. 2002; Knapp and Smith 2001). Fortunately, this

limitation may be mitigated by the availability of remotely sensed data. The Normalized Difference Vegetation Index (NDVI) calculated from satellite data relates red and near-infrared canopy reflectance and it is closely associated with the fraction of photosynthetically active radiation absorbed by the canopy (Sellers et al. 1992). Several works have shown that NDVI is correlated with ANPP (Paruelo et al. 2000, 2004; Pineiro et al. 2006). Therefore, exploring the relationship between NDVI and precipitation contributes to understanding ANPP variation caused by precipitation. In addition, it's much more convenient to explore ANPP variation with precipitation on a regional scale than field observation.

Several studies have been done to explore the relationship between vegetation and precipitation in Africa or North America, but there is still a lack in China. This research focused on vegetation biomass variation across a precipitation gradient and the spatial pattern of its temporal variation across precipitation.

2. Materials and method

2.1. Study area

The Northern China region lies between 73°-135° E and 26°-54° N, covering 14 provinces, autoumous regions or cities (Fig. 1). As shown in Fig.1, precipitation increases gradually from northwestern (less than 100 mm) to southeastern (more than 600 mm), and the aridest center is Tuokexun of Xinjiang uygur autonomous region, receiving annual precipitation around 3.5 mm. In most area, it's less than 600 mm. It varies greatly intra-yearly, especially in arid and semi-arid region, more than 70% rainfall is concentrated in July and August.

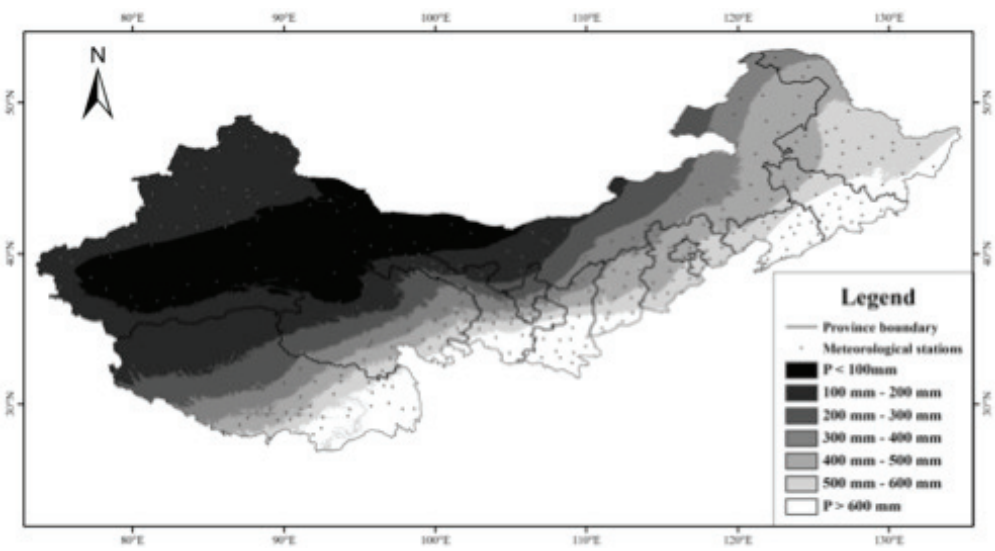

Figure 1. Average annual precipitation gradient and meteorological stations in ***the study area***

2.2. Materials and method

Daily precipitation data are collected from 297 meteorological stations with 25 years successive records across northern China during 1982-2006 (available at website: http://www.cma.gov.cn). For the study purpose, four precipitation parameters are computed: annual precipitation (AP), annual efficient precipitation (AEP), annual precipitation uniformity (APU) and growing season

(April - October) precipitation (GSP). EP is defined as precipitation amount more than 5mm in a rainfall event. APU is proposed the first time in this study to quantify the uniformity of precipitation distribution in a year. It is given by:

$$APU = \sum_{i=1}^{n} \frac{t_i^{\,2}}{p_i}$$

where is the length between *ith* and *th* precipitation events, and is the amount of *ith* precipitation events. APU decreases with the increasing uniformity of intra-yearly precipitation distribution.

NDVI dataset employed in this study were processed by the GIMMS group at NASA's Goddard Space Flight Center, as described by Tucker et al. (1994, 2005) (available at website: ftp://ftp.glcf.umiacs.umd.edu/glcf/GIMMS). The 15-day NDVI composites with 8 km spatial resolution were generated by using the maximum value compositing procedure to minimize effects of cloud contamination, varying solar zenith angles and surface topography (Holben 1986). In addition, calibration based on invariant desert targets has been applied to the original data to minimize the effects of sensor degradation (Los 1993). Stratospheric aerosol corrections were applied to remove the effects of the eruptions of El Chichon from 1982–1984 and Mt. Pinatubo from 1991 to 1993. For this study, the monthly NDVI were acquired by using MVC of two 15-day composites first, then the ANDVI were computed by averaging the monthly NDVI during the growing season. ANDVI values of pixels containing the meteorological stations were extracted according to their geographic coordinates. The data are processed by C++ program.

3. Results and Discussion

3.1. Relationship between ANDVI and different precipitation parameters

As the scatter plot of average annual ANDVI and four precipitation parameters shows in Fig.2, ANDVI is linearly related to AP and AEP significantly, but a second order polynomial can fit the variation of ANDVI across APU or GSP gradient best. The ANDVI-AP model explains the most variability of ANDVI across AP (R^2=0.706), while GSP explains the least (R^2=0.250). This result indicates that biomass is not only affected by the precipitation during growing season but also certain previous period. It agrees with the lag effect of precipitation on vegetation observed in other areas (Justice et al. 1986; Wang 2003).

ANDVI decreases with the increase of APU. But APU is negatively related to precipitation size and frequencies. In another word, lower APU means larger annual precipitation. What's more, the ANDVI-APU model (R^2=0.581) accounts for less ANDVI variability than ANDVI-AP model (R^2=0.706) does. Thus, how much precipitation is received determines the ANDVI and not when the rainfall occurs. More specifically, under current precipitation regime, the APU can affect ANDVI limitedly.

3.2. Spatial pattern of precipitation parameters' effect on ANDVI

To further analyze the relationship between ANDVI and precipitation, we calculated Pearson correlation coefficients between ANDVI and the four precipitation parameters for each meteorological stations during 1982-2006. There are 80, 83, 53 and 42 of 297 stations with significant coefficients ($P<0.05$) between ANDVI and AP, AEP, APU and GSP respectively. This result confirmed that AP or AEP is the most important factor affecting annual vegetation biomass.

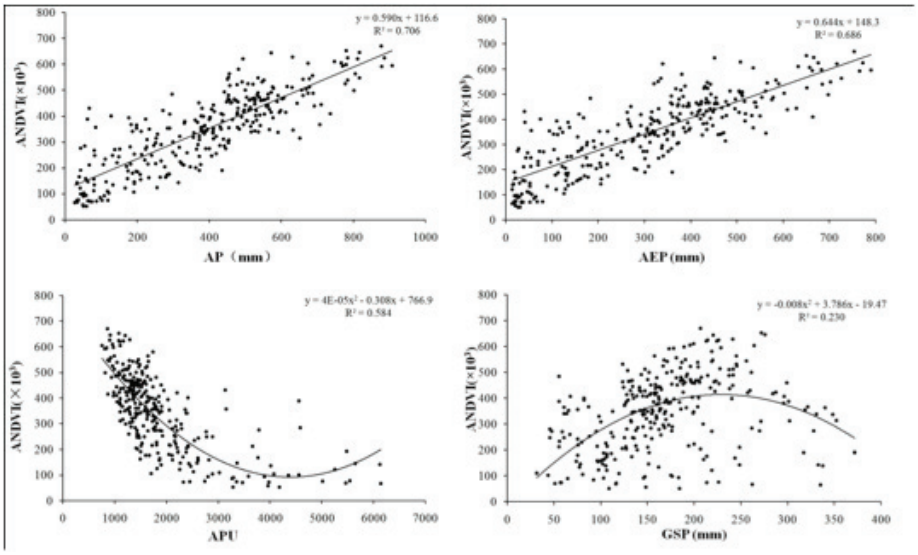

Figure 2. Relationship between ANDVI and different precipitation parameters.

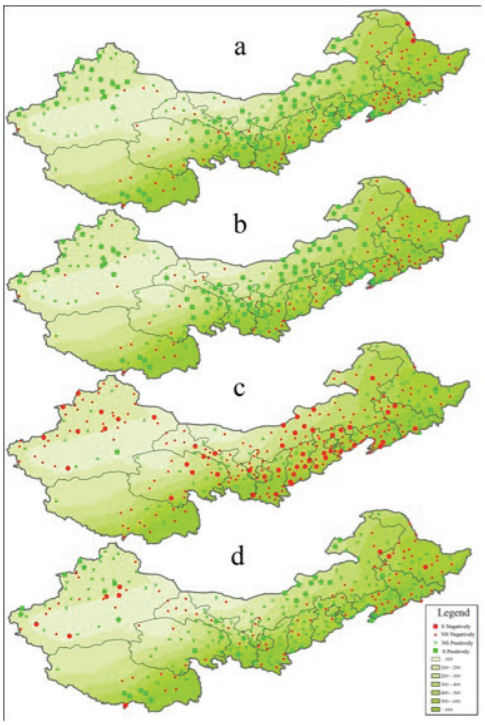

Figure 3. Spatial pattern of relationship between ANDVI and different precipitation parameters

As compared to the above spatial model, the temporal model is less significant, only 29.45% sites (ANDVI-AEP model) show significant linear relationship. And most sites with significant coefficient are concentrated in the 200-400mm rainfall area (Fig. 3). This implies that vegetation biomass is most sensitive to precipitation when the annual precipitation is around 200-400 mm. In extremely arid areas, strong evaporation processes ensure that slight increases in precipitation have only limited effect on vegetation biomass. As precipitation increases, the relationship between ANDVI and precipitation becomes closer, around 200-400 mm. After that value, greater precipitation increasingly fails to raise ANDVI, perhaps indicating the limits of the water-use

capacity (Piao et al. 2006). Alternatively, this may arise from the lower temperature and sunshine levels as precipitation increases. This case is very typical in the northeast area of this region, where precipitation is comparatively ample but mean temperature is low. As it shows in Fig.3.a or b, ANDVI is negatively related to precipitation, although it is not significant.

4. Conclusion

In northern China, annual vegetation biomass is mostly determined by annual precipitation or annual effective precipitation. Under current precipitation regime, the timing of precipitation occurrence is less important in affecting vegetation biomass. Our findings also confirmed the lag effect of precipitation on vegetation. Vegetation in 200-400mm precipitation area is most sensitive to precipitation, this will help understand the tendency and spatial pattern of vegetation response on future precipitation change.

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2. Long-term trend analysis in heavy and extreme events in semi-arid rainfall station, as an indicator of climate change

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Abstract

Trends in extreme events have been worldwide analyzed as an indicator of change in the climate driven by increase in atmospheric greenhouse gases. Statistical analysis of extreme events in the maximum daily rainfall for 83 years for a semi–arid rainfall station in Jordan has been presented. The regression approach, as well as, the Mann-Kendall test were used to investigate significant trends in those data. Both methods assure a significant downward trend. It is however, observed that other related variables including yearly total rainfalls as well as the yearly frequency of rainy days do not show any significant trend. It is also, observed that the fitted linear trend model of maximum daily rainfall shows an estimated rate of decrease of nearly 2mm per decade. A plausible change in the trend is detected in the year 82/1983. The fitted trend models for both periods show that the rate of decrease after the change point is doubled. Finally, "extreme events" of maximum daily rainfalls are investigated through the readings falling above the 75th and 90th percentiles as well as readings above 30mm. It is observed in all cases that the frequency of those events is decreasing.

1. Introduction

Precipitation is a very important climatologically element of climate that affects the natural environment and human society. Worldwide, there is an increasing evidence that human–induced climate change," global warming", is changing the precipitation and the hydrological cycles, especially, the extremes (Karl and Knight 1998; Trenberth, 2005; Emily 2009; Trenberth 2010). Arid and semi–arid regions such as Jordan are solely dependent on rainfall as the main source of water supply. Therefore water resources in arid and semi–arid regions are very sensitive to variations in precipitation. Heavy precipitation events which may cause damaging floods in many parts of the world are considered the main hydrologic events that result in good water harvesting and groundwater recharge in arid and semi–arid regions (Al-Qudah 2010). For example, only during heavy rainfall events, surface storage is maximized in Jordan. Given the fact that Jordan is one of the lowest (< 150 m^3/year) in per–capita water availability worldwide, any change in the precipitation due to climatic changes, will have significant impacts on the quality of life and the whole ecosystem. One of the major concerns with a potential change in climate is that an increase in extreme events will occur. Results of observational studies suggest that in many areas changes in total precipitation are amplified at the tails, and changes in some temperature extremes have been observed (Easterling et al. 2000).

Most countries that experienced a significant increase or decrease in monthly or seasonal precipitation also experienced a disproportionate change in the amount of precipitation falling during the heavy and extreme precipitation events (Easterling et al. 2000; Groisman et al. 2005). Patterns of where it rains also have been observed to change, with dry areas becoming drier

(generally throughout the subtropics) and wet areas becoming wetter, especially in the mid to high latitudes (Trenberth 2005). It is also noticed that in most extratropical regions that an increase in precipitation total is associated with increase in intense precipitation (Karl et al. 1995; Karl and Knight 1998; Groisman et al. 2005). "Intense drying and longer drought have been observed over wider areas since 1970s, particularly in the tropics and subtropics" (IPCC 2007)

Over the Mediterranean region, precipitation trends are mixed. The central part represented by the Italian stations showed significant positive trends in intense rainfall and greater amounts of precipitation (Kostopoulo and Jones 2005). In contrast, the eastern parts have shown general negative trends in all precipitations indices (Paz et al.1998; Kadioglu et al.1999; Kostopoulo and Jones 2005; Oikonomou et al. 2008). For example, Oikonomou et al. (2008) studied future changes in the occurrence of extreme precipitation events in eastern Mediterranean. They found a general tendency for drier eastern Mediterranean with a reduction in rainfall intensity. Eastern Mediterranean region is going into drier conditions and would become significantly dryer under future climate scenario (IPCC 2007).

In Jordan, most studies on precipitation have focused on trends in total, daily, monthly and annual values. Emily (2009), in a study of the impact of climate change on daily precipitation statistics in Jordan and Israel, concluded that the region will get significantly drier at the peak of rainy season, reflecting a reduction in both the frequency and duration of rainy events. Decreasing trend, but statistically non significant, in average annual rainfall is detected in most rainfall stations in Jordan (Freiwan and Kadioglu 2007). Also, statistically non significant decreasing trend in average daily rainfall has been observed in precipitation analysis in Jordan since 1970–2006 (Hazaymeh 2009). Analysis of rainfall in Amman city over fifty years period shows a decreasing trend (–0.4mm/year), but with no statistical significance (Ghanem 2010). Trend in maximum and intense precipitation in Jordan has not been studied in the past, although it may draw attention to any possible climate change in the region. Therefore, this paper highlighst the trends in maximum and intense (above 75th and 90th percentiles) daily rainfall as an indicator for climate change at a semi–arid rainfall station in Amman, Jordan.

2. Study site: Amman Airport Meteorological Station

Trends analysis of maximum and extreme events requires long–term daily data. Amman Airport Meteorological Station (AAMS) was selected because it has the longest (83 years), continuous, and complete record of daily rainfall. It represents the longest record of daily rainfall data in Jordan and the data are of good quality, because of good monitoring and maintenance on this station as it is located in a very sensitive facility like airport. The rain gage located in the eastern side of Amman (Lat. 31.98 N, Lon. 35.98E) at an elevation of 780m above sea level (Fig. 1) . The long–term (1923–2006) mean annual rainfall at AAMS amounts to 270mm with maximum of 547.7mm and minimum of 110.5mm. From a climatological point of view, AAMS represents a transition climate between sub–humid climate to the west (western part of Amman with average rainfall of about 500mm) and the arid climate to the eastern parts where precipitation decrease gradually to less than 50mm in Azraq area.

3. Data and methodology

The original data consists of daily rainfall data covering the period Jan 1923 through Dec 2006. However, for a more accurate analysis the data are transformed into rainy years scale. It is assumed that the rainy year start by the first of September and ends by the 31st of May next year.

For instance, the first rainy year in our data covers the period Sept 1, 1923 to May 31, 1924. From a seasonal point of view we only focus on three seasons, namely Fall (Sept to Nov), Winter (Dec to Feb) and Spring (March to May). The overall number of rainy days for the whole period was 4014 with percentages of nearly 14.9, 59.5, 26.4 and 0.2 for the fall, winter, spring and summer seasons, respectively. The rainfall during summer is rare and usually does not affect the yearly rainfall.

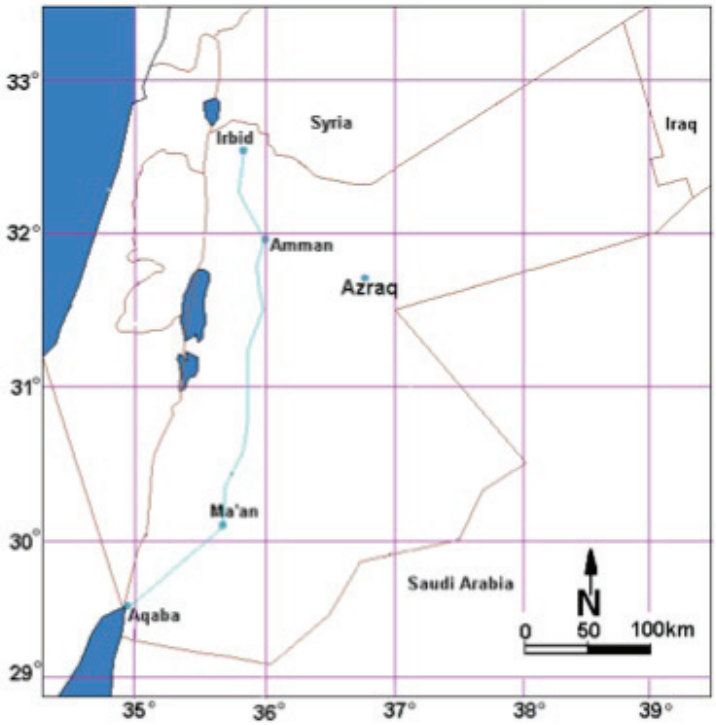

Figure. 1. Location map of Jordan.

In this study, we used time series analysis to investigate the trends in annual rainfall sum, maximum annual daily rainfall and trends in extreme events, namely events with rainfall above 75th and 90th percentiles. We used two approaches to test the trends, the T−test via regression analysis and the Mann-Kendall test.

3.1. Linear trend model

Given a time series $X_1, X_2, \ldots, X_n$, the linear trend model is given by:

$$X_t = \beta_0 + \beta_1 t + \varepsilon_t \quad , t = 1, \ldots, n$$

whereand are the intercept and slope parameters, respectively, t is the time index and {}are random errors assumed independent and normally distributed with mean zero and constant variance . This model is usually fitted using ordinary simple linear regression approach. The standard statistical packages including Excel can be used to obtain such fitted equation. Usually, such packages provide ANOVA table of regression and p−values for both the intercept and slope parameters. The p−value of the slope is usually used to carry out a two−sided test for significant trend in the time series. This test is a parametric statistical test that is based on the t-distribution and requires several assumptions mentioned above. This test is also sensitive for the presence of outliers.

3.2. Mann-Kendall trend test

The Mann-Kendall (MK) test is a very popular test of trend especially in climatology and related fields. It is a non–parametric test which only assumes that the observations are independent. Given a time series $X_1, X_2, \ldots, X_n$ then the test is carried out as follows:

Let S be the number of occurrences of $X_i < X_j$ for $i < j$ in the given time series. Then the statistic

$$u = \left(\frac{4S}{n(n-1)}\right) - 1$$

is asymptotically normally distributed with mean zero and standard deviation

$$\sigma(u) = \sqrt{\frac{2n(n+5)}{9n(n-1)}}$$

Thus, the test–statistic of the MK–test is $Z^* = u/s(u)$ which has asymptotically a standard normal distribution. Therefore, a two–sided test for the presence of trend in a time series is considered significant at significance level a if $|Z^*| > Z_{\alpha/2}$. We can also apply this test for investigating a one-sided trend, i.e. upward or downward. For instance, for testing the presence of an upward trend in a time series the test is considered significant if $Z^* > Z_\alpha$.

As the MK–test it is based on the ranks of data it is more robust for the presence of outliers than other tests including the T–test. If the assumptions of the T–test are satisfied and no outliers are detected in data, then the T–test is usually more powerful than the MK–test. Besides, if the MK–test indicates a significant trend then usually the linear trend model above is fitted to obtain an estimate of this trend. Onoz and Bayazit (2003) made a comparison between the MK–test and the T–test through simulation and investigated the ability of detecting trends in stream–flow data in various regions of Turkey.

3.3. Change-Point analysis

Firstly, for detecting change points we search for the optimal breakpoints in the time series so that the fitted linear trend models change before and after those breakpoints. Then the Chow's average F-test is applied to investigate a significant change at those breakpoints.

In our study we have used the R computing language (R Development Core Team 2010) along the package "strucchange" for detecting the optimal breakpoints and then testing for change at those points. More details about this package are found in Zeileis et al. (2002).

3.4. Extreme events

In our study we focus on extreme events among maximum daily rainfall data. Here, we adopt a simple and common method in climatology for the definition of such events using percentiles. Using both the 75th and 90th percentiles for all data, any data value that exceeds those percentiles is considered an extreme value. Doubtless, based on the 75th percentile the number of "extreme events" is larger than that based on the 90th percentile. This approach is considered, for example, by Tolika et al. (2007).

4. Results

Total annual rainfall as well as the number of rainy days for AAMS from 1923 to 2006 show slight decreasing linear trends. The T–test of regression gave p-values of the two time series of 0.364 and 0.487, respectively, which are statistically non significant. Similarly, the p-values of the M-K test were 0.079 and 0.285, respectively, which also indicate that the decrease is statistically non significant.

4.1. Maximum daily rainfall trends

The average maximum daily rainfall at AAMS for 83 years was 40 mm (median 38mm) with maximum of 80mm and standard deviation of 14.7.

There is an obvious linear decreasing trend in the annual maximum daily rainfall (Fig. 2) with a fitted linear trend of *Max. = 47.34 - 0.17 t*. The estimated slope of –0.17mm/year makes a decrease of nearly 2mm per decade. The decreasing trend is found statistically significant via the T–test (p–value=0.008) and the MK–test (p–value=0.009).

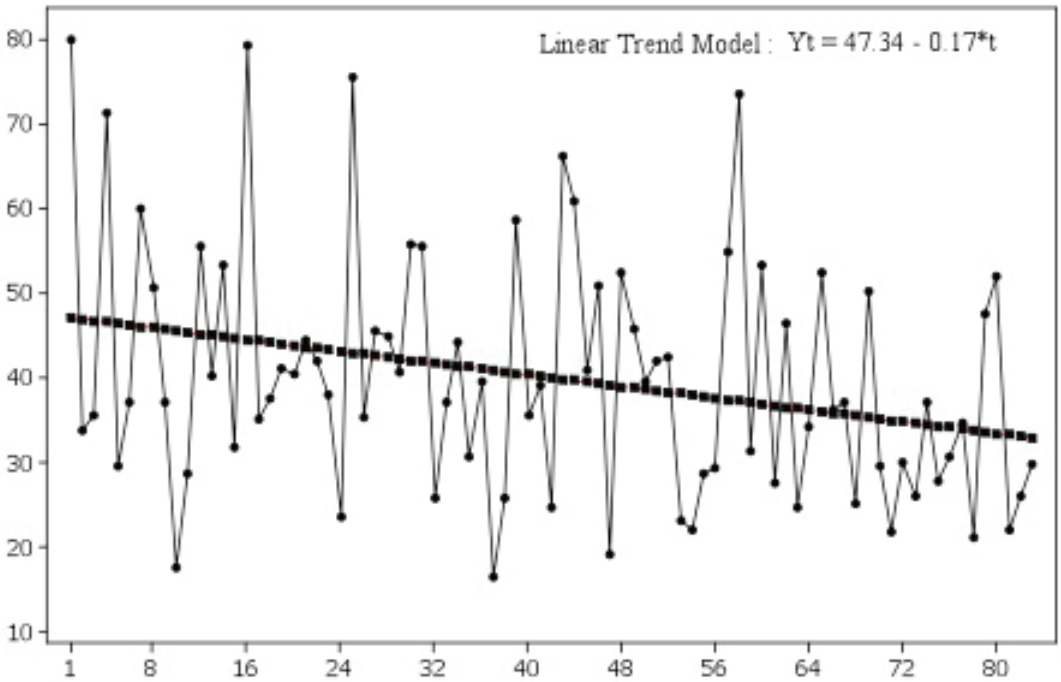

Figure 2. The time series plot of the maximum daily rainfalls for AAMS along the fitted linear trend.

Also, we have investigated if there is any possible change points in the trend of maximum daily rainfalls. Based on the Chow's F-test, it is found that a significant change (p-value = 0.01) occurs in the rainy–year index 60 which is equivalent to year 1982/1983. Fig.3, shows the fitted linear trend models of the maximum daily rainfalls before and after the detected place of change. It is found that the slope of the trend equation before 1982/1983 is -0.098 whereas it becomes -0.223 after this year.

The seasonal distribution of maximum daily rainfalls is not surprising. It is found that 71% of the events occur in winter, 19.2 % in spring and 9.6% during fall season. Also, on a monthly basis, it is found that 31% events fall in January while the least percentage was in October (1%).

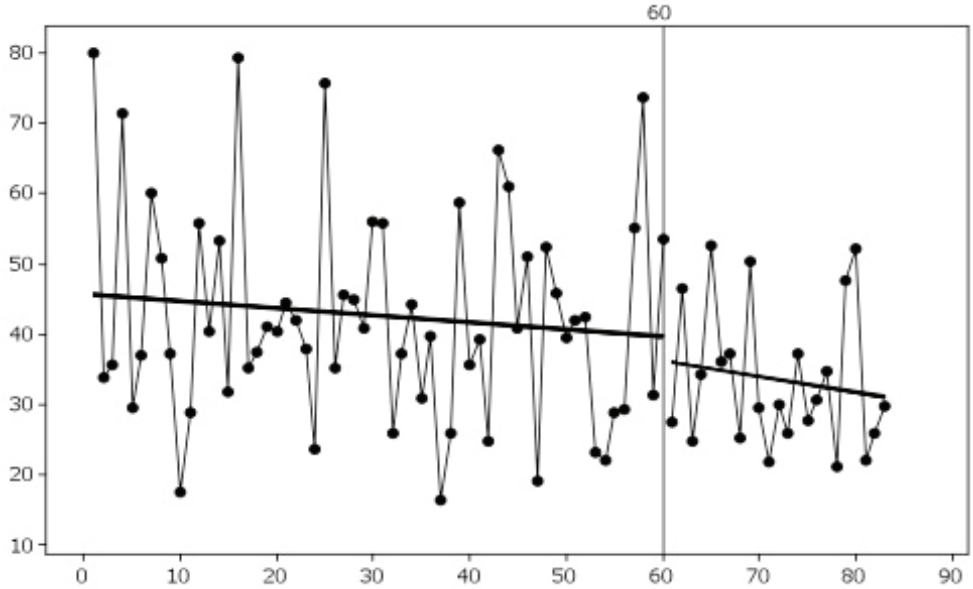

Figure 3. Linear-trend change of maximum daily rainfalls before and after rainy-year index 60 (82/1983).

Finally, we investigated the linear relationship between annual maximum daily rainfall in one side and other annual figures such as the annual sum, number of rainy days and length of the rainy year in the other side. Significant correlations were detected between maximum and annual sum as well as between maximum and number of rainy days with correlation coefficients of 0.55 and 0.25, respectively.

4.2. Extreme events of maximum daily rainfall

4.2.1. Annual daily maximum above 75th and 90th percentiles

Extreme annual daily rainfall events which are defined in this study to be events with daily rainfall intensity above 75th and 90th percentiles among the maximum were also tested in this study (Fig.4). The equivalent amounts of rainfall for 75th and 90th percentiles are 50.3 mm and 58.8mm respectively. Frequency of events with maximum that was within the highest 25%, i.e. above the 75th percentile, shows a decreasing rate with time. Only one single such event occurred during the last 17 years (Fig. 4a). In other words, the width of time intervals between such successive events is increasing with time. A similar behavior was observed of maximum rainfall above 90th percentile (Fig. 4b). Approximately, out of 8 such events in the whole period, only one event occurred during the last 40 years.

4.2.2. Trends in daily rainfall with intensity exceeding 30mm

We also tried to examine extreme-events based on the daily rainfalls for the whole time series with intensity above 30mm. For this time series, the fitted linear trend is shown in Figure 5. The regression T–test does not show a significant trend (p–value = 0.052) whereas the MK–test

verified a significant downward trend with p-value 0.0057. As the T−test is two sided and the MK−test is one sided, we believe that there is no contradiction between both results and the result of MK−test show a highly significant decreasing trend.

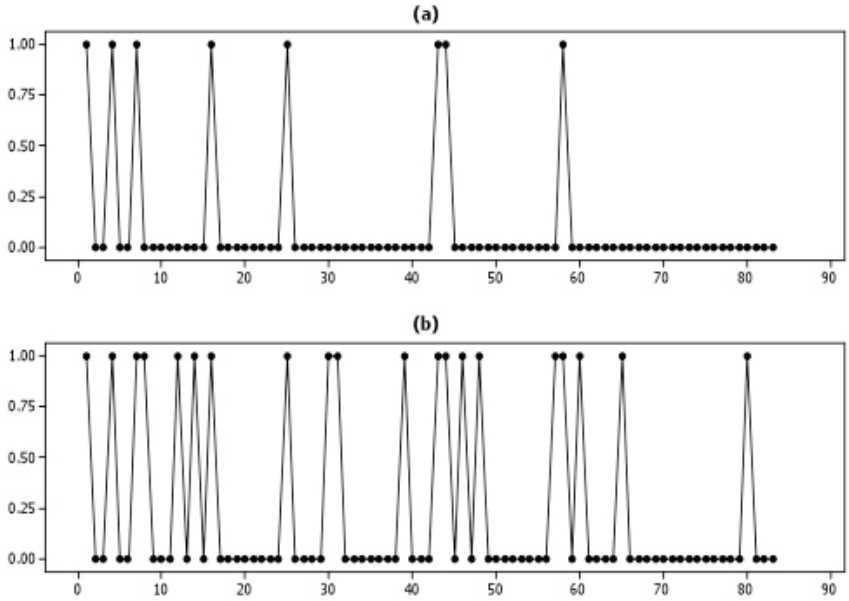

Figure 4. Extreme events of maximum daily rainfalls. (a) Above the 75th percentile, (b) Above the 90th percentile.

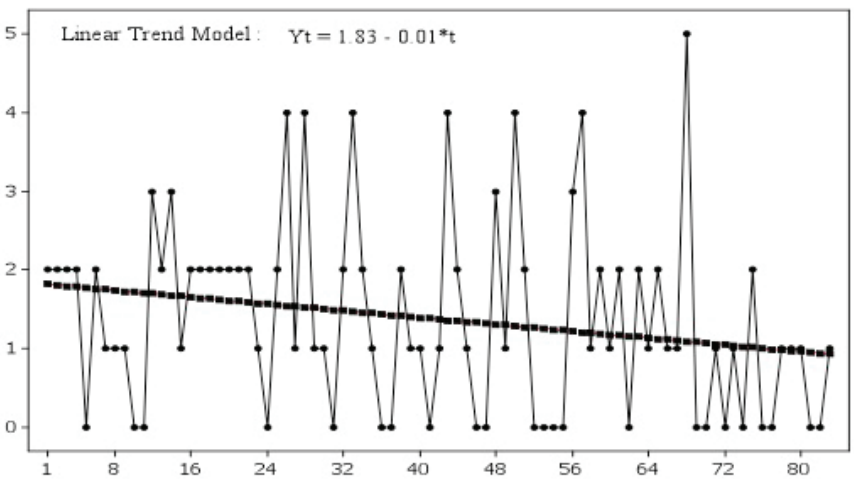

Figure 5. The fitted linear-trend of number of rainy days per rainy-year above 30mm.

This result agrees with the results above regarding detected decreasing maximum events above 75th and 90th percentiles. Both results are also related to the observed significant decreasing trend in the maximum daily rainfall.

5. Discussion

Changes in the character of precipitation on local and regional levels depend greatly on atmospheric circulations and some of these observed circulation changes are associated with climate change (Trenberth 2005; Emily 2009; Evans 2009).

The decrease in heavy precipitation at AAMS is found to be correlated with general decrease in the total annual rainfall (correlation coefficient = 0.55) . However, it is found that the decreasing trend in annual total is statistically non significant whereas the decrease in maximum annually daily rainfall was statistically significant. This can be explained by the fact that the magnitude of the maximum events has declined significantly while low intensity rainfall events have increased. The decrease in annual daily maximum precipitation is also associated with decrease in the extreme events that are above 75th and 90th percentiles.

Along the significant decreasing trend in the maximum daily rainfall, a change point in the trend is detected in the early 1980's. The rate of decrease in the trend has more than doubled after this change point. A general trend of decrease is also observed in the daily rainfall events with intensity above 30mm/day. This also, confirms that there is decreasing trend in the heavy rainfall at AAMS.

The trend of decrease in total annual rainfall in general and of heavy rainfall in particular could be related to weakening of Mediterranean storm tracks which is driven by possible pole-ward shift of subtropical high pressure system (Trenberth 2005; Bengtsson and Hodges 2006; Emily 2009). Changes in intense precipitation are highly pronounced and this could be linked to climate change driven by greenhouse gasses.

6. Conclusion

Statistical analysis of 83-years of daily precipitation record of a semi–arid meteorological station located in eastern Amman was performed in this study. Regression analysis and Mann-Kendal test were used to investigate the trends. A decreasing trend in annual precipitation is detected; however, this trend is not statistically significant. Whereas significant decreasing trend was observed in heavy precipitation including precipitation intensity greater than 30mm /day, precipitation above 75th and 90th percentiles. A break point of change in the trend in heavy rainfall events was detected around the year 1982/1983. The change in heavy precipitation may be linked to a reduction in the strength of the Mediterranean storm tracks. This climate change driven by greenhouse gases is one possible reason behind the change in the trend of intense precipitation.

However, the results only from one meteorological station are not enough to conclude that there is decreasing trend in heavy precipitation but the results are consistent with general trends in the region. Further research should be carried out in similar semi–arid stations in the region including meta-analysis of precipitation of such stations along with other climatic indices. A major difficulty in the course of such studies, especially in our region, is the availability of realistic, reliable and sufficiently long time records of data.

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3. Integrating meteorological and MODIS land surface temperature data for large-scale moisture availability assessment in the Loess Plateau of China

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Abstract

Droughts have become widespread in the Northern Hemisphere, including in China, where they have affected farmland resources on the Loess Plateau; the potential use of these resources is substantially limited by the availability of water. Given this background, we proposed a new index, the Normalized Day-Night Surface Temperature Index (NTDI), to estimate moisture availability (ma; defined as the ratio of actual to reference evapotranspiration). The NTDI is defined as the ratio of the difference between the maximum daytime surface temperature and the minimum nighttime surface temperature, to the difference between the maximum and minimum surface temperatures estimated from meteorological data by applying energy balance equations. To calculate the index, we used data of 20 clear-sky meteorological observations made during the 2005-growing season at a natural grassland station in the Liudaogou River basin on the Loess Plateau. The one-point-based NTDI showed a significant inverse exponential correlation with ma ($R2 = 0.97$, $p < 0.001$). This result encourages us to examine the index capability to monitor the moisture availability on the regional scale; we combined the one-point but detailed meteorological data (including radiation components) and spatial remote sensing (MODIS) data of land surface temperature (LST). The NTDI showed a significant inverse exponential correlation with ma ($R2 = 0.91$, $p < 0.001$) and reveals a pattern similar to those for the NDVI and land use classification. However, the NTDI has an advantage over the NDVI in distinguishing bare ground and rain fed farmland (with almost the same NDVI values) due to its higher sensitivity to surface wetness. These results strongly suggest that the NTDI based on the MODIS data will provide a promising tool for a regional-scale drought monitoring.

1. Introduction

In the current decade, large-scale intensive droughts have been observed in several countries (Kogan 2000). The Loess Plateau in the northwest of China is subjected to drought that occurs more than once a year .The crop production in this area is limited by the availability of water and is severely affected during drought (Shaowu et al. 2000).

Drought can be obviously be avoided if land utilization can adapt to low soil water availability by reducing the demand on water when it is scarce or increasing the efficiency of water use. The quantitative estimation and prediction of drought phenomena has been an important issue to policy makers and the science community (Jupp et al. 1998). In the past, conventional drought monitoring approaches based on climatic and meteorological observations were only representative of local scale. Recently developed methods are typically based on satellite derived vegetation indices (VIs), land surface temperature (LST) based methods and empirical

methods using a certain combination of LST from thermal band data versus VIs from visible and near infrared data. These aforementioned methods best serve as an after-effect indicator of a drought since, there is a time lag between the occurrence of a drought and NDVI changes. So these methods may be outdated when the focus must be on the real time monitoring of drought conditions (Ghulam et al. 2007).

Plant water stress is often preceded by insufficient soil moisture; thus, an understanding of spatio-temporal vegetated surface moisture dynamics is very useful for monitoring agricultural drought (McVicar and Jupp 1998). The thermal inertia method is commonly used in soil moisture research (Pratt et al. 1978; Pratt and Ellyet 1979; Xue and Cracknell 1995). However, the thermal inertia of soil cannot be measured remotely; instead, it is inferred from the diurnal surface temperature range, especially from the difference between daytime and nighttime surface temperatures (Price 1982). We therefore took up the study to explore the potential of the diurnal surface temperature difference to provide a simple and real-time drought monitoring method, as there has been no attempt to apply the diurnal surface temperature difference to the measurements of plant water stress. Moreover, integration of both ground and satellite data would provide spatial assessment of dryness conditions that would greatly improve the resolution and certainty of drought monitoring on large scale.

2. Data

2.1. Study area

In most regions of the Loess Plateau of China, the average annual rainfall ranges from 300 mm in the northwest to 650 mm in the southeast, but the relevant mean annual evaporation varies from 623.8 mm to 1254.0 mm (Wang et al. 2001). This climatic environment of low rainfall and high evaporation suggested that drought might easily take place in the Loess Plateau (Li and Shao 2001; Yang and Tian, 2004; Chen et al. 2005), and might directly result in a condition where the available moisture is at or below a point where harm is caused to vegetation. (Fig.1).

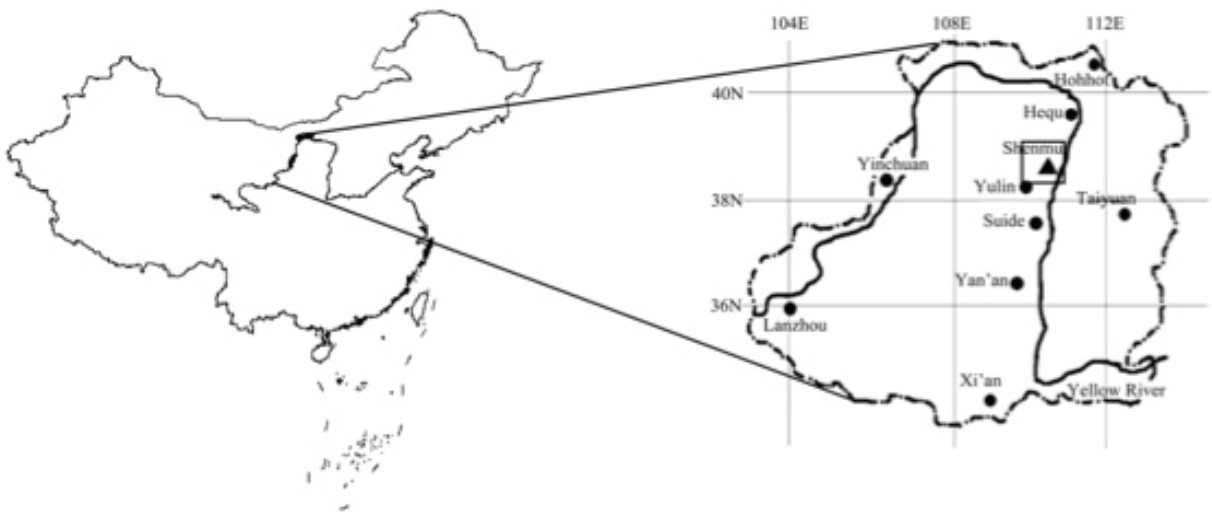

Figure 1. Location maps of the Loess Plateau and of the experimental site at Shenmu (triangle). The NTDI spatial targeted area (square).

2.2. Ground measurements

Data was collected from an experimental station located in the Liudaogou River basin, Shenmu District, Shaanxi Province, Loess Plateau China (lat 38o 47′, long 110o 21′), with 1224 m altitude (Fig.1). Meteorological data was recorded for the growing season of the year 2005 May to the beginning of October (DOY 121-273). The meteorological data include air temperature and humidity (instrument height 150 cm); wind speed (instrument height 220 cm); precipitation; solar radiation, reflected solar radiation, downward long wave radiation, and upward long wave radiation (instrument height 175 cm). Soil water content was measured using Delta-T Theta Probe Soil Moisture Sensor ML2X; depths 6, 10, 18, 26, 34, 42, 50, 58, 66, and 100 cm. These data were recorded every minute and finally averaged for each hour.

2.3. MODIS products

NASA's Terra/Aquao MODIS sensors have 36 channels and provide many environmental and geophysical parameters. Of the many products MODIS provides the land surface temperature (MOD 11A1of Terra and MYD11A2 of Aqua) in a daily 1 km spatial resolution in both daytime and nighttime periods. The daytime and nighttime MODIS land surface temperatures (LST) of 2005 growing season with 1×1km spatial resolution (DOY, 123,126,131,141,144,150,152, 153,157,162,166,and 237) were used in this study. Over 12 cloud-free LSTs products images during the May to October growing season (DOY 121-273) were used to pick the diurnal surface temperature of Shenmu experimental station in order to define NTDI based on combination of LST and ground-based meteorological data.

3. Methods

3.1. NTDI index theory

The difference between daytime and nighttime surface temperatures is a function of thermal inertia and is controlled by the amount of water in the environment (McVicar and Jupp 1998). In other words, in a wet environment, thermal inertia is high and the diurnal surface temperature range is small, whereas the reverse is true in a dry environment. (McVicar and Jupp 1998; Pratt and Ellyett, 1979). Stomata of stressed plants are closed to minimize water loss by transpiration, which results in a decreased latent heat flux. At the same time, due to the requirement that the energy flux must be kept in balance, there is an increase in the sensible heat flux that may result in increased leaf temperatures and, finally, result in high LST (Mcvicar and Jupp 1998). We therefore, defined the Normalized Day–Night Surface Temperature Difference Index as follows:

$$NTDI = \frac{T_{s(day)} - T_{s(night)}}{T_{ssim(day)} - T_{ssim(night)}} \qquad (1)$$

where $T_{s(day)}$ and $T_{s(night)}$ were the observed radiometric maximum and minimum surface temperatures in the daytime, and nighttime, respectively. $T_{ssim\ (day)}$ and $T_{ssim\ (night)}$ are the daytime maximum and nighttime minimum surface temperatures when the ET=0, for a reference crop estimated by using energy balance equations and meteorological data. If the measured daily range of surface temperature is close to the simulated one, then conditions are dry, otherwise conditions are wet. (Fig.2).

The observed maximum surface temperature in the daytime and the minimum surface temperature in the nighttime can be derived from the long-wave radiation data as follows:

$$T_{s(day\ or\ night)} = \left\{ L^{\uparrow} - (1-\varepsilon)L^{\downarrow})/\varepsilon\sigma) \right\}^{0.25} \qquad (2)$$

where $L^{\uparrow}$ is the upward long-wave radiation (Wm^{-2}), ε is the surface emissivity, $L^{\downarrow}$ is the downward long-wave radiation (Wm^{-2}), and σ is the Stefan-Boltzmann constant (5.67 ´ 10^{-8} Wm^{-2} K^{-4}). Surface emissivity, was set to 0.98 in this study.

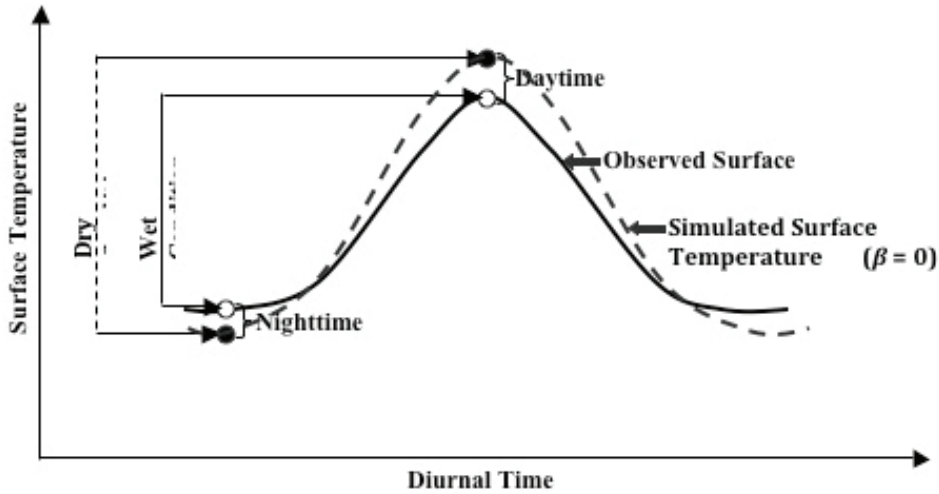

Figure 2. Conceptual model of the NTDI for estimating moisture availability. Dashed line shows the dry condition range derived from meteorological variables and land surface heat balance equations (when the ET=0), and the solid line shows the wet condition range resulted from the observed diurnal surface temperature.

In the simulation of daytime and nighttime surface temperatures, we applied the land surface heat balance equations and the observed meteorological data in each calculation. (Fig.3).

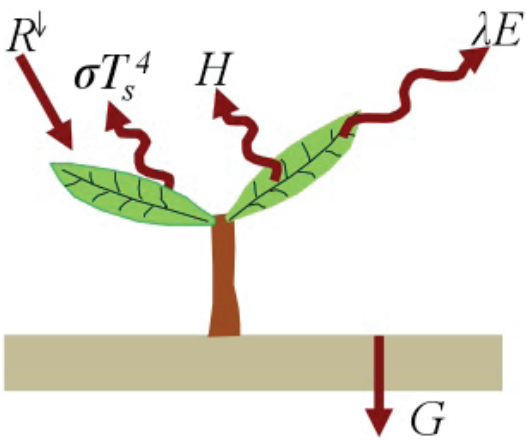

Figure 3. Land surface heat balance components.

The land surface heat balance equations are as follows:

$$R^{\downarrow} - G = \sigma T_s^{\ 4} + H + \lambda E \qquad (3)$$ where

$$R^{\downarrow} = (1 - ref)S^{\downarrow} + L^{\downarrow} \qquad (4)$$

Here, $R^{\downarrow}$ is the total incident radiation (Wm^{-2}), G is the soil heat flux (Wm^{-2}), H is the sensible heat flux (Wm^{-2}), λE is the latent heat flux (Wm^{-2}), *ref* is surface albedo, and $S^{\downarrow}$ is the global solar radiation (Wm^{-2}).

Using bulk transfer equations, the fluxes H and λE can be written as follows:

$$H = c_p \rho C_H U (T_s - T) \quad (5) \text{ and}$$

$$\lambda E = \lambda \rho C_H U \beta \{ q_{sat}(T_s) - q \}, \quad (6)$$

where c_p is the specific heat of air (J kg^{-1} K^{-1}), ρ is the air density (kg m^{-3}), C_H is the bulk transfer coefficient, U is the wind speed at the observation height (m s^{-1}), Ts is the surface temperature (ºC), T is air temperature (ºC), λ is the latent heat of vaporization (J kg^{-1}), and β is the evapotranspiration efficiency (which has a value of one under completely wet conditions and a value of zero under extremely dry conditions). In this study, β was set to zero for both the daytime and nighttime surface temperature simulation to represent the maximum hypothetical estimated diurnal surface temperature range (when the ET=0). q_{sat} (T_s) is the specific humidity at saturation at Ts (kg kg-1), and q is the specific humidity (kg kg^{-1}).

If the vegetation canopy and the land surface are assumed to be a single plane, T_s can be expressed in an alternative form by substitution of Eqs. (5) and (6) into Eq. (3), yielding a nonlinear equation for Ts as follows:

$$R^{\downarrow} - G - \sigma T_s^4 - c_p \rho C_H U (T_s - T) - \lambda \rho C_H \beta \{ q_{sat}(T_s) - q \} = 0 \quad (7)$$

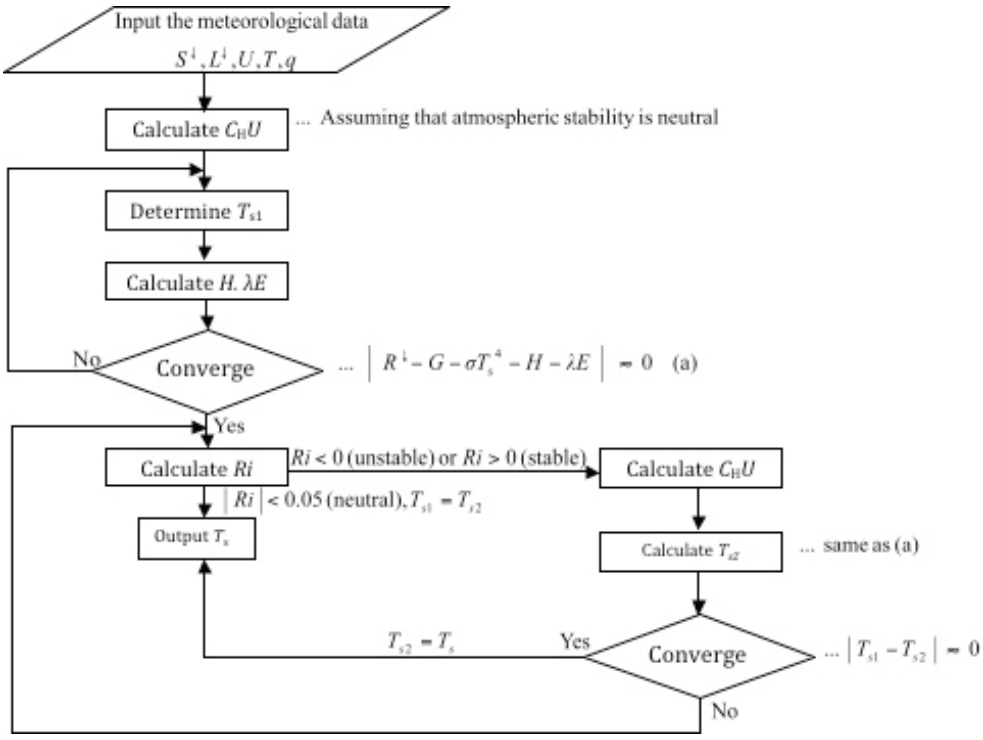

Figure 4. Flowchart for calculating the simulated surface temperature for both daytime and nighttime.

The solution of Eq. (7)for T_s can be found by an iterative process. (Fig.4).

The soil heat flux (G) (Allen et al. 1998) has the form:

$$G = 0.1 * R_n \quad \text{(daytime)} \qquad (8)$$

$$G = 0.5 * R_n \quad \text{(nighttime)} \qquad (9)$$

$$R_n = (1 - ref)S^{\downarrow} + L^{\downarrow} - \sigma T_s^{\,4} \quad \text{where} \qquad (10)$$

Here, Rn is net radiation (Wm^{-2}).

The estimated surface temperature calculation takes into account the atmospheric stability, represented by Richardson number (R_i), and is used as the index to determine the atmospheric stability. The Richardson number is given by:

$$R_i = [g(T_s - T)(z - d)]/TU^2 \qquad (11)$$

where g is the acceleration due to gravity (m s^{-2}), z is the observational height (2 m), d is the zero-plane displacement height (m), which is determined by the following equation

$$d = 2/3H_c \qquad (12)$$

where H_c is the plant height of the reference crop (=0.12m). Calculations considered the neutral conditions ($-0.05 < R_i < 0.05$).

3.2. Calculation of evapotranspiration and moisture availability

Kimura et al. (2005) conducted a comparison between observed ET ($mmday^{-1}$) using the Zero Flux Plane (ZFP) method and estimated using Penman-Monteith method over this observational site in 2004, they parameterized surface resistance r_s in the Penman-Monteith method as a function of soil moisture content. The ZFP is defined as a plane that separates the two zones of upward or downward movement of water in the soil (Arya et al. 1975; Scott 1993) (Fig.5). Accumulated ET for the observation period can be calculated from the change in soil water content above the ZFP. The root mean square error (RMSE) between the observed and estimated values of ET was 0.55 mm day^{-1}. This error was close to the observational error, and the total simulated ET agreed with the observed total for the growing period (Kimura et al. 2005). Such consistency validates the use of the Penman-Monteith equation for estimation of ET in this study. We estimated ET of 2005 growing season following Kimura et al (2005) using the Penman-Monteith method with parameterized surface resistance r_s

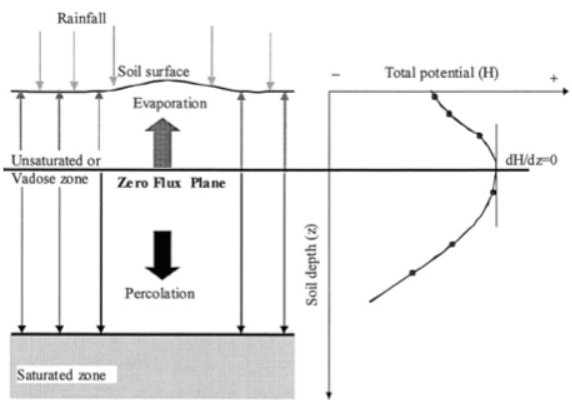

Figure 5. Zero Flux Plane (ZFP) concept (after Khalil et al. 2003).

The Penman-Monteith equation is defined as:

$$\lambda E = \frac{\Delta(R_n - G) + c_p \rho \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_a}{r_s}\right)} \quad (13)$$

where e_s is saturation vapor pressure (hPa), e_a is the actual vapor pressure (hPa), Δ is the slope of the saturation vapor pressure curve (hPa °C^{-1}), γ represents the psychrometric constant (hPa °C^{-1}), and r_s and r_a are the (bulk) surface and aerodynamic resistances respectively (s m^{-1}). r_s is represented as a function of soil water content as follows.

$$r_s = 108439e^{-38.344\theta} \quad (14)$$

where q is the averaged volumetric soil water content from the surface to the bottom of the root zone (34 cm depth) (m^3 m^{-3}). r_a can be represented as follows (Allen et al. 1998):

$$r_a = \frac{\ln\left(\frac{z-d}{z_{om}}\right)\ln\left(\frac{z-d}{z_{oh}}\right)}{K^2 U} \quad (15)$$

where z_{om} is the roughness length governing momentum transfer (m) and z_{oh} designates the roughness length governing transfer of heat and vapor (m). z_{om} and z_{oh} are determined by the following equations (Allen et al. 1998):

$$z_{om} = 0.123H_c \quad (16)$$

where H_c is the averaged crop height from the observational data (= 0.13 m), and

$$z_{oh} = 0.1z_{om} \quad (17)$$

Finally, we defined the moisture availability m_a as follows:

$$m_a = \frac{ET}{ET_0} \quad (18)$$

where ET is the estimated evapotranspiration by the Penman-Monteith equation and ET_0 is the reference crop ET (mm day^{-1}), obtained by the Penman-Monteith equation for a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sm^{-1}, and an albedo of 0.23 (Allen et al. 1998).

4. Results and Discussion

NTDI based on meteorological parameters observed in Shenmu station was plotted against m_a on the grassland on Liudaogou river basin for 2005 growing season. The following equation describes the NTDI and m_a relationships:

$$\text{NTDI} = 11.106 * \exp(-6.323 * m_a) \quad (R^2=0.97,\ P<0.001) \quad (19)$$

Such high correlation between one-point-based NTDI and m_a (Fig 6), suggests regional expansion of NTDI based on combination of land surface temperature (LST) sensed from MODIS and

ground observed meteorological parameters. Some cautious is necessarily needed to validate the sensed surface temperature before direct implying into the NTDI index numerator.

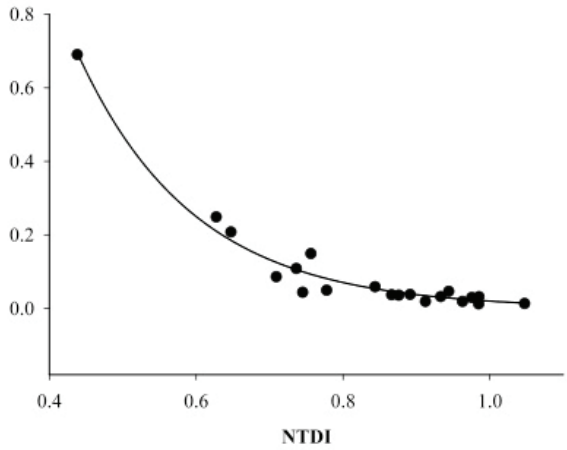

Figure 6. Relationships between the one-point-based NTDI and moisture availability

4.1. Validation of MODIS LST products for the NTDI deriving

Figure. 3a and 3b represent the ground-measured LSTs versus MODIS LSTs. The RMSE were found to be 2.0 oC and 1.41 oC for daytime and nighttime, respectively (Fig.7a, 7b). This level of accuracy agrees with GCOS (2006) recommended that meteorological, hydrological, and agricultural research communities require an accuracy of 0.5 – 2 oC for LST retrieved from satellite observations at 1–10 km spatial resolutions. The coefficient of determination of the relation between NTDI derived using MODIS LSTs and ma was as high as R2=0.91, p<0.001.

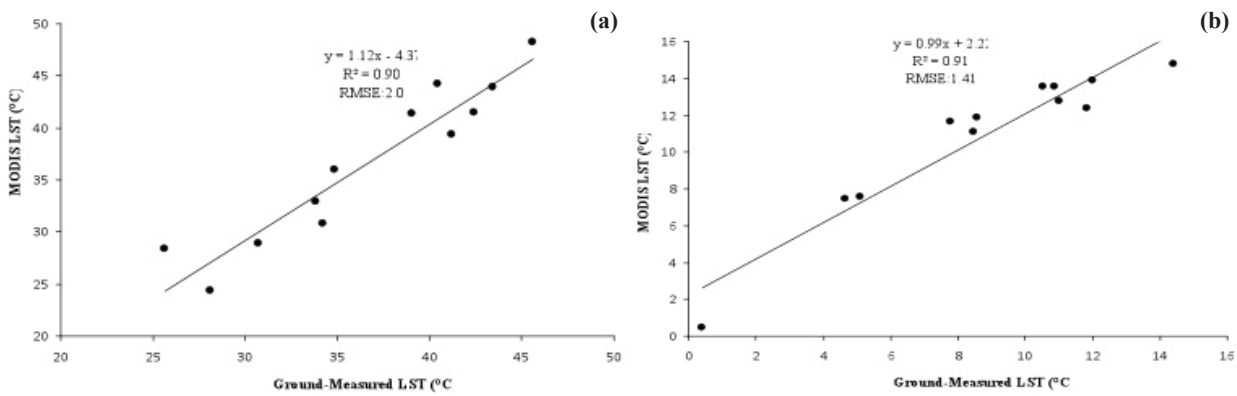

Figure 7. Plots of the Loess Plataeu grassland site (a) ground-measured LSTs versus MODIS LSTs (Daytime) (b) ground-measured LSTs versus MODIS LSTs (nighttime).

4.2. Spatial distribution of NTDI

An area of 100×100km (Fig.1) including our experimental meteorological station was chosen for understanding the NTDI spatial distribution, by our proposed method. In order to assure that the meteorological parameters around our station, the meteorological conditions around the experimental station at Shenmu were examined. The difference of daily average meteorological data of Yulin station (38o 23′ N, 109o 7′ E, 1058 m altitude), Suide station (37o 5′ N, 110o 22′

E, 930 m altitude) and Hequ station (39o 38′ N, 111o 15′ E, 862m altitude) were compared. These meteorological data include daily averaged temperature, vapor pressure, and wind speed. The temperature difference is under the estimated error of radiometric surface temperature. It is assumed that these differences will be negated by normalization in the NTDI calculation (Kimura 2007). Vapor pressure and wind speed difference are almost close to the observational error. Solar radiation and downward long wave radiation assumed to be constant; hence days selected for NTDI calculation were free clouds satellite images.

Figure. 8 illustrates the NTDI map with 1×1 km spatial resolution of DOY= 153. Figure 6 shows that the highest values of NTDI spatially correspond to the sand and bare ground, whereas the lower ones correspond to irrigated land and mixed of water and paddy fields land use.

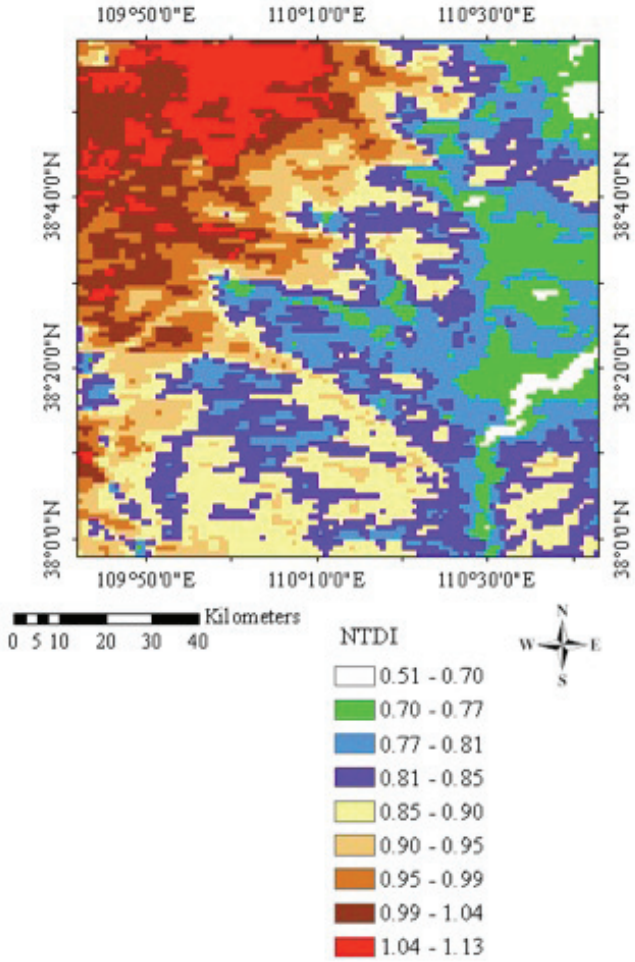

Figure 8. NTDI map of DOY 153 produced using MODIS LSTs products on 1 km spatial resolution.

NDVI image of DOY=145 with 250×250 m spatial resolution is shown in Figure 9. Obviously, the dense vegetation values occurred in the NE where the rain fed cultivation concentrated, besides the farming activities around the rivers and wadis as can be interpreted from the NDVI image. Sand soils and water bodies showed negative NDVI values, which mean non-existence of vegetation.

Figure 10 illustrates land classification map of DOY=154 with spatial resolution of 30 m. 6 classes resulted; these are water including irrigated paddies, sand, irrigated land, natural vegetation, rainfed cultivations, and bare ground.

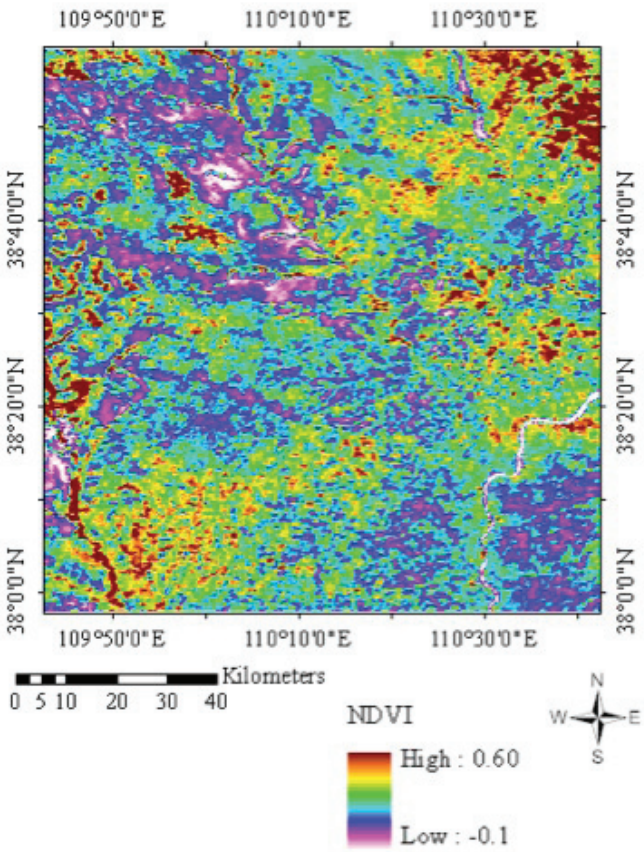

Figure 9. Spatial distribution of NDVI by MODIS product mod13 for the DOY 148 with 250 m spatial resolution.

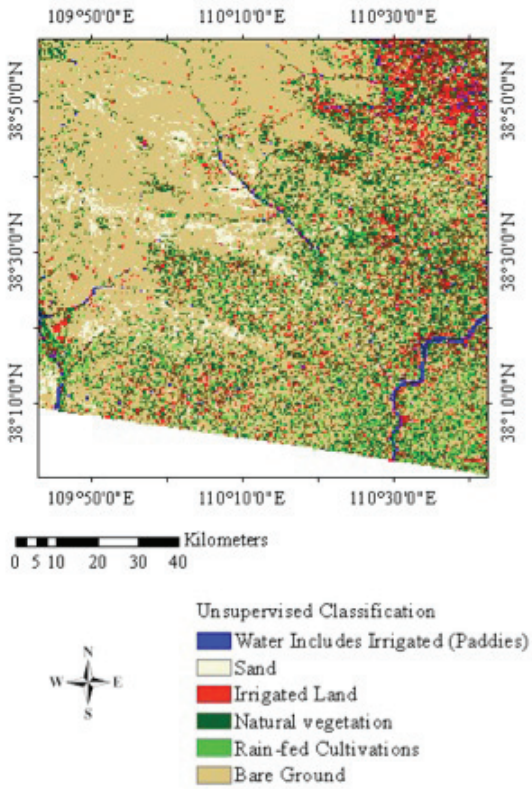

Figure 10. LANDSAT-TM unsupervised land classification map for the DOY 154.

Figure.11 shows the mean and standard deviation of the NTDI and NDVI for different land use. The land use classes based on NTDI can be ranked from wet to dry as water with paddy fields, irrigated farms, natural vegetation, rain fed cultivation, bare ground, and lastly sand. These results agree with those obtained by Kimura et al. (2007), who estimated the ET for different land-use in Liudaogou Basin, Loess Plateau during the period from 5 June to 31 August 2004 using a remote-sensing technique. They found that the ET from grassland and shrub was greater than that from rain-fed farmland. On NDVI basis, the classes arranged from high to low NDVI were irrigated farms, natural vegetation, bare ground, rain fed cultivation, water and paddy fields, and lastly the sand. There was a slight difference between the bare ground and rain-fed cultivation, although the area received 29.3 mm of rainfall few days before DOY 153. This result indicates the sensitivity of NTDI to variation in the available soil moisture more than NDVI. These findings agree with Goetz (1997) who mentioned that there is a lag time in vegetation response to site conditions.

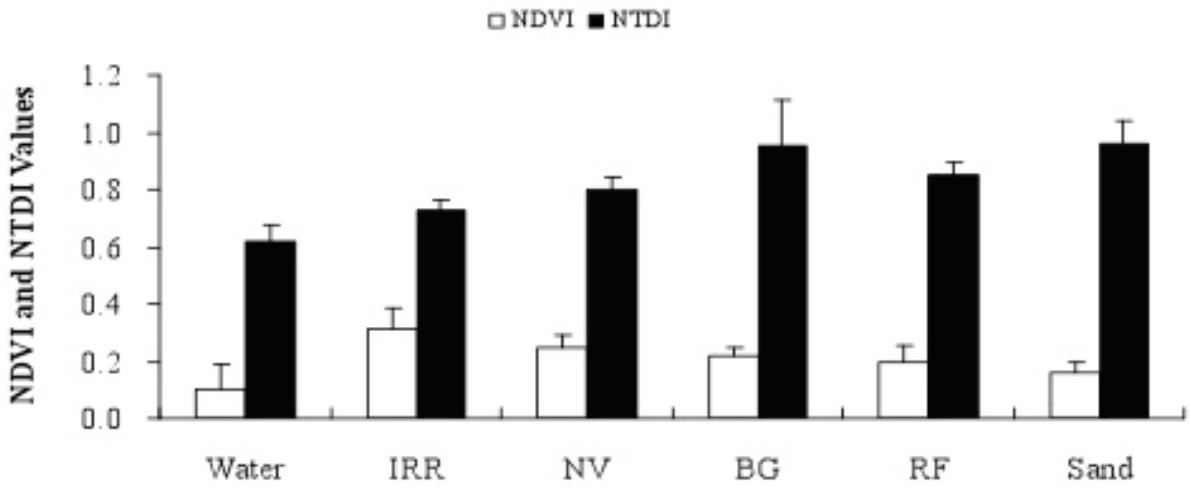

Figure 11. Mean and standard deviation values of NDVI and NTDI.

5. Conclusion

A NTDI based on remotely sensed surface temperature and meteorological data has been proposed and validated for large scale in the Loess Plateau of China. The index is an application to a previous formulation using only ground-based meteorological data. Based on the MODIS LST data, the moisture availability (ma) was quantitatively well defined over grassland in the Loess Plateau, China ($R2=0.912$, $P<0.001$).

NTDI map was compared to NDVI image and land use map. Similar spatial patterns between these maps were found, despite the difference in spatial resolutions. A complete validation of the NTDI index was not feasible in the current context, but the consistency of the NTDI spatial distribution with land use map was promising. The comparison with NDVI demonstrates the strength of the NTDI method in the potential of using the index as indicator of surface wetness. The results of the preliminary analysis showed in Fig.7 suggest that the NTDI methodology is robust for application over large areas, and that the NTDI is related to surface cover types and sensitive to site conditions at least in semi-arid Loess Plateau-China. However, there are some limitations to wide use of NTDI; some meteorological data required for NTDI such as solar radiation are not available at many meteorological stations. Additional work using meteorological parameters from the reanalysis data is required to test the robustness of the method over larger areas.

6. Future work

To achive more validation of NTDI in different environments, field experiments using meteorological stations with detailed parameters are recommended for the future work and at the same time it can offer the possibility of the remote sensing results. Being low cost, free of charge and their temporal coverage, the moderate resolution sensors like MODIS will prove of paramount importance in estimation and monitoring of the surface wetness status and it is considered as the best choice for NTDI index. Further work should consider using these data for regional-scale studies. The use of advance technology tools such as satellite remote sensing and Geographic Information System can greatly help improve real time monitoring of agricultural drought, this can be done by deriving different maps of NTDI, crop types, and crop coefficient and correlating to agricultural drought indices maps. The integration of spatial and temporal information in GIS will help to evaluate the performance of the agricultural system over several years. A comprehensive analysis of aforementioned data has the potential for improving real-time drought monitoring system, thereby providing valuable information for decision-makers to be used in assessing exceptional conditions related to drought.

Acknowledgements: This research was supported by the Japan Society of the promotion of science (JSPS) Core University Program and KAKENHI (20405038) of the Ministry of Education, Culture, Sports, Science, and Technology of Japan. We sincerely thank Dr. Masao Moriyama of the Faculty of Engineering, Nagasaki University, for providing MODIS LSTs data.

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Theme 2: Local impact of climate change on the natural resources of water, land and biodiversity & agricultural productivity

1. Ecological and physical response and feedbacks to fires in western North American deserts

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Abstract

Large fires (>2000 ha) have increased in western North American deserts since the mid-1980s, with local and regional impacts on soil erosion, vegetation communities, and winter snowpacks in adjoining mountain regions. The trend of increased fires is expected to continue under climate change projections of higher temperatures, decreased precipitation (particularly spring and summer), and continued spread of invasive annual plants (e.g., *Bromus tectorum*, *B. madritensis*, *Taeniatherum asperum*). However, precipitation events are projected to be more intense. Consequently, in the Great Basin and Mojave Deserts, the combination of increased fire frequency and climate change are likely to enhance establishment of introduced annual grasses over native shrubs. Subsequent annual plant biomass production during wet periods creates large fuel loads resulting in increased fire frequency when dry conditions return, a contributing factor in the 2005 Southern Nevada Complex fires. Another feedback is that introduced annual grasses can quickly colonize burned areas with little or no recruitment of native shrubs. This process has occurred in many of the blackbrush (*Coleogyne ramosissima*) dominated shrublands that have burned in eastern Nevada since 2000. After these sites become dominated by introduced annual grasses, short duration, high intensity precipitation events may cause greater runoff and soil erosion. Fire studies are underway in both the Great Basin and the northern Mojave Desert to examine linkages between fire-included changes in soil structure and post-fire hydraulic and aeolian erosion of soil. During the prescribed burn in a sagebrush/juniper community in the Great Basin, fire temperatures (maximum 315 ^{o}C) were insufficient to develop soil hydrophobicity and bulk density actually decreased. However, it is hypothesized that vaporization of soil moisture and combustion of interstitial soil organics reduced particle adhesion. After a low intensity wildfire occurred in a blackbrush community in the northern Mojave Desert, there was deterioration of soil structure as well. Post-fire measurements of potential particle emissions at both sites were one or more orders of magnitude higher after the fire than before, and remain elevated one and two years after the respective fires. However, at both sites, there are exceptions to common regional post-fire feedbacks and responses. At the blackbrush site, *C. ramosissima* recruitment occurred the following spring, while introduced *Bromus* spp. recruitment continues to be extremely low two years post-fire. During the first year post-fire at the sagebrush/juniper site, invasive grasses

had not colonized the site. Understanding these exceptions could help in developing restoration techniques and strategies for limiting destructive post-fire responses.

Introduction

Since the mid-1980s, the frequency, severity, total area burned, and duration of the wildfire season has increased in the western United States (US) (Westerling et al. 2006). This includes dry land regions of western North America where fires were historically rare (Brooks and Pyke 2001). (See Figure 1.) Contributing factors in the Great Basin and other deserts include increased spring and summer temperatures, drought conditions, the spread of invasive annual grasses, and, especially during the twentieth century, accumulated fuel loads due to wildfire suppression (Savage and Swetnam 1990; Neary et al. 1999; Westerling and Swetnam 2003; Westerling et al. 2006). Particularly in the Great Basin, historic fire suppression activities and overgrazing by cattle, sheep and feral horses have led to thick stands of sagebrush (*Artemisia spp*.) at lower elevations, and increasingly dense forests of juniper (*Juniperus* spp.) and pinyon pine (predominantly *Pinus monophylla*) at higher elevations, and the encroachment of pinyon and juniper downslope into sagebrush communities (Pierson et al. 2009). The development of dry fuel conditions in the Great Basin in recent decades has been augmented by winter snowpack declines being among the largest observed in the western US (Mote et al. 2005), resulting in snowpacks being a less reliable reserve of summer moisture for soil and vegetation.

A measure of the magnitude of changing fire regimes is that between 1998 and 2008, an average of nearly 850,000 ha per year burned in the Great Basin, including more than 1 million ha in 2007 (Chambers et al. 2008). In June 2005, as part of the "Southern Nevada Fire Complex," over 500,000 ha of southern Great Basin and northern Mojave Desert vegetation burned in a series of fires started by lightning (National Interagency Fire Coordination Center 2006). In addition, on land managed by the Bureau of Land Management (BLM) in eastern Nevada (southern Great Basin and northern Mojave deserts), more than 40% of blackbrush (*Coleogyne ramosissima*) shrub communities have burned since 2000 (Karen Prentice, BLM, personal communication 2008).

The increase in fires is a response to past land use impacts (introduction of non-native grasses, overgrazing, and fire suppression) that now appears to be exacerbated by climatic change. Increases in the frequency and size of fires in the deserts of western North America are projected to occur under both lower and higher greenhouse gas emission scenarios of the Intergovernmental Panel on Climate Change (Karl and Peterson 2009). In addition, there are both ecologic and physical responses in these dry lands that are expected to reinforce fire cycles, as well as responses that could have important local and regional impacts on ecologic and hydrologic resources. Although fire is becoming a more significant disturbance agent to varying degrees in all the arid and semi-arid regions of western North America, this paper focuses primarily on the Great Basin and Mojave Deserts where the authors have ongoing research on the temporal persistence and mechanisms of post-fire erosion of soil by wind and water.

Background

Fire was historically rare in the deserts of North America. Although native grasses contributed to plant community structure in these deserts, they were generally not dense enough to fill the interspaces between shrubs, resulting in perennial plant covers of generally less than 25% (Humphrey 1974). Exceptions in the Great Basin include plant communities dominated by

single species such as some sagebrush communities and Mojave Desert shrublands dominated by blackbrush where the similar stature of individual shrubs allowed larger fires to occur (Sapsis and Brown 1991). However, even in these cases, fires remain localized, particularly compared to those fires that have occurred since the mid-1980s (Brooks and Esque 2000; MacMahon 2000). In general, fire return intervals have been reduced from 30 to 100 years in the Great Basin (Wright and Bailey 1982) to as short as five years (Whisenant 1990).

Land use that has contributed to changes in historic fire regimes include heavy livestock grazing after settlement of the region by Anglo-Americans, with peak grazing occurring between about 1870 and 1920. Grazing resulted in severe decreases in native grasses and replacement of them by woody shrubs in the Chihuahuan and Sonoran Deserts (Brooks and Pyke 2001). In addition, introduction of what are today some of the most significant invasive grasses, cheatgrass (*Bromus tectorum*) in the Great Basin and red brome (*Bromus madritensis*) in the Mojave Desert, probably occurred inadvertently as seed within supplemental feed provided for cattle (Knapp 1996). Also, the peak period of livestock grazing coincided with the beginning of a policy of human-induced suppression of all fires in the western US. In the Great Basin, this allowed pinyon-juniper woodlands at higher elevations in the Great Basin to move downslope into shrub communities as well as tree and shrub densities within these communities to increase between 10 and 100% depending on location (Miller et al. 2008). In the most severe cases, closed stands of pinyon-juniper forests resulted in the loss of shade intolerant understory plants and their seedbanks. Under these conditions, when fires occur, post-fire soil erosion is enhanced and the soil seedbanks for natural revegetation are lost (Miller et al. 2005).

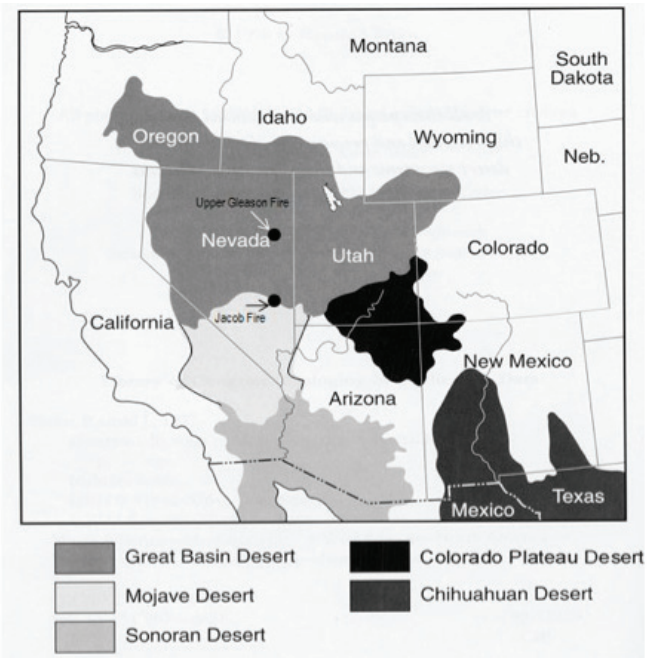

Figure 1. Arid and semi-arid dry lands of western North America, with the locations of study sites discussed in the text. Map adapted from Taylor (1998).

Sites and methods

Increased runoff and soil erosion rates after fires and macroscale factors contributing to it have been frequently documented. Less research has been done on the microscale mechanisms,

although it has been attributed to factors such as development of soil water repellency (e.g., Inbar et al. 1998), alteration of soil organic matter (OM), decreased aggregate stability, and splash erosion from loss of vegetation and plant litter (Debano et al. 1998; Shakesby and Doerr 2006). All or a combination of these can reduce infiltration and increase runoff. Less research has been done on the mechanics of increased aeolian erosion after fire, although Shakesby and Doerr (2006) and Sankey et al. (2009) have both examined changes in soil structure and particle adhesion as contributing factors. The authors are currently examining fire sites in the Great Basin and the Mojave-Great Basin transition zone to better understand linkages between fire-induced changes in soil structure and pore size and distribution, and macroscale water and aeolian erosion of soil.

The 155 ha Upper Gleason Fire in a sagebrush/juniper community conducted in August 2009 was a "controlled" or "prescribed" fire as opposed to a wildfire. Prescribed burning is one technique being used to return a more natural wildfire regime in the Great Basin, particularly to decrease the chances of more catastrophic fires by reducing fuel loads. The site is located in east-central Nevada (39°23'43"N, 115°03'57"W) at an elevation between 2183 and 2397 m. No site-specific precipitation data is available. Annual precipitation (including snow) in Ely, Nevada, 25 km east of the burn, averaged 171 millimeters precipitation between 2003 and 2008, although precipitation at the burn site is probably greater as it is about 300 m higher in elevation. Between November and April, most of the precipitation is as snow. An advantage in examining a controlled burn was the ability to take pre- and post-fire measurements of soil properties at the same locations. The fire was low intensity, with soil temperatures briefly reaching 315°C at 1 cm depth at a sagebrush canopy site; interspace soil temperatures were probably lower. Measurements described below were taken one week before, as well as one week, nine months, and 12 months after the burn (MAB).

The Jacob fire (37°42'17"N, 115°12'41"W), was a lightning-caused fire that burned approximately 200 ha between August 6-8, 2008 in southeastern Nevada in a transition zone between the Great Basin and Mojave Deserts. The fire burned a shrub community dominated by blackbrush and Mormon tea (*Ephedra nevadensis*), a community, as previously discussed, more prone to fires than others in the region, but whose susceptibility to fires has increased because of invasive grasses (Sugihara 2006). The site is at an elevation of 1200-1500m and annual precipitation at nearby Hiko, Nevada between 1999 and 2009 averaged 170mm. Because it was a wildfire, it was not possible to measure soil temperatures during the burn. However, analysis of fuel loads and interpretation of Landsat thermal infrared imagery by the US Geological Survey during the burn suggest it was also a low intensity fire. Measurements described below have been conducted one, three, six, 13, 18, and 24 MAB.

At the Gleason fire, plots were established within the area to be burned and an adjacent control area of native vegetation. Soil hydraulic property measurements collected the week prior to, and one week after the fire included *in situ* saturated hydraulic conductivity (K_s) and air permeability (k_a). Soil samples were collected for bulk density (BD), percent OM, soil moisture, and particle size distribution (PSD). Hydrophobicity was also measured using water drop penetration time (WDPT). At each location, four replicates of K_s, k_a, and WDPT were made in shrub interspace and under shrub canopy microsites. Measurements of K_s were made using a mini-disk tension infiltrometer (MDTI) (Decagon Devices, Pullman, WA) (Caldwell et al. 2008), an array of 8 TIs (4.5 cm diameter) spaced at 50 cm so that interspace and canopy measurements could be collected simultaneously along the same transect. For the MDTI tests, the first tension was set at -6 cm of water for approximately 1 hr or until steady state was reached. Tension was subsequently set to

-3 cm of water and finally to near saturation tension of -0.5 cm of water. Analysis was conducted on the last 300 seconds of steady state data for each tension step. Measurements of k_a were made using a Soil Corer Air Permeameter (SCAP) (Chief et al. 2006) (Iversen et al. 2001). The SCAP was developed to rapidly assess soil k_a in the field, in both unburned and burned soils, and to serve as a possible surrogate measure of K_s (Chief et al. 2008).

At the Jacob Fire, in lieu of examining changes in $\boldsymbol{K_s}$, and $\boldsymbol{k_a}$, a portable rainfall simulator (PRS) was used to determine the runoff and infiltration properties of soils under non-ponded conditions. The PRS consisted of a flat Plexiglas reservoir (61 x 61 cm) for water, with hypodermic needles on the underside (Mutchler and Moldenhauer 1963; Munn and Huntington 1976). Water drops were produced on the needles by providing a constant gravity head, wetting a 3612 cm^2 area of ground directly beneath the rainfall simulator. Rainfall simulations were conducted at rates of approximately 4.17 cm/hr, the maximum intensity during a local 1-hr, 100-yr storm, as per the US National Oceanic and Atmospheric Administration Atlas 14 (www.hdsc.news.noaa.gov) for the location. Runoff volume and sediment transported during the tests were collected in a trough at the downslope footprint of the PRS. Runoff collection was stopped after one hr.

After the initial calibration measurements, the experimental precipitation event was started on the test surface, during which four time measurements were recorded: (1) when initial ponding occurred anywhere on the surface test plot, (2) when initial runoff occurred anywhere on the surface test plot, (3) when runoff occurred in each quadrant of the surface test plot, and (4) when initial runoff reached the collection trough. The time measurements, combined with the rainfall intensity, allow an initial abstraction (I_a) value to be estimated for each ponding and runoff event. A total of six rainfall simulation tests were performed, with two test plot locations selected at each of three sites. At each site, one rainfall simulation test was performed on a shrub mound, and a second test was done in the adjacent interspace. The three sites consisted of a burned ridge, a burned channel area, and an unburned control area.

Once I_a was established for a PRS test, a US Soil Conservation Service Curve Number (CN)—an estimate of precipitation losses--was calculated that relates to the drainage characteristics of a soil (e.g., soil group classification) and antecedent moisture conditions (USDA-SCS 1986). Curve numbers range from 100, which represents a completely impervious surface, to values less than 100 for more permeable surfaces. As at the Upper Gleason site, soil samples were also collected for moisture content, OM, and PSD.

At both sites, potential emissions from wind erosion in burned and control areas were measured using a Portable *In-Situ* Wind ERosion Lab (PI-SWERL™) (Kavouras et al. 2009), a portable wind tunnel in which shear stresses are generated on the soil surface to estimate emissions of suspendable PM_{10} particles (aerodynamic diameter 10 microns or less) at different wind speeds (Etyemezian et al. 2010). Filter samples, collected from the exhaust of the PI-SWERL during measurements, were collected for chemical composition. Replicate measurements were made in burned and control area microsites. For all measurements, a hybrid ramp/step measurement cycle was used that measures the soil response to "gusts" of wind as well as sustained winds. The cycle consisted of 1) a 60 second clean air flush, 2) sharp acceleration to 500 revolutions per minute (RPM), 3) 60 second linear ramp to 2000 RPM, 4) maintain 2000 RPM for 60 seconds, 5) 60 second ramp to 3000 RPM, 6) maintain 3000 RPM for 90 seconds, 7) 60 second ramp to 4000 RPM, 8) maintain 4000 RPM for 90 seconds, and 9) turn off motor and clean air flush for 60 seconds. Lastly, vegetation surveys conducted in the burned and control areas included the density and diversity of shrubs, trees, and grasses as well as their canopy dimensions.

Results and discussion

Particularly at the Upper Gleason Burn, hydraulic and other properties of soils measured one week after the fire is in contrast to typical post-fire measurements 6 to 12 MAB. For example, average BD decreased for both interspace and canopy sites by -16% and -15%, respectively in the burn area. In addition, average K_s at the burned interspace and canopy sites increased by 95% and 4%, while average k_a also increased (20% for interspace and 29% for canopy microsites (Fig. 2) although one-way analysis-of-variance showed that the average K_s in unburned, burned, and control canopy microsites were not significantly different. Furthermore, the Upper Gleason average pre-burn OM content at the canopy microsites was higher compared to interspace sites, and the post-fire average OM content increased slightly for the canopy and interspace microsites (Chief et al. 2010). Similar conditions have been observed after shrublands fires elsewhere in the Great Basin (e.g., Pierson et al. 2008), but with little explanation for them. Although further analysis of the PI-SWERL data is underway, PM_{10} emissivity from the burned area was one to three orders of magnitude higher from the burned than control area one month after the fire, with emissions being highest off of burned canopy sites. After 12 months, emissivity remained similarly elevated.

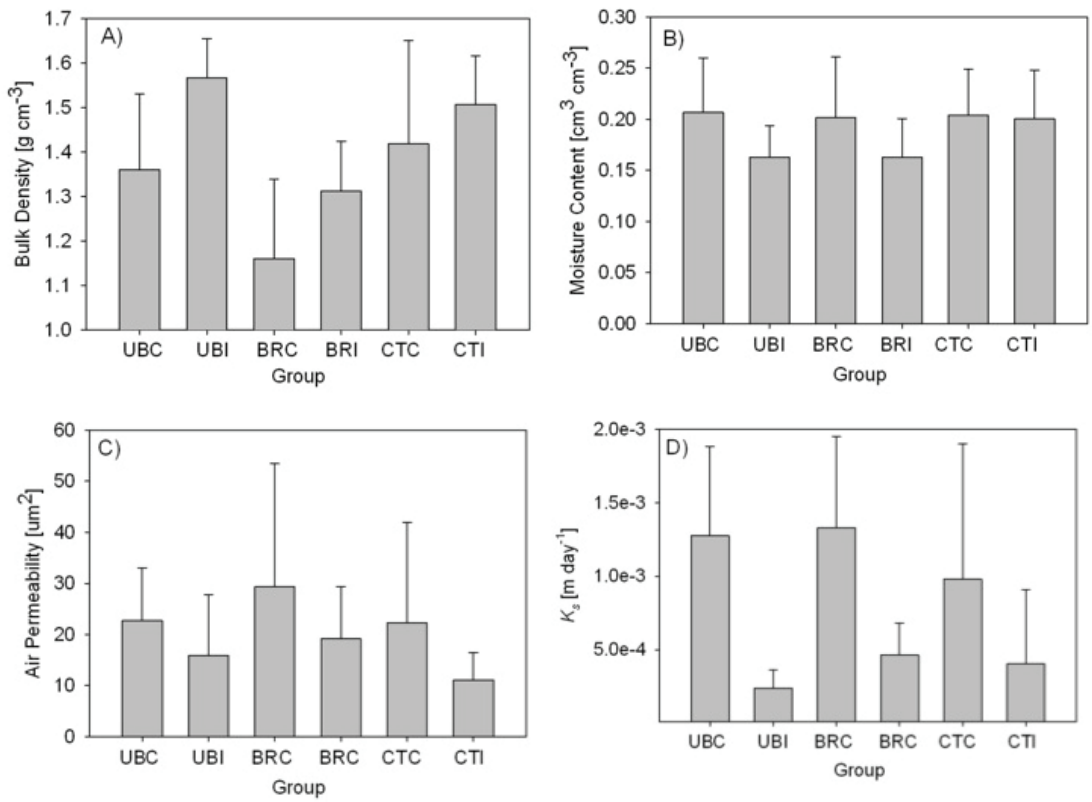

Figure 2. Soil physical and hydraulic properties one week before and one week after the Upper Gleason Burn including A) bulk density, B) saturated moisture content, C) air permeability, D) and saturated hydraulic conductivity for unburned (UB), burned (BR), and control (CT) sites. Canopy sites are denoted with a "C" at the end, interspace sites with an "I."

At the Jacob Fire site, the most significant hydraulic property changes were in burned canopy sites in the drainages. At 1 MAB, average CNs for these sites was 96, whereas no runoff occurred at corresponding unburned sites. Over the course of first year after the fire, CNs decrease at these sites, with no runoff occurring from them 9 MAB. However, at 13 MAB, average CN

values for the burned canopy sites in channels had increased again to 94. For the PI-SWERL measurements, with the exception of 3 MAB when results were strongly influenced by high soil moisture, particle emissivity from all the burned microsites was a factor of 10 or higher than in unburned native vegetation. At sustained wind speeds of approximately 24 km/hr (Fig. 3), emissivity of burned sites became progressively greater than in the control area (Etyemezian et al. 2010).

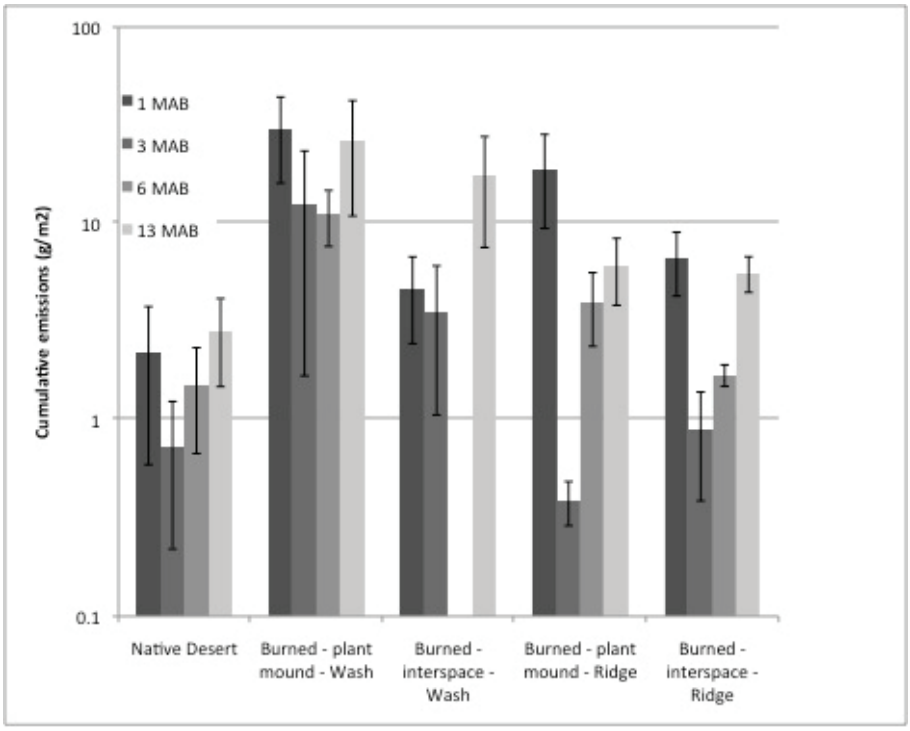

Figure 3. PM_{10} emissions at the Jacob Fire site at the end of the 3000 RPM step (39 km/hr sustained wind) at 1, 3, 6, and 13 months after burn (MAB). No data is available from burned interspace-wash sites for 6 MAB.

Post-fire soil structural changes at the Jacob Fire site were largely confined to canopy microsites. The largest changes occurred in canopy microsites on the ridges where soil structure that was originally moderate, coarse subangular blocky structure was deteriorated to a massive, weak granular structure with loose, friable particles. Burned drainage channels and ridge interspace microsites underwent little change in soil structure, suggesting that maximum burn and soil temperatures at the Jacob Fire may have been less than those at the Upper Gleason Fire. The CNs 16 MAB remained relatively high for canopy microsites, but was lower for interspaces. Greater runoff off of plant mounds has been noted at other burns in the Great Basin, possibly because higher OM beneath shrubs contributes to hydrophobicity or ash that inhibits infiltration (Pierson et al. 2008). Soil textures at the Jacob site are coarser than those of the Upper Gleason site and declines in runoff and sediment transport as well as emissivity with time may be a result of a limited supply of fine particles.

There are processes that could account for the soil hydraulic, structure, and compositional results measured one-week post-fire. For example, fires may cause loss of interstitial OM and disaggregation of soil structure, resulting in a decrease in porosity and an increase in BD (DeBano 1981). Particularly for lower intensity fires, post-fire OM can increase due to the incorporation of overlying fuel loads (Hungerford et al. 1990; Terefe et al. 2008). Loss of soil macropores may

also decrease K_s and k_a (Fuller et al. 1955; Barfield et al. 1985), potentially increasing surface runoff and erosion. At the Upper Gleason Burn, pre-burn soil structure had moderate to strong coarse subangular blocky structure with hard dry consistency to a depth of 7 cm. Surface soil structure deteriorated after the fire to a weak medium subangular blocky structure, but without increases in BD or decreases in K_s or k_a. Results at canopy sites showed a slight hydrophobicity, but no significant changes in soil properties. The most notable hydrochemical effect of fire can be the creation of a hydrophobic organic layer in which volatized organic compounds diffuse into the soil and condense in deeper cooler soil, coating mineral surfaces and changing the surfaces from hydrophilic to hydrophobic (DeBano 1981). Depending on the continuity, depth, and thickness of this layer, hydrophobicity may further reduce infiltration and increase overland flow (Robichaud 2000). However, hydrophobicity does not appear to have been a significant post-fire effect at either the Upper Gleason or the Jacob Fire.

Among the most significant results of the vegetation surveys is the low density of invasive grasses at both burn sites. Two years after the Jacob Fire, cheatgrass density is still less than 1 plant/m^2 while there are more than 150 plants/m^2 in adjacent unburned communities. Cheatgrass was also essentially absent one year after the Gleason burn, although adjacent unburned communities also had very low densities of it. Another significant post-fire event at the Jacob Fire site was the natural recruitment of blackbrush seedlings in the spring of 2009 (Zitzer 2009). Although only minor recruitment occurred in the burned drainage channels in 2010, blackbrush seedlings that became established in the previous year have continued to increase in stature at the site. Since 2000, at only a few sites near the northern part of its range has there been natural recruitment of blackbrush after fires.

Conclusion and broader impacts

The legacy effects of past land use such as overgrazing and fire suppression, coupled with projected changes in climate may mean fire regimes in the deserts of western North America never return to those prior to Anglo-American settlement of the region, including heavily impacted communities such as the sagebrush steppe of the Great Basin (Chambers and Wisdom 2009). However, despite relative increases in fuel loads, fires in dry lands of western North America are likely to be of lower intensity than those in more mesic areas and—as suggested by results at the Upper Gleason and Jacob Fire sites--mechanisms of post-fire erosion of soil by water and wind may also differ. Research at the these sites indicate that the post-fire changes in soil hydraulic and physical properties, and the mechanisms responsible for them, may differ from those normally measured 6 to 12 months post-fire, or shortly after higher intensity burns (Kennard and Gholz 2001; Chief et al. 2010). DeBano (1981) and others have hypothesized the loss of OM and disaggregation of soil structure increases surface runoff and erosion by decreasing total porosity and BD. For lower intensity fires such as the Jacob and Upper Gleason, the loss of soil structure may create more fine particles that are available for aeolian and water transport.

For the Upper Gleason Fire, the high emissivity of PM_{10} particulates may be the best evidence of fire-induced changes to soil structure and particle adhesion. The original interstitial OM in the soil may have been burned off and contributed to structural deterioration. However, for lower intensity fires such as this one, post-fire OM can increase due to the incorporation of ash from overlying fuel loads (Hungerford et al. 1990; Terefe et al. 2008). The authors hypothesize that this combination of properties—lower BD, and increased K_s and k_a—could be attributed to the expansion of vaporized water through the soil, breaking up soil aggregates and weakening of

the medium subangular blocky soil structure. Thus, the mechanisms that contributed to these changes immediately after the fire differ from those that lead to soil alteration 6 to 12 MAB. It is also hypothesized that fundamental soil pedogenic processes and seasonal changes (precipitation, winter snowpack, and temperature) will eventually reverse the soil property changes such that K_s and k_a will decrease, and BD increase. The structure of soils on controlled burns site from 2007 adjacent to the Upper Gleason site are currently structureless and fine textured. If this is an indication of future conditions of soils at the Upper Gleason site, then further soil structure change will occur and there will remain soil particles for potential water and aeolian transport.

Hydrophobicity is an important contributor to post-fire runoff and erosion in chaparral vegetation in the Mediterranean climate from coastal central California south to northern Baja Mexico (e.g., DeBano and Krammes 1966; Dallman 1998). However, hydrophobicity is strongly linked to fire temperatures, with low intensity burns resulting in only slight hydrophobic conditions that are limited to the surface (Huffman et al. 2001). Although there may be local effects, hydrophobicity may not be a significant contributor to post-fire runoff and erosion in most arid and semi-arid regions in most North American dry lands, at least relative to more mesic regions.

One factor that could limit post-fire runoff and erosion in dry lands of western North America is projected increases in aridity by the end of this century, particularly during the winter and spring (Wehner 2005; Karl and Peterson 2009). However, offsetting decreases in total annual precipitation are projected increases in the percent of precipitation in the southwest US that occur as intense events (>4.17 cm/hr, the heaviest 1% of all events) (Karl et al. 2009), a trend documented across the US from 1958 through 2007 (Groisman et al. 2005; Karl et al. 2009). Consequently, although the number of runoff events may decrease, runoff and sediment transport from burned sites from single events could increase. Another factor that could contribute to greater erosion is if what were historically shrublands become dominated by shallow-rooted, annual invasive grasses. Under such conditions, the loss of shrubs with large deep root systems could result in increased hillslope runoff and erosion, regardless of climate change projections.

The data collected to date from the Upper Gleason and Jacob Fire sites may be indicative of generalized post-fire processes in dry land soils. However post-fire plant recruitment can vary significantly within a similar set of fire-induced changes in soil properties. For example, the low density of cheatgrass two years after the Jacob Fire, and its near absence at the Upper Gleason site is in stark contrast to many fire sites in the region. Often one of the most destructive feedbacks to fires in the Great Basin and Mojave Deserts is that invasive grasses that are significant contributors to fuel loads are quick to colonize burned sites. In the worst cases in the Great Basin, cheatgrass monocultures have become established that make natural recruitment of native plants difficult (Bradley and Mustard 2005). Other invasive plants that have rapidly invaded areas after fires include medusahead (*Taeniatherum spp.*), and starthistle (*Centaurea spp.*) (Brooks and Pyke 2001). Both cheatgrass and red brome respond quickly to early season (February to May) soil moisture, germinating when soil temperatures are still too low for most native plants, and then begin senescence in early summer (Chatterton, 1994). As a consequence, by the start of the fire season, large amounts of dry biomass is available, a factor that is shortening the return interval between fires (Whisenant 1990).

The lack of cheatgrass establishment at the Upper Gleason site was not completely unexpected since it was the last of a series of controlled burns conducted between 2007 and 2009 in which native vegetation has successfully restablished. Cheatgrass density is low at all of these burn sites. A controlled burn program was initiated in Pleasant Valley on the Nevada-Utah border northeast of Ely, Nevada because a wildfire that occurred there has revegetated in the absence

of invasive plants. It is hoped that native plants will colonize controlled burns in the same area. However, more research is needed to understanding these situations, where common negative feedbacks from fires is absent or less severe, as it may provide clues to recovery of dry lands from fires.

Lastly, greater attention needs to be given to addressing emissions associated with fires. Post-fire aeolian erosion has local impacts including further degradation of soil quality, and potential inhalation health effects for people living in the region. A significant regional impact during a fire and from post-fire aeolian erosion is particle deposition on snow at higher elevations. Major population centers in the deserts of the western US are highly dependent on the two major rivers—the Colorado and the Rio Grande—that traverse the region. However, the base flow for both of these rivers is winter snowfall in the Rocky Mountains.

Aerosols associated with wildfires, as well as other sources, are impacting snowfall in the Rocky Mountains in two ways. First, although cloud condensation nuclei are needed for precipitation to occur, too high a concentration of them reduces the size of individual nuclei and prevents many of them from reaching critical size to fall out of atmosphere as snow (Saleeby et al. 2009). Secondly, dust deposition on snow decreases the albedo of it during the melting season (primarily April through July in the Northern Hemisphere) (Painter et al. 2007; Qian et al. 2009). Deposition of aerosols in mountain ranges occurs primarily in spring when frontal systems entrain dust particles from both disturbed and undisturbed land (Wake and Mayewski 1994). This period also coincides with when solar irradiance approaches its annual maximum which magnifies the accelerated melting of snow from aerosol material in it (Painter et al. 2007). The result is both reductions in total snowfall, and more rapid melting of it.

Fires are certainly not the only source of aerosols contributing to reduced snowpack and more rapid melting. Work by Saleeby et al. (2009) was conducted at the Storm Peak Laboratory (3220 m elevation; 40.455^{o}N, 106.744^{o}W) in northwest Colorado where aerosols from areas of China undergoing desertification have been measured. Painter et al. (2007) attributed significant snow albedo decreases in 2005 and 2006 in the San Juan Mountains of southwest Colorado from a greater frequency of dust-producing events on the Colorado Plateau where the ongoing drought in the southwest US has reduced total plant cover.

Increased sediment yield from rangeland fire runoff is generally the greatest in the first two years post-fire (Robichaud 2005). However, full recovery to pre-fire conditions may take from 5 to more than 10 years (Wright and Bailey 1982; Robichaud et al. 2000). Less is known about the duration of post-fire aeolian erosion. However, with fire return intervals reduced to as little as 5 years (Whisenant 1990), increased aerosol production from dry lands disturbed by fire in western North America may become a permanent contributing factor to decreased total snowfall, increased rates of spring snow melt, and overall water supply in the region.

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2. Changes of water resources and their impact on ecological environment in Minqin Basin

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Abstract

Based on a hydrogeological survey and analysis, a case study of the Minqin Basin is presented to illustrate change of water resources and its effects on the ecological environment in the arid area of northwest China. The results show that with the over use of water resources in the upper and middle reaches of the Shiyang River results in the rapid reduction of water flow into Minqin Basin.At the same time, with the development of human production activities and increase of population in the basin, the needs for water resources are ever-growing from year to year, which has led to over exploitation of groundwater. Human activity, in particular large-scale water resources development associated with dramatic population growth in the last 50 years, has led to tremendous changes in the ground-water regime. Over exploitation of groundwater leads to many ecological environment problems, such as groundwater level decrease and water quality worsening, the serious degeneration of the natural and artificial vegetation in the marginal zones of the deserts, soil salinization or alkalization and land desertification

1. Introduction

China's water resources rank the sixth in the world in total volume, but water availability per capita is only one quarter of the world average. Moreover, water resources are not evenly distributed spatially and temporally (Du et al. 2010). Water shortages have become an increasingly serious problem in China, especially in the arid zones of the northwest Ma and Wei 2003. Agriculture is the largest single user of water with 65–75% of freshwater being currently used for irrigation (Bennett 2000; Prathapar 2000). In some cases, it draws as much as 90% of the total water (Allan, 1997). Agriculture in arid area relies heavily on irrigation (Tong Ling 2007) and this is especially true for the Shiyang River basin which is located in the east Hexi corridor, north of the Qilian mountains, and between the Badai Jaran Desert and the southern part of the Tenger Desert. Minqin Basin is in the lower reach of Shiyang River, it is one of the driest regions in the world (Shi and Zhang 1995) and its irrigated agriculture has continuously increasing with the population and standard of living (Ding et al. 2003). Ecological environment in Minqin Basin is very fragile which is characterized by low and irregular rainfall, high temperature, strong evaporation and prolonged periods of drought (Zhu et al. 2007; Ma et al. 2005). All the runoff of Minqin Basin is come from Shiyang River. Under such conditions, the distribution of annual precipitation and the partitioning between surface water runoff and recharge to ground-water varies from year to year. Climate change and over use of water source in the upper and middle reaches of Shiyang River results in the rapid reduction of water flowing into the lower reach, which force the local farmers over exploitation the groundwater in Minqin Basin. The over

exploitation of groundwater resources lead to reduction of water availability and increase in groundwater table. There are many ecological environment problems arise such as water quality poor and vegetation degradation, soil salinization and desertification because of short of supplied water resources. Added the irrational water exploitation and irrational activities of local people in recently years, the ecological environment issues of Minqin Basin has been regard seriously (Kang et al. 2004), almost every index exceeds the national standards for groundwater quality in Minqin Basin.

Due to its arid climate, limited water resources and inappropriate water-related human activities, the area has developed serious loss of natural vegetation, and gradual soil salinization and desertification, which have greatly impeded the sustainable development of agriculture, ecological environment and economy in this region (Kang et al. 2004). Therefore, the aims of this study are to analysis the changes of water resources and their effects on ecological environment in Minqin oasis during the past 50 years.

2. Study area

Minqin Basin is at the lower reaches of Shiyang River, northwest China with the geographical position of 102°03′E~104°03′E and 38°05′N~39°06′N (Chang and Zhao 2006). It is surrounded by Badai Jaran Desert and Tenger Desert, and about 91% of the total area is covered by desert, Gobi, salina and deflation basin, dry lake basins, abandoned river beds, fluvial and lacustrine deposits, and alkali or saline lands are overlain by shifting, semi-fixed, and fixed dunes(Dong et al. 2010; Zhang et al. 2005). The total area is 1.6×10^4 km^2 in which the desert area is 0.853×10^4 km^2 and the oasis area is 0.144×10^4 km^2. The basin is located in continental temperate zone with arid climate and variable topography. The annual precipitation is about 113 mm, and almost 74% of it is recorded range June to September, however the rainfall from November to next February only is 3.4% of the total rainfall, there is no rain for 194 d from 13th October in 1998 to 24th April in 1999. Evaporation is very strong and the mean annual evaporation can reach 2640 mm (Liao et al. 2009). The mean annual temperature is around 7.7 °C and the mean annual wind speed is 2.8 m s^{-1}, the highest wind speed can reach 23 m s^{-1}, and the main wind direction is northwest (Chang et al. 2002). Average air humidity is 49% and aridity is 5.3 (Zhao et al. 2003). The average frost free period is 173 d and the longest one reached 202 d. The main cereal crops include cotton, spring wheat, fennel, melon and watermelon and these crops usually irrigated with flood or furrow irrigation which demanding very much water resources.

3. Change characteristics of water resources

3.1. Change of water quantity

The Shiyang River basin, which is one of the earliest to have been developed and is one of the most overexploited inland basins in northwest China. There had human activities 4000a BP and had already started development large-scale agriculture based on water resources exploitation in 121 BC. The area of lake in the end of Shiyang River is 540 km2 in 121 BC, while there just seasonal water flow into the lake in 1840. There did not flood into the lake since 1924 and it has totally dried up in 1953.

Although the discharge of the Shiyang River at the mouth of mountain valleys has remained near 15.8×10^8 m^3 yr^{-1} since the 1950s, the flow into the lower reaches has decreased seriously because of needs for water resources in upper and middle are ever-groing. Annual recharge quantity

from Shiyang River to the Minqin Basin was 5.73×10^8 m^3 during the 1950s (Zhu et al. 2007) but present it is less than 1.0×10^8 m^3. Exploitation of groundwater in Minqin Basin is less then 1.0×10^8 m^3 before 1970s and it received 6.65×10^8 m^3 in 2003, the mean increasing rate is 0.2×10^8 m^3 every year (GSWRB 2007). Fig.1 shows the runoff of Minqin Basin and the population from 1950 to 2005.

Rapid increase of population and living level lead to increasing of needs for water resource, otherwise the water resource from Shiyang River is decreasing which cannot satisfy the needs of irrigation and living, so groundwater was exploited seriously and ecological environment is amid deteriorating. Some studies have suggested that the changes in population size Hou 1973), precipitation (Chang et al. 2004, 2005) and the amount of water flowing into this region also played important roles in the evolution of the Minqin Oasis and its adjacent regions (Zhang 2008).

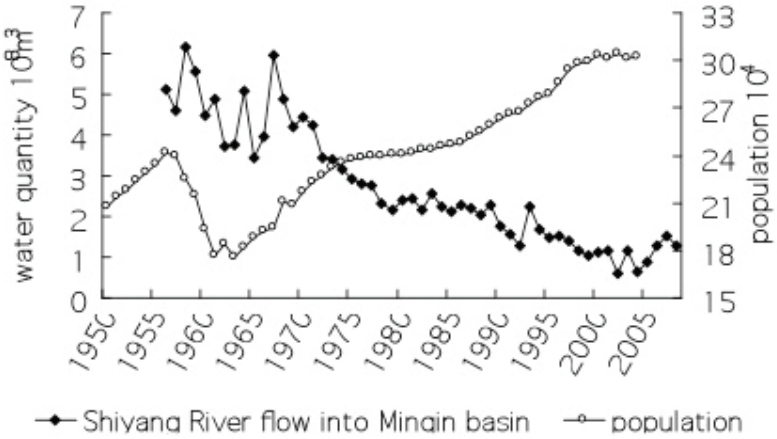

Figure 1. Changes of population and runoff of Minqin Basin.

It is more than 3 thousand millions cube meter groundwater was exploited in recently 50 years in Minqin Basin(Sun 2003). Over exploitation of groundwater in the Minqin Basin lead to the falling of groundwater table. According to data of observing wells, the fall depth of groundwater level is 1-20 m in 1979-2005. The maximum depth of table in some irrigation area can reach 40 m. Table 1 shows the groundwater level changes in Minqin Basin based on the observation of wells which used for irrigating from 1961 to 2000. The groundwater level is declining and its declining speed is increasing from year to year.

Table 1. Variations in the depth of the water table from the 1960s to the late 1990s in the Shajinzi area, Minqin Basin. Data from E et al. (1997) and E (2005)

Period	Groundwater depth(m)	Rate of depth increase(m/year)
1961-1967	2.24–2.93	0.12
1967-1978	2.93–5.20	0.21
1978-1988	5.20–9.00	0.38
1988-1994	9.00–12.99	0.67
1994-2000	>20.00	>1.00

3.2. Deterioration of water quality

Water quality can be affected by many factors, such as hydrology, groundwater flow conditions, chemical deposition, environmental background, irrigation conditions and so on; in particular the impact of human activities which broke the original chemical composition of groundwater equilibrium and accelerated the rate of change. Combination described about the law of hydrogeological and water quality change, change of water quality mainly affected by the reduction of water quantity from Shiyang River and over exploitation of groundwater, and both of them is controlled by human activities. Indexes used for evaluating the groundwater quality include total dissolved solids (TDS), total hardness (TH), and contents of chloride, sulphate, and nitrate. According to the National Standards for Groundwater Quality (NSGQ) (GB/T14848–93) issued by the State Bureau of Technology Monitoring of the People's Republic of China in 1993, it can be clearly seen that groundwater in Minqin Basin almost every index exceeds the NSGQ. The Minqin Basin is a well-confined hydrologic basin, in which the equilibrium of groundwater is mainly adjusted by evaporation and transpiration. Due to the low circulation rate in this area, overuse of groundwater has already induced much higher TDS (Fig.2).

Table 2 shows that the indexes have an eminent tendency to change rapidly from south to north in Minqin Basin. In the south there is a reservoir and groundwater can be recharged by reservoir water, so the groundwater there has a better quality than that in other parts of the basin. In the north, adjacent to the Tenggri desert, the groundwater quality becomes the worst because of lacking of surface water recharge and overuse of groundwater. The TDS of well water along the desert margin is higher, some wells' TDS can reach 10 g L^{-1}; even wild birds do not drink that bitter water. The special changes of water quality in the Minqin Basin, result from not only the strong evaporation but also the over irrigation which lead to excessive exploitation of the groundwater resources.

Table 2. Times of various indexes exceeding the national standards for groundwater in Minqin Basin

Area		TDS	Total hardness	Chloride	Sulphate	Nitrate
Minqin Basin	North	6–4	5.7–3.7	4.5–2.0	8.2–5.0	
	Middle	3	1.5	1.5	3	
	South	3–1	3.3–2.0	3.4–1.2	6.5–1.7	2.5

4. Impact of water resources change on the ecological environment

4.1. Vegetation degradation

The relationship between vegetation growth and groundwater in arid areas is one of the most actively researching topics in eco-hydrology. On account of little precipitation, the oasis is the only form of sustenance for living and economic development, for the local people in the arid

areas of northwest China. The vegetation growth of the oasis has a close relationship with the water resources (Jin 2008). Vegetation degradation and death is an important environmental issue in Minqin Basin. Most groundwater table is between 1-3 m before 1960s and the environment for plant is favorable, and there are meadow plants in dune slacks and margins of rivers and lakes; From 1970s wet plants begin to degenerate and instead by mesoxerophytes, and large area of natural and artificial forest degradation and death. There are 0.9×10^4 ha elaeagnu*s angustifolia* wood and 2.3×10^4 ha *nitraria tangutorum* and *tamarix ramosessima* have dead or near dead, 1.2×10^4 ha windbreak and sand – fixation forests have dead or spike top.

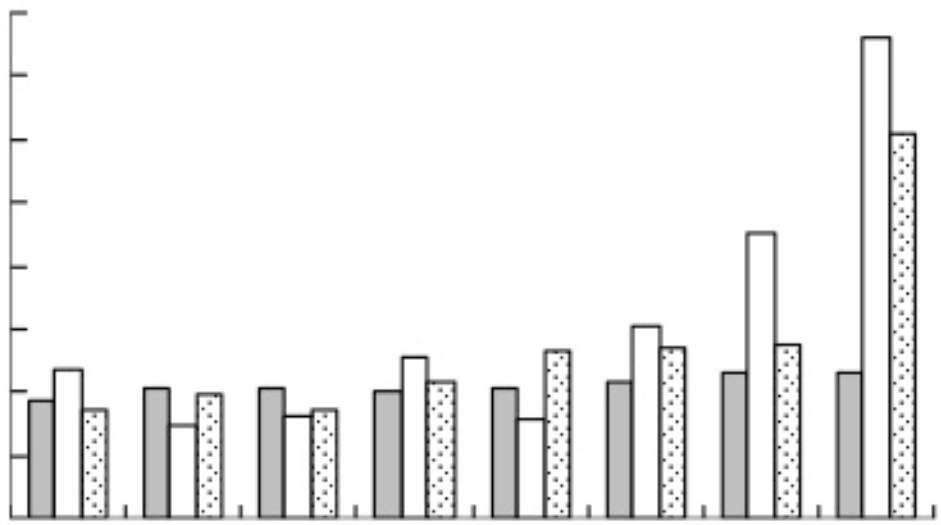

Figure 2. TDS changes in Minqin Basin from 1998 to 2005.

4.2. Drainage change and lake degradation

Prehistoric times, Minqin is a fishing village in the end of Shiyang River but with the decrease of inflow water and natural sediment deposition, it was divided many small lakes; it has become marsh during the late years of the Qing dynasty. On the eve of the founding of new China the small lakes have become beach and wilderness. It is begin to build artificial reservoir and channels in 1950s and then artificial water system instead natural rivers. Artificial water system distributes plentiful water into farmland which promotes the development of Minqin economy. Exploitation of water resources accelerates the economic development but the contradiction between water supply and demand is becoming prominent, the ancient oasis is facing serious water resources and survive crisis.

4.3. Land salinization and desertification.

Minqin Basin is a typical agriculture basin and majority income comes from the agriculture. But now, the oasis in the basin gradually withers resulting from the shortage of water resource. Due to the drought from the decrease of water resource, the soil water content decrease, vegetation and ecosystem succession gradually take place along the xerosere. Salinization and desertification speedy develop with the reduction of water resources and vegetation degradation in Minqin Basin.

In Minqin Basin, the average salt content of the soil is up to 16.7 g kg^{-1} and, most of the farmland can no longer be used for cultivation. As the hydrochemical types of groundwater change, from bicarbonate to sulphate and chloride from the upper to the middle and lower reaches, the stability of inorganic salt increases and makes them easily accumulate in soils. The average salt content of cultivate layer in 1950s and 1990s is 0.27% and 0.5-1.5% respectively; 1.7% in 2000. The area of salinized land reached 16% of the total area.

It is widely recognized that desertification is a serious threat to arid and semiarid environments which cover 40% of the global land surface (Deichmann and Eklundh 1991) and are populated by approximately 1 billion humans (UNSO Office to Combat Desertification and Drought 1997; Reynolds and Smith 2002). The only surface water in Minqin Basin is come from Shiyang River and it has decreased by 74% since 1950s which lead to desertification in the basin which adjoins Tenger desert and Badain Jaran desert. The monitor result by satellite image data shows that the desertification area of Minqin Oasis increased by 4,094.5 ha from 337,126 ha to 341,221 ha representing 0.90％ of studied area，from 1998 to 2003, for which the wind erosion land increased by 5,857.24 ha (Wei 2007).

Continuous decrease of water flow from the Shiyang River and over exploration of groundwater led to deterioration of water resources and rapid development of desertification. The sands area increase 2.0×10^4 hm^2 since 1950s in Minqin Basin. Wang et al. (2003) and Xie et al. (2004b) suggested that over-use of the region's water resources and a rapid increase in the region' population were the principal causes of rapid desertification in the past 100-300 years. Yang et al. (2002) also stated that over the past 50 years, the degradation of oases in this region has been due to the expansion of traditional agriculture, which to a large extent is supported by heavy use of water resources. At present, Minqin Basin is considered to be a representative region of severe desertification by the Chinese government and UNEP (1992) due to the high density of human activities in this region (Zhang 2008).

5. Conclusions

Water resources problem is the essential problem of ecological environment in Minqin Basin. Many ecological problems, such as water quality poor and vegetation degradation, soil salinization and desertification because of short of supplied water resources, are serious in the basin. Therefore, by artificial factors such as modernized irrigation technology and new regulation to cover water resources management and allocation within the river basin, to regenerate ecological environment is an urgent matter for the regional sustainable development in Minqin Basin.

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3. Responses of some rangeland and crop plants of Uzbekistan to climate change

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Abstract

Countries such as those in Central Asia that have arid and semi-arid climates with already high temperatures and limited water may be particularly vulnerable to future climate changes. Annual temperatures have risen by about 1.4 ^{0}C during the last 100 years and are predicted to continue to rise in the future. This could intensify droughts, but rising carbon dioxide concentrations might alleviate effects of drought on plant growth. To evaluate the influence of these global changes on crop and rangeland production in Uzbekistan, there is a critical need to develop more precise, realistic techniques to evaluate the effects of water stress and elevated carbon dioxide on plant growth. We used a new method of applying a uniform soil water deficit to plants to test whether elevated carbon dioxide protects cotton plants from the effects of soil water deficits. We also compared responses of some rangeland species to short-term and long-term changes in carbon dioxide and temperature. Results indicate that the equivalent soil water stress decreases cotton leaf gas exchange less at elevated than at ambient carbon dioxide, and that plant adjustments to the stress result in no inhibition of growth at elevated carbon dioxide while growth is reduced by the same stress at ambient carbon dioxide. While long-term exposure to elevated carbon dioxide increased growth in all of the rangeland species examined, in some of the species studied long-term exposure to elevated carbon dioxide increased the inhibition of photosynthesis by high temperature stress.

Introduction

Population growth and associated expansion and intensification of agricultural activity in many areas of Central Asia, including Uzbekistan, have caused increased rates of land degradation and subsequent declines in plant biomass production. The region faces a serious challenge to its natural resource base with degradation becoming a concern on croplands, rangelands, and mountainous areas. The reduced availability of agricultural inputs, feed, and fodder is resulting in a decline in livestock numbers. Water scarcity and misuse is compounding the threat to food security, human health, and ecosystems. Temperature and water regimes are the main factors that affect the growth, development, and yield of plants growing in arid and semi-arid regions. Consequently, any change in climate will likely have a major influence on plants growing in these areas. For example, a 1-3 ^{0}C rise in temperature can shift growth to 5-14 days earlier, which may result in growth initiation during the last week of February. This shift may be critical for the growth of vegetation where growth would be shifted to a period of more intensive rainfall and lower air temperatures, resulting in declines in total biomass production. This may be particularly important for sedges (Carex spp.), a main fodder crop in Central Asia, which have previously been shown to exhibit considerable reductions in height during the last 30 years.

Drought is an overriding environmental factor that affects production of agricultural crops around the world. Drought can reduce plant yields or in extreme cases can lead to plant death. Global

climate change is a critical issue facing agriculture that could lead to the intensification of drought effects on crop production. Countries such as those in Central Asia that have arid and semi-arid climates with already high temperatures and limited water may be particularly vulnerable to future climate changes. For example, analysis of climatic patterns in Uzbekistan indicates that annual temperatures have risen by about 1.4 ^{o}C during the last 100 years. Predictions for Uzbekistan indicate that annual temperatures in Uzbekistan will continue to rise in the future. These changes have the potential to intensify drought effects on plants, making both irrigated and non-irrigated plants less efficient in their use of water (lower water-use efficiency). To evaulate the influence of these global change effects on crop production in Uzbekistan, there is a critical need to develop more precise, realistic techniques to evaluate the effects of water stress on arid crops in Uzbekistan. Controlled environments minimize variability and allow for the precise testing of hypotheses related to environmental effects on plant growth. The combination of these techniques will allow careful statistical comparisons to be made to precisely evaluate water stress effects in arid plants.

Methods

We used a new method of applying a uniform soil water deficit to plants to test whether elevated carbon dioxide protects cotton plants from the effects of soil water deficit. We applied a vacuum to ceramic filters imbedded in the soil to produce a continuous mild water stress in cotton plants grown at 380 and 560 ppm CO_2. It was convenient to maintain the soil water potential at -0.1 $\pm$ 0.01 MPa for a week during early vegetative growth. We measured leaf water potential, stomatal conductance and photosynthesis, and leaf area and biomass growth in stressed and control plants.

Three species of rangland plants: *Artemesia, Poa* and *Carex* were grown at 27 ^{o}C, at 380 and 560 ppm CO_2. The response of whole shoot and/or leaf photosynthesis, stomatal conductance and water use efficiency to temperatures of 17, 27, and 37 ^{o}C and CO_2 concentrations of 380 to 700 ppm was determined.

Results and discussion

One of the most documented effects of increasing CO_2 is stimulation in plant physiological processes relative to current CO_2 levels (Kimball 1993; Ghannoum et al. 2000). However, this simple observation may reflect a number of complex physiological changes in addition to any effect of CO_2.

Elevated CO_2 in our study increased photosynthesis and decreased stomatal conductance of unstressed cotton plants, but did not affect leaf water potential. The mild soil water stress reduced leaf stomatal conductance and photosynthesis more at the lower than at the higher CO_2 concentration. In fact, photosynthesis and growth were unaffected by the stress in the elevated CO_2 treatment, while the same stress significantly reduced photosynthesis and growth at the lower CO_2 (Fig. 1). Elevated CO_2 reduced the impact of high temperature on photosynthesis in some of the species. However, in other species elevated CO_2 made photosynthesis more susceptible to high temperatures (Fig. 2).

Results indicate that the equivalent soil water stress decreases cotton leaf gas exchange less at elevated than at ambient carbon dioxide, while growth is reduced by the same stress at ambient carbon dioxide, and that plant adjustments to the stress results in no inhibition of growth at elevated carbon dioxide while growth is reduced by the same stress at ambient carbon dioxide

While long term exposure to elevated carbon dioxide increased growth in all of the rangeland species examined, in some of the species studied long-term exposure to elevated carbon dioxide increased the inhibition of photosynthesis by high temperature stress.

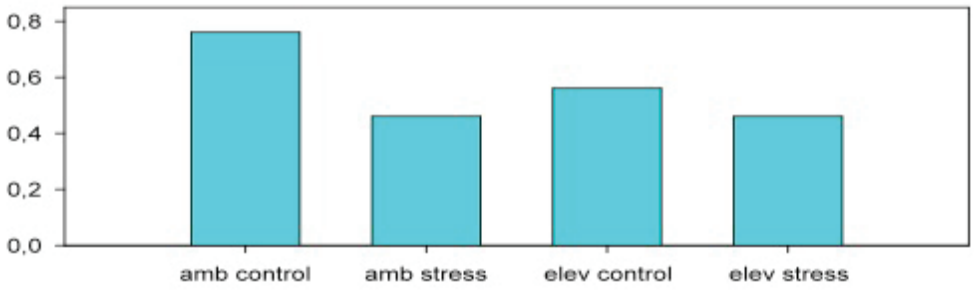

Fig.1. Stomatal conductance under ambient and elevated CO_2 levels and drought stress.

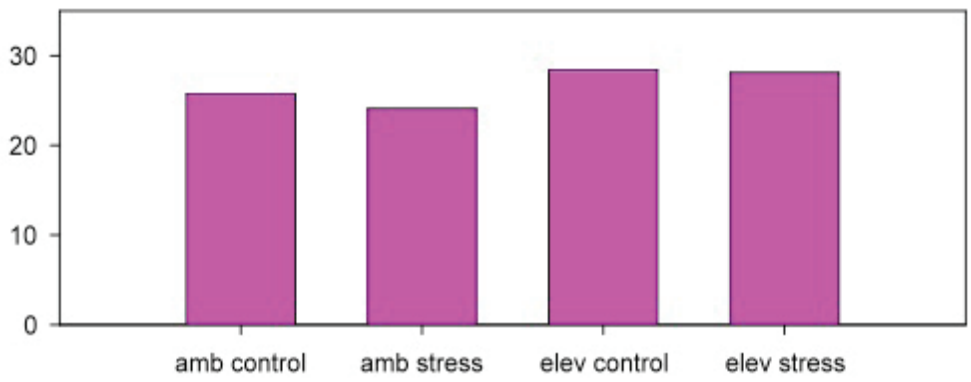

Fig.2 Response of photosynthesis under ambient and elevated CO_2 levels and drought stress

The new system of controlled application of water deficits in vegetation pots was useful to test two interrelated hypotheses: that elevated CO_2 results in a relatively smaller sensitivity of photosynthesis to mild soil water deficits than does the current ambient CO_2, and secondly, that the opposite pattern will exist for more severe soil water deficits. These hypotheses were tested for a number of crop (cotton, wheat, corn, sorghum, beans) and rangeland (*Poa* sp., *Carex* sp.) plants.

The first hypothesis is based on the fact that photosynthesis at ambient levels of CO_2 is limited by CO_2 supply, and that mild soil water deficits cause partial stomatal closure which further restricts CO_2 supply. For plants at elevated CO_2, CO_2 supply is not as limiting to photosynthesis, so stomatal closure would impose relatively less limitation on photosynthesis.

The second hypothesis is based on the idea that more severe water deficits reduce photosynthesis additionally primarily by reducing the biochemical process of RuBP regeneration (reviewed in Flexas et al. 2004). RuBP regeneration limits photosynthesis especially at high CO_2 concentrations, so photosynthesis of plants at elevated CO2 would be relatively more susceptible to severe water deficits.

There is remarkably little information in the literature to judge these hypotheses. This is because most research on water deficits at elevated CO_2 has focused on the water-saving aspect of elevated CO_2, which has largely prevented photosynthetic comparisons at equivalent soil water deficits (Bunce 2004).

The use of different species allowed to test the generality of the hypothesized responses, and its applicability to both C3 and C4 species (i.e. cotton is C3, sorghum and corn are C4). Additionally, comparisons of susceptibility of the different species to soil water deficits at both ambient and elevated CO_2 will indicate whether these plants are likely to become more or less competitive with cotton during drought and as atmospheric CO_2 rises.

Observed reduction in stomatal conductance with increase in CO_2 are widespread, but not universal. While the mechanism by which carbon dioxide alters stomatal opening can be considered at the cellular or biochemical level (Assman, 1999), the overall impact is especially relevant to whole leaf processes, particularly stomatal limitation on photosynthesis and changes in water use. A number of studies have addressed the former question, arguing that reduction in stomatal aperture and conductance might reduce CO_2 availability with a subsequent negative impact on photosynthesis, independently of any direct change in carbon availability. However, review of these studies suggests that while stomatal conductance is generally reduced by increasing CO_2, stomatal limitation of photosynthesis decreases (Drake et al. 1997). Similarly a number of studies have that rising CO_2 increases the water-use efficiency (WUE) of the leaf, usually defined as ratio of leaf carbon uptake to water loss.

Conclusions

The results for cotton supported the hypothesis that elevated CO_2 reduced the impact of soil water stress on photosynthesis. Responses of other species are now being assessed. The hypothesis that elevated CO_2 reduced the inhibition of photosynthesis at high temperature was supported in some species, but contradicted in others. Reasons for the contradictory responses are being investigated.

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Theme 3: Enhancing resilience of local agricultural communities in drylands through adaptation strategies

3a: Agronomy and water management

1. Performance and adaptation of the Vallerani mechanized water harvesting system in degraded *Badia* rangelands

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Abstract

Rainwater harvesting in micro-catchment contour ridges and semicircular bunds is an option for utilizing the limited rainfall, improving productivity and combating land degradation in dry rangeland areas (*Badia*). However, implementation of this practice using manual labor or traditional machinery is slow, tedious and costly, and often impractical on a large scale. These limitations can be overcome using the 'Vallerani' plow for quickly constructing continuous and intermittent ridges. The plow (model Delfino (50 MI/CM, manufactured by Nardi, Italy) was tested and adapted to Badia conditions in Jordan. The performance of the machine, its weaknesses and potential improvements were assessed in the 2006/07 season at three sites on 165 hectares of various terrain, slope and soil conditions. The performance parameters included effective field capacity (EFC), machine efficiency (ME) and fuel consumption. Field tests were carried out at different tractor (130 HP) traveling speeds, pit sizes and contour spacings. Overall mean performance indicators gave an EFC of 1.2 ha/h, 51% ME and an average fuel consumption of 5.15 liter/ha. Increasing ridge spacing had a small effect on ME; increasing traveling speed had a greater effect. A guide table was developed, relating performance parameters with ridge spacing, speed, and bund size setting. This could be a useful reference for the implementation and management of mechanized micro-catchment construction in the Badia. The system performed well in the construction of continuous ridges. However, it was unable to construct intermittent ridges at speeds over 4 km/h; problems were encountered in properly staggering the bunds at successive contours.

1. Background

As pressure on land increases, more and more marginal areas in the world are being used for agriculture. Much of this land is located in the arid or semi-arid belts where rain falls irregularly and much of the precious water is soon lost to evaporation and surface runoff to salt sinks. Recent intense droughts have highlighted the risks to human beings and livestock. Consequently, there is now increased interest and growing awareness of the potential of water harvesting (WH) as a low cost alternative for improved crop and rangeland production.

During the last few decades, a number of WH projects have been implemented in the Eastern Mediterranean and North and sub-Saharan African regions. They have aimed to improve plant production (usually forage crops and shrubs), and in certain areas to rehabilitate abandoned and

degraded lands (Critchley and Reij 1989). While few of the projects were successful in combining technical efficiency with low cost and acceptability to local farmers or agro-pastoralists, others have failed because the technology used proved to be unsuitable for the specific prevailing natural and socio-economic conditions of the site In some areas the technical resources and tools were limited (Siegert 1994; Oweis et al. 2001). The lack of specialized (unconventional) machinery to support the implementation of techniques for water harvesting and plant establishment (catchment constructing, transplanting or seeding) was one of the most serious constraints faced. Using conventional machinery did not prove to be adequate for rehabilitating large areas. It proved to be imprecise, tedious, slow and costly. Al-Tabini et al. (2008) reported that the lack of mechanized power limited the establishment of WH systems in small-scale projects.

Significant progress came with the development of the mechanized system of collection of surface runoff known as the 'Vallerani System' (named after its Italian inventor). The first experiments of the Vallerani system was carried out in 1988 in the framework of the Integrated Programme for Rehabilitation of the Damergou (FAI-Niger). In this system, the WH structures are constructed by a special plow, of which there are two versions, Delfino (dolphin) and Treno (train). The Delfino was designed to open micro-catchments or semicircular micro-basins (bunds). The hydraulically controlled movement of the plough bottom while traveling, alternating from an upwards to a downwards motion, simulates the movement of dolphins riding the waves. With each plunge, the plough digs a semi-circular micro-basin (half-moon bund) and forms a pad of earth towards the uphill side for catching runoff. Each half-moon is broken up when the plough is raised. The plough is also equipped with sub-soiling ripper for fissuring deep soil layers.

The water-holding capacity of the micro-catchment is 200 – 600 l, on either side of a continuous ridge. Using this plow, up to 400 micro-basins per hour can be constructed (Antinori and Vallerani 1994; http://www.valleranisystem.com). Malagnoux (2006) reported even higher rates of construction of 700–1200 micro-basins per hour. To build similar water harvesting structures using traditional tools and intensive labor required 80 man days per hectare (Malagnoux 2006), while using the Vallerani ridge-opener (Prinz 1994 and 2001; http://www.valleranisystem.com) 1 to 2 hectares of land could be treated in one hour.

Reports (Antinori and Vallerani 1994; Malagnoux 2006; Prinz 2001) indicate that this system can be used in areas with an annual precipitation of more than 200 mm and on slopes of 2–10%. They have also shown that the use of the Vallerani plow can be economic when large areas need to be treated and if quick action is required. Since 1988, this new technology has been tested in many countries (Burkina Faso, Chad, Egypt, Kenya, Morocco, Niger, Senegal, Sudan, Syria, Jordan, and Tunisia), where a total of nearly 100,000 ha have been treated.

The system was first tested in the Badia of Syria (Somme et al. 2004). The Vallerani plow was used to construct micro-catchment intermittent bunds on slopes of 4 and 6% with catchment areas of 40, 80, and 120 m^2 per bund, each planted with two *Atriplex* shrubs. This research showed that the mechanized bunds provided three times more water to the shrubs than those with no water harvesting bunds. Under micro-catchment, shrub survival rate was increased from 30 to 90%. Mechanically constructed bunds outperformed handmade bunds in all indicators due mainly to the impact of subsoil ripping.

In 2003 ICARDA initiated a research project "Communal Management and Optimization of Mechanized Micro-catchment Water Harvesting for Combating Desertification in the East Mediterranean Region" in the marginal steppe (Badia) of Syria and Jordan. The project was centered on mechanized implementation of micro-catchment WH using the Vallerani system and

was aimed at reducing land degradation and improving the livelihoods of local communities. In addition to community participation and institution related aspects, the implementation process aimed to answer questions related to the technical performance, cost-effectiveness, and impact of the mechanized system on soil–water–plant conditions at the experimental sites.

The work presented in this paper, as part of the Vallerani project, concentrated on the technical evaluation and adaptation of the Vallerani mechanized system to the prevailing conditions in the Badia. The objectives include: 1) Performance parameters determined under varying operational and field conditions. 2) Guidelines developed for the efficient use and management of the mechanized system for WH under Badia conditions. 3) Technical weaknesses of the system identified and suggestions for possible improvements developed.

2. Methods and materials

2.1. Equipment description and field tests

The machine (model Delfino) (Figure 1) is a hydraulic single ridge plow with a specially shaped working body (mounted moldboard type), fitted with a subsoiler and a programmable hydraulically-operated lifting mechanism. The implement is also equipped with a front knife that assists stability during operation and a sweeping blade designed to move back to the ridge the soil clods that are thrown up by the moldboard out to the runoff area side. The lifting mechanism uses category II PTO (power take off) of the tractor at 540 rpm as a source of power.

The machine was designed and built to allow plowing heavy soils (thick and flat soils of alluvial origin) that the African farmers were not able to work with their traditional implements (Malagnoux, 2006). For the weight of this plough to be lifted and the movement that animates it and the necessary execution speed for optimal operation, a heavy tractor with the power of at least 130-160 hp (96- 119 kW) (as set in the factory specification sheet) was required. Working heavy soils with less tractor power may cause improper operation of the machine, impose reduction of working depth or damage the hitching system of the tractor. However, lower tractor power may be allowed when working lighter soils.

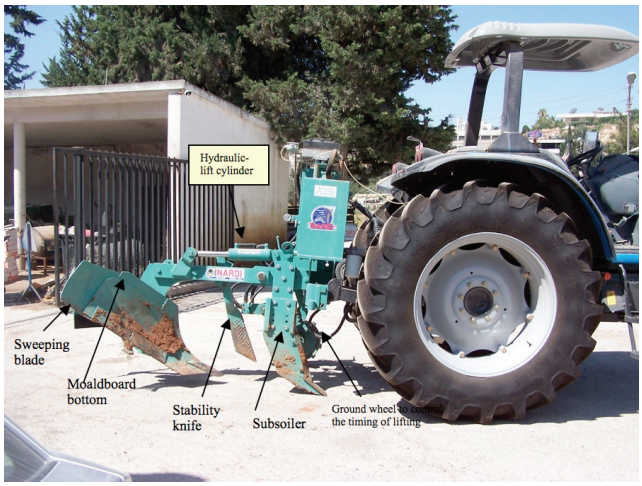

Figure 1. The Vallerani machine (Delfino) mounted on 134 – hp tractor (Category II - 3PHS + 540 rpm – PTO).

When the lifting mechanism is activated discontinuous ridges (semicircular micro-basins) are produced, otherwise, the plough can open only continuous ridges. The raising and lowering

action of the plow is controlled by a directional control valve (spool type). This is operated by a ground-driven wheel through a series of drive/driven sprockets and chains of different sizes. Depending on the selected combination of sprockets engaged, four pit's sizes can be obtained (1.6, 2.5, 3.6, and 4.7 m long with 0.7, 1.1, 1.6, and 2.3 m spacing between successive bunds, respectively). The machine is able to create either intermittent or continuous ridges of 50 + 50 cm wide and 50 cm high (from the bottom of the ridge), with a 40 cm ridge depth, plus subsoiling to 15–25 cm below the ridge bottom.

The Vallerani plow (Delfino 50 MI/CM) was mounted on the 3-point-hitch system (3PHS) of a 134 HP (98.5 kW) tractor (Landini, Italy, model L135 TDI) and the pump of the hydraulic lifting mechanism of the plow was powered from the PTO of the tractor. The field tests to evaluate the performance of the integrated unit (tractor and Delfino plow) were carried out on three project sites, in the Majdiyyeh, Mhareb, and Mafraq regions (Jordanian Badia) for 4, 8, and 6 working days (118 working hours) covering approximately 20, 85, and 60 hectares, respectively.

The dominant soils in the three test sites were *silty clay loam* (a few were silty clay and even fewer were clay loam and silt loam) with low organic matter, weak aggregation, platy structure, and crusty surface with poor vegetation cover. As a result of erosion by water, the soil depth decreased proportionally with increased slope. It ranged between 20 and 50 cm on slopes higher than 8%, while on locations where the slope was less than 2%, the soil was more than 160 cm deep. In some locations, medium-sized stones (5–15cm diameter at depths of about 30 cm) were moved with the plow. In other locations (mostly uphill) shallow rocky pans were found. In such cases the working depth was reduced to avoid breaking the soil-engaging tools. The soil and topography conditions of the mentioned test sites, in general, required lower operational power than that designed for conditions in Niger and sub-Saharan African regions that the machine was initially built for.

Tested on different hilly fields with slopes ranging between 1 and 8%, the machine constructed both continuous and intermittent (micro-basins) contour ridges with 4, 8, and 12 m spacing between ridges, and at different average tractor traveling speeds (2, 3, 4, and 5 km/h). Speeds greater than 5 km/h were not used due to machine and human safety considerations. The working depth ranged between 0.4 and 0.5 m while the subsoil ripper reached down to a depth of 0.5–0.6 m from the soil surface.

Trials were implemented on 165 hectares, on 145 hectares of which 21,900 intermittent bunds of four different sizes (length and spacing) were constructed. The continuous contour ridges covered an area of 20 hectares, which was estimated to be equivalent to 3000 bunds.

2.2. Measurements and parameters

Measurements to evaluate the performance of the tractor/plow system included time, speed, ridge lengths, number of bunds and area covered.

2.2.1. Theoretical machine capacity

According to Bowers (1987), theoretical machine capacity can be determined by the following equation:

$$TMC_A = V * E_w * 0.1 \qquad (1)$$

where TMC_A is the theoretical machine capacity by area (worked area per time, hectare/hour), V is the tractor traveling speed (km/hour), E_w is the effective working width (m), which equals runoff area length + bund (or ridge) + ridge width, and 0.1 is the unit conversion factor.

Equation (1) is used when both continuous ridges and intermittent bunds are constructed. However, if we ignore the length of the runoff catchment, two other versions of the equation can be derived:

$$TMC_L = V \quad (2)$$

and

$$TMC_P = TMC_L / L_P \quad (3)$$

where TMC_L is theoretical machine capacity by the length of constructed ridges (km/hour), TMC_P is the theoretical machine capacity by bunds (number of constructed bunds/hour), and L_P is the length of the bund + spacing between successive bunds (m).

Equation (2) was used when the machine opened continuous ridges and Equation (3) when intermittent ridges were constructed.

2.2.2. Potential and actual machine capacities

Two effective machine capacities were considered: the potential machine capacity ($PMC_{A,L,P}$), and the actual machine capacity (AMC_A). Both were assessed by determining either the area A, the ridge length L, or the number of bunds P constructed over time spent as measured in the field. $PMC_{A,L,P}$ took into consideration real time lost on a) turning and going back to the start at every new pass to keep the uphill side to the left side of the tractor, and b) aligning subsequent ridges to maintain proper staggering of bunds or proper spacing between ridges. AMC_A took into consideration the time lost on the factors mentioned above plus the time lost on a) switching from one site or one hill to another, b) refueling, making adjustments, checkups, maintenance and breakdowns, and c) work planning and time lost due to the lack of skill of the operator. AMC_A counted the area covered over all work hours of all work days.

2.2.3. Machine efficiency

According to Bowers (1987), machine efficiency is the ratio of the effective machine capacity to theoretical machine capacity and hence, two types of machine efficiency were considered:

a) Potential machine efficiency, where

$$PME_{A,L,P} = (PMC_{A,L,P} / TMC_{A,L,P}) * 100\% \quad (4)$$

b) Actual machine efficiency, where

$$AME_A = (AMC_A / TMC_A) * 100\% \quad (5)$$

2.2.4. Fuel consumption

Fuel consumption was assessed per unit area (hectare), per bund and per hour for the entire 165 hectares. To measure fuel consumption, a topping-up method was used, where the fuel tank of the tractor was fully topped up before starting work, then the number of liters added to refill the tank again was determined.

3. Results and discussion

On the three experimental sites, the tractor/implement unit constructed continuous and intermittent ridges smoothly at the preset plowing depth, traveling speed and micro-basin size, whereas no overloading incidents were encountered. No slipping situations due to overload were met, and no breakage to the soil engaging tools or to the tractor hitching devices occurred. This obviously indicated that the selected tractor power to operate the Vallerani machine, under soil and topographical conditions of the *Badia*, was adequate.

3.1. Capacity and efficiency of the system

In WH systems, spacing between ridges (length of runoff area) may vary considerably depending on crop water requirements, rainfall characteristics and runoff coefficient. The latter greatly depends on the slope. Theoretical machine capacity by area (TMC_A) can be conveniently used to compare techniques with similar spacing between successive ridges or bunds, though not when different spacings are to be compared. In such cases, the machine's effective working width was ignored and TMC_A (Equation 1) was replaced by TMC_L and TMC_P (Equations 2 and 3) to express the length of the worked ridges and the number of bunds constructed per hour, respectively. Such parameters of machine capacity were thought to be more convenient for use in these cases.

3.1.1. Constructing contour ridges

In constructing continuous ridges, the potential machine capacity, either by area (PMC_A) or by length (PMC_L), increased with increased traveling speed (Table 1). Nevertheless, this gain in capacity decreased as the traveling speed increased. For example, in 4 m ridge spacing, switching from 2 to 3, from 3 to 4, and from 4 to 5 km/h, resulted in 32, 20, and 12% gains, respectively (Table 1).

Table 1. Theoretical machine capacities (by area covered TMC_A and by lengths of ridges worked TMC_L), and the respective potential machine capacities (PMC_A, PMC_L) as calculated for Vallerani machine at different average traveling speeds and spacing between successive continuous ridges. (Badia, Jordan)

Spacing between ridges, (m)	Average traveling speed, (km/h)	TMC_A (ha/h)	TMC_L (km/h) [a]	PMC_A (ha/h)	PMC_L (km/h)
4	2	1	2	0.73	1.46
	3	1.5	3	0.95	1.89
	4	2	4	1.14	2.28
	5	2.5	5	1.28	2.55
8	2	1.8	2	1.25	1.39
	3	2.7	3	1.62	1.80
	4	3.6	4	2.03	2.26
	5	4.5	5	2.29	2.54
12	2	2.6	2	1.82	1.40
	3	3.9	3	2.11	1.62
	4	5.2	4	2.89	2.22
	5	6.5	5	3.21	2.47

[a] *TMC_L = Average traveling speed*

Increasing spacing between successive ridges increased machine capacity by area, PMC_A (Table 1). This is due to the increase in the effective width covered by the machine. However, there was no significant effect of ridge spacing on capacity when considering machine capacity by length, PMC_L. Therefore, PMC_A should be used to evaluate the technique rather than the machine, while PMC_L should be used to evaluate the machine.

Although increased traveling speed increased machine capacity, the traveling speed had a noticeably reverse effect on machine efficiency. Increasing traveling speed from 2 to 5 km/h reduced the potential machine efficiency $PME_{A,L}$ from 70.5 to 50.5% (Table 2). This reduction can be attributed to: a) the time lost by the tractor when turning and traveling back to start a new ridge was the same at 2 and at 5 km/h speeds, and b) the theoretical machine capacity at 5 km/h was 2.5 times greater than it was at 2 km/h (Table1), while the potential capacity at 5 km/h was only 1.7 times greater than it was at 2 km/h. Increasing spacing between successive contour ridges (catchment length) had a slight effect on potential machine efficiency $PME_{A,L}$ (Table 2). This can be attributed to the extra time lost traveling between farther ridges.

Table 2. Potential machine efficiency $PME_{A,L}$ (%) for Vallerani machine as affected by traveling speed and spacing between successive continuous ridges. (Badia, Jordan).

Spacing (m)	Traveling speed (km/hour)				Average
	2	3	4	5	
4	72.0	63.3	57.0	51.2	60.9
8	69.4	60.0	56.4	50.9	59.2
12	70.0	54.1	55.6	49.4	57.3
Average	70.5	59.1	56.3	50.5	59.1

3.1.2. Constructing intermittent bunds

Tests revealed that, at speeds around 2 km/h, the machine was able to open intermittent ridges of all calibrated bund sizes. At speeds of around 3 km/h (Table 3), bund size I was lost (the plow continued constructing the ridge without being lifted to form a bund), while bund sizes I, II, and III were lost at speeds of around 4 km/h. Increasing traveling speed over 4 km/h resulted in constructing continuous ridges rather than intermittent ones. The lifting and lowering action speed was not enough to cope with the traveling speed. This also explains why traveling speeds greater than 4 km/h were not shown in Table 3.

Moreover, measurements showed that the four factory-set bund sizes (length of bund L + spacing between successive bunds S) were, in fact, different from those actually performed by the machine (Table 3). This can be attributed, first, to the non-synchronous performance of the hydraulic plow-lifting mechanism with the traveling speed and second, to the ground slipping conditions experienced by the tractor due to the weak structure and traction of the soils in the Badia. This

also explains why the actually measured bund size increased with increasing traveling speed. Bund size IV, for example, measured at 2, 3, and 4 km/h was 6.3, 6.5 and 7.2 m, respectively (Table 3).

Table 3. Theoretical machine capacities (by area covered TMC_A and by number of bunds constructed TMC_P), and the respective potential machine capacities (PMC_A, PMC_P) as calculated for Vallerani machine at different spacing between intermittent ridges, different traveling speeds, and different bund sizes. (Badia, Jordan)

Spacing between ridges, (m)	Average traveling speed, (km/h)	Bund size			TMC_A (ha/h)	TMC_P (bund/h)	PMC_A (ha/h)	PMC_P (bund/h)
		Size	Length + Spacing (m)					
			Factory set	Actually measured				
4	2	I	2.3	2.1	1	952	NM	NM
		II	3.6	3.2		625	0.59	368
		III	5.2	4.8		416	NM	NM
		IV	7	6.3		317	0.56	177
	3	I	2.3	NA	NA	NA	NA	NA
		II	3.6	3.3	1.5	909	0.84	510
		III	5.2	5		625	NM	NM
		IV	7	6.5		462	0.79	244
	4	I	2.3	NA	NA	NA	NA	NA
		II	3.6					
		III	5.2					
		IV	7	7.2	2	556	0.96	267
8	2	I	2.3	2.1	1.8	952	NM	NM
		II	3.6	3.2		625	1.08	375
		III	5.2	4.8		416	NM	NM
		IV	7	6.3		317	0.97	171
	3	I	2.3	NA	NA	NA	NA	NA
		II	3.6	3.3	2.7	909	1.45	490
		III	5.2	5		625	NM	NM
		IV	7	6.5		462	1.49	256
	4	I	2.3	NA	NA	NA	NA	NA
		II	3.6					
		III	5.2					
		IV	7	7.2	3.6	556	1.73	267
12	2	I	2.3	2.1	2.6	952	NM	NM
		II	3.6	3.2		625	1.46	350
		III	5.2	4.8		416	NM	NM
		IV	7	6.3		317	1.29	158
	3	I	2.3	NA	NA	NA	NA	NA
		II	3.6	3.3	3.9	909	1.93	448
		III	5.2	5		625	NM	NM
		IV	7	6.5		462	1.94	230
	4	I	2.3	NA	NA	NA	NA	NA
		II	3.6					
		III	5.2					
		IV	7	7.2	5.2	556	2.55	272

NA = Not applicable

When constructing intermittent ridges (micro-basins), the effects of both spacing between successive ridges and traveling speed on machine capacity were similar to those when constructing continuous ridges. In addition, increasing bund size had a negative effect on both PMC_A and PMC_P. In 4 m ridge spacing, for example, switching from size II to size IV at 2 km/h traveling speed, greatly reduced PMC_P (from 368 to 177 bund/h), but only slightly reduced PMC_A (from 0.59 to 0.56 ha/h). Such changes in basin sizes and machine capacities should be evaluated together with WH system requirements and with the impact of these changes on soil–water–plant conditions.

The effect of ridge spacing on potential machine efficiency ($PME_{A,P}$), when constructing intermittent ridges (Table 4), was similar to that when constructing continuous ridges. However, the effect of traveling speed on machine efficiency in constructing intermittent ridges was not as great as in continuous ridge construction. It seems that the time lost by the operator ensuring the good staggering of bunds between successive contour ridges had masked the expected difference in efficiencies between different traveling speeds. This also explains why the magnitudes (Table 4) of machine efficiency (55.8, 52.8, and 48.3% at 2, 3, and 4 km/h, respectively) in constructing intermittent ridges were lower than those obtained (Table 2) in constructing continuous ridges (70.5, 59.1, and 56.3% at 2, 3, and 4 km/h, respectively).

Table 4. Potential machine efficiency $PME_{A,P}$ (%) for Vallerani machine as affected by traveling speed and spacing between successive intermittent ridges. (Badia, Jordan).

Traveling speed	2 km/hour		3 km/hour		4 km/hour		
Bund size	II	IV	II	IV	II	IV	
Spacing (m)							Average spacing
4	59	56	56	53	NA	48	54.4
8	60	54	54	55	NA	48	54.2
12	56	50	49	50	NA	49	50.8
Average speed	55.8		52.8		48.3		53.1

NA = Not applicable

Working 165 hectare in 118 hours gave an actual machine capacity by area of

AMC_A = 165 ha / 118 h = 1.4 ha/h.

Dividing by the average theoretical machine capacity TMC_A calculated over all worked sites (2.7 ha/h), and multiplying by 100%, the actual machine efficiency over 18 working days was $AME_A = (1.4 \text{ ha h}^{-1} / 2.7 \text{ ha h}^{-1}) * 100\% = 51\%$.

This efficiency of 51% calculated over 18 working days was less than either the 59.1% efficiency calculated by averaging all potential efficiencies of continuous ridging (Table 2) or the 53.1% efficiency of intermittent ridging (Table 4). These differences were due to the fact that time losses (such as time needed to switch from one location to another or time for rests, maintenance and field work planning) were taken into consideration when calculating actual machine efficiencies, but they were not considered when potential machine efficiencies were calculated.

In general, either potential or actual efficiencies, if compared with efficiencies of regular ridging, seem to be even lower. Nevertheless, in constructing WH contour ridges, a level of 53% machine efficiency is still acceptable knowing that a one-way plow has to keep plowing in one direction, whereas the tractor has to spend time turning and going back to the start at every new pass to keep the basin facing the uphill side in order to capture the runoff water. Average fuel consumption was 7.2 l/h, 0.34 l/bund and 5.15 l/ha

3.2. Technical issues and potential solutions

Working under the soil and topographical conditions of the Badia, the performance of the hydraulic lifting mechanism was affected by the soil working depth. When the machine encountered rocky or shallow soil (shallower than 50 cm), which is usually met with on the upper hill sides, the plowing depth had to be reduced forcing the ground wheel of the hydraulic mechanism to loose its continuous contact with the soil and thus delaying the lifting action of the plow, which consequently affected the micro-basin set size and further led to irregular staggering of bunds on successive contour ridges. Therefore, it was more stable and convenient to open shallow continuous ridges, on the uphill sides, rather than intermittent ones.

In some circumstances and due to terrain roughness, the sweeping blade either lost contact with ground and was therefore not able to throw the soil clods produced by the moldboard back to the ridge, or it scraped the soil surface instead of sweeping it, causing damage to the entrance of the basin. To overcome this problem a rubber extension was added to the metal blade. This improved the contact with the soil making it flexible but not rigid and enabled soil sweeping instead of scraping. Staggering between bunds of subsequent intermittent ridges was irregular when: a) contour ridges were not parallel, which was very common on the double grade slopes of Badia, and b) when the hydraulic system guide wheel lost contact with the ground due to the rough surface or to shallow plowing. To overcome this problem, the guide wheel was modified so that in these circumstances, it was lifted to roll against the rear wheel of the tractor instead of the ground.

The programmable hydraulically-operated lifting mechanism of the machine began to fail at traveling speeds of around 4 km/h. At higher speeds, either the ridge tended to be continuous rather than intermittent, or the bund size was noticeably increased. This means that the lifting mechanism had not been fast enough to raise the plow from the soil (due to insufficient fluid flow) before the cycle of constructing the next bund had started. This problem can be attributed to the relatively low capacity of the system's pump when higher flow rates at greater traveling speeds were required. Replacing the hydraulic pump and the spool valve with higher capacity ones may be an effective solution of overcoming such system weakness.

4. Conclusions

The actual capacities and efficiencies obtained in this study were lower than those previously reported for Vallerani plows. Nevertheless, the Vallerani mechanized system for the implementation of water harvesting structures proved to be a practical way of eliminating much tedious manual work or even traditional mechanized systems. The machine field capacity, its effective efficiency, and its energy consumption were all quite satisfactory for large-scale rehabilitation and improvement in water productivity in the dry areas of the East Mediterranean region, as has been previously shown in other regions.

The machine was easily adapted to Jordanian Badia condition. The results of the technical tests

performed at different sites under different conditions of the Badia provide useful guidance for the technical management of water harvesting systems to be implemented in the region. With some technical improvements to the existing machine that were suggested in this study, the performance could be further enhanced for more effective management of the system.

The main technical problems encountered were first, the slow speed of the hydraulic plow-lifting mechanism, which can be overcome by using a higher capacity pump, so enabling the machine to work at a higher traveling speed and increasing significantly the potential machine field capacity and the actual efficiency, and second, the improper bund staggering across the field, which can be partly improved by modifying the contact conditions of the ground wheel of the plow-lifting mechanism. Replacing the one-way plow with a reversible one will enable the machine to work on slopes in two directions, which can be expected to significantly increase the machine's effective efficiency.

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2. Contour Laser Guiding for the mechanized "Vallerani" micro-catchment water harvesting systems

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Abstract

Mechanized construction of micro-catchments for water harvesting was successfully tested in *Badia* (rangeland) areas in Syria and Jordan, using the Vallerani plow, model Delfino (50 MI/CM), manufactured by Nardi, Italy. The plow was able to construct intermittent and continuous contour ridges, and could potentially be used to rehabilitate degraded rangelands. However, one major issue for large-scale implementation is the high cost and time required to manually identify contours for the plow to follow. The objective, therefore, was to add an auto-guiding system to enable the tractor to follow contours without demarcation through conventional surveying. Most existing auto-guiding systems, which are usually used in road construction and agricultural land leveling, were found to be expensive or impractical. A low-cost Contour Laser Guiding (CLG) system, with specifications that suit the contour ridging in undulating topographic conditions of dry rangelands (badia), was chosen, mounted, tested and adapted to water harvesting applications. The system consisted mainly of a portable laser transmitter and a tractor-mounted receiver, connected to a guidance display panel. The system was field-tested over 95 ha, and system capacity determined under different terrains, different slopes (1-8%), and different ridges' spacing (4-12 m). The easy adaptation and implementation of the CLG to the Vallerani unit tripled system capacity, improved efficiency and precision, and substantially reduced the cost of constructing micro-catchments for water harvesting. The system is recommended for the large-scale rangeland rehabilitation projects in dry areas, not only in West Asia, but also in North Africa.

1. Background

Micro-catchment water harvesting systems were tested in the dry rangelands for the rehabilitation and combating desertification in this low rainfall areas. In the Jordanian and Syrian dry rangelands (Badia), investigations showed several successes as demonstrated over hundreds of hectares. WH techniques included contour ridges and bunds implemented along contour lines of sloped areas. However, most of theses techniques lacked specialized machinery that supports the implementation. The conventional methods were slow, costly and laborious. Al-Tabini et al. (2008) reported that the lack of mechanized power (of unconventional machinery), supporting the establishment of WH system, has limited its large-scale implementation.

The most successful so far was the mechanized intermittent and continuous contour ridging, the so called "Vallerani", which was introduced and successfully tested to rehabilitate the degraded dry rangelands in many West-Asian and North- and Sub-Saharan African countries as well as in the Badia. In that system, the WH structures were constructed by a special plough designed

to open contour micro-catchments of either a continuous furrow/ridge or semicircular micro-basins (bunds) with high capacity of 400 micro-basins per hour (Antinori and Vallerani, 1994). Malagnoux (2006) reported even 700 – 1200 micro-basin per hour. It can provide substantial soil water storage capacity of 0.200 – 0.600 cubic meters per bund (Somme et al. 2004). In addition, its implementation provided a low cost and practical means of constructing the water harvesting system with a field capacity of 15 to 20 hectares a day (Antinori and Vallerani, 1994; Malagnoux, 2006 and Prinz, 2001). Taking into account the harsh topographic conditions prevailing in the Badia, such capacity is acceptable for large scale implementation.

Having been tested by ICARDA since 1997 in Syria and Jordan as well as many North African countries, the Vallerani system, however, was not able to reach its potential capacity due to the slow pace and high cost of manual layout of the contour lines, which should precede the implementation. A team of three surveyors was able to contour only 5 hectares a day, which was considered as a bottle neck in the implementation process of the system. In Syria, research within the project *"Communal Management and Optimization of Mechanized Micro-catchment Water Harvesting for Combating Desertification in the East Mediterranean Region"* on the costing of the implementation of the system showed that the cost of the manual identification of contour lines preceding the operation more than doubled the total cost per hectare of constructing the ridges. (ICARDA, 2007).

To overcome this limitation of the system, this work aimed at developing a mechanism to guide the tractor to run automatically along the contour lines without the need to follow surveyors' marks. Several GPS-based auto-guiding systems were considered (www.trimble.com/agriculture) for this purpose, but found either very costly and/or very complicated. The most suitable was found to be a laser-based guiding system (LGS). The system was first adapted for land leveling in agriculture, mining and road construction applications, but now is common for several precise agricultural operations in many countries such as Australia, India, Japan and the United States. The LGS in such applications consisted of:

a. A laser transmitter that transmits a rotating laser beam. The laser transmitter mounts on a tripod which allows the laser beam to sweep above the tractor unobstructed with the plane of light above the field
b. A laser receiver mounted on a mast intercepts the laser beam, detects the position of the laser reference and sends a signal to control panel,
c. An electrical control panel which interprets the signal from the receiver, magnifies it and sends an actuating signal to the tractor hydraulic system,
d. An electro-hydraulic control valve which control oil flow in order to raise or lower the leveling bucket or blade.

This system, as described by Rickman (2002) and Jat *et al*. (2006), needs interfering into the tractor hydraulic system in order to install the electro-hydraulic control valve. It also needs a lot of field preparation and requires conducting a topographic survey.

Fortunately, in contour ridging there is no leveler (blade or bucket) that needs to be lowered and raised by an electro-hydraulic valve, which encouraged the use and adaptation of the LGS without the fourth components mentioned above to be a Contour Laser Guiding (CLG) system.

Launched by ICARDA in 2003 the project "Communal Management and Optimization of Mechanized Micro-catchment Water Harvesting for Combating Desertification in the East Mediterranean Region" (known as Vallerani Project) looked, as one of its objectives, into the possibility of improving the performance of the Vallerani mechanized system by facilitating this

research work (ICARDA 2007). The objective of this research work, therefore, was to improve the capacity of the Vallerani mechanized system in contour ridging by adding and adapting a CLG, which enables the tractor to follow the contour lines on-the-go.

2. Methodology

The WH contour ridging is a heavy load soil formation that consists of constructing deep (30-60 cm) continuous or intermittent ridges or bunds (pits) along a contour line using the "Vallerani" or similar plow attached to a tractor on slopes that range between 1% and 10%. The ridges are opened to face upstream slope so runoff water flowing downstream is intercepted and collected within the created bund to infiltrate later and stored in the soil profile for plants use. Distance between two successive contour ridges usually ranges from 4 to over 12 m depending on the runoff coefficient, soil characteristics and plants to be grown. Therefore, the fall in elevation between ridges vary accordingly.

2.1. CLG devices and the principle of operation

The CLG can detect and measure the difference in elevation between the current tractor position (while traveling) and the position of a reference point in the field to be displayed on a panel in front of the tractor operator. The operator would easily steer the tractor in a way that keeps this difference unchanged in order to maintain the tractor travel on the contour line. In this case, the required CLG devices to be used were a laser transmitter (1000 m radius of coverage) mounted on a tripod (Figure 1), a laser receiver mounted on a mast (Figure 2), and an electrical display panel (Figure 3), with visual and sound display.

Figure 1. The laser beam transmitter mounted on a tripod on uphill side.

The laser transmitter transmits a rotating laser beam (in horizontal plane), which is intercepted by the laser receiver mounted on a telescoping mast on the tractor and sends a signal to the display panel. The display panel interprets the signal from the receiver and displays signals for the operator. The signals indicate not only the matching of levels, but also how far (up or down) the levels are not matching, so the operator can decide where to steer the tractor, left or right in order to maintain the tractor traveling along the contour. This is true as far as the beam is intercepted by the receiver. Therefore, the length of the receiver determines the difference in

elevation that can be detected and determines the time that the display can show a reading on the panel and hence, the number of contours worked at the current position of the receiver.

Figure 2. Laser receiver mounted on a telescoping mast on the tractor.

Figure 3. Display panel mounted in front of the tractor operator.

When switching to the next down hill (or uphill) contour line, if the receiver still can intercepts the laser beam, then the operator can continue opening ridges without any adjustments. Otherwise, the operator should raise (or lower) the receiver on its mast until the signal is displayed and then continue the operation. After working some passes, when it is already not possible to raise or lower the receiver on the mast due to insufficient length of the mast, the transmitter with its tripod should be either lowered (or raised) or relocated down hill (or uphill) so the laser beam can be intercepted by the receiver.

Providing that the transmitter was located on the uphill side, the operator, while driving along the contour line, might face the following five possible guiding situations and react accordingly:

a) The signal on the display panel indicates no difference in elevation between the laser beam and the position of the tractor (the tractor is traveling exactly on the specified contour line). The operator should keep traveling without steering right or left.

b) The signal on the display panel indicates increased difference in elevation between the laser beam and the position of the tractor (the tractor went off the specified contour line downhill). The operator should turn the steering left to the uphill side to achieve zero difference again.

c) The signal on the display panel indicates decreased difference in elevation between the laser beam and the position of the tractor (the tractor went off the specified contour line uphill). The operator should turn the steering right to the downhill side to achieve zero difference again.

d) Passing through situation (b), the operator did not react properly and continued driving down hill until the signal on the display panel has been lost. The operator should turn the steering left to the uphill side to catch the signal and achieve again zero difference.

e) Passing through situation (c), the operator did not react properly, and continued driving uphill until the signal on the display panel has been lost. The operator should turn the steering right to the downhill side to catch the signal and achieve again zero difference.

Therefore, the operator may react differently in each situation to maintain traveling along the contour line. A skilled operator should work within the first three possibilities **a**, **b**, or **c** described.

2.3. Determining system capacity

In order to evaluate the capacity and the appropriateness of the CLG in practical implementation of contour ridging under prevailing conditions, the following parameters were determined:

- Number of contour ridges (**B**) that can be worked without any need to readjust the position of the receiver on the mast.

  B = **L** / **A** (Rounded), where **L -** Length of photocells on the receiver. According to ordered devices (L = 31cm), **A -** The fall in elevation when moving from the uphill ridge to the next downhill ridge in cm. A = percentage slope x ridges' spacing.

- The number of ridges (**C**) that can be constructed without any need to lower (raise) the transmitter on the tripod or to relocate it downhill (or uphill).

  C = **D** / **A** (Rounded), where **D -** Adjustable difference in alleviation between the transmitter and the receiver on the mast according to ordered devices (D = 120 cm).

The parameters **B** and **C** can be considered as reasonable indicators for high performance during ridging application on-the-go. The higher they are the less action from the operator is required while traveling and consequently the higher the capacity and the automation level of the system.

3. CLG system performance

The CLG mounted on the "Vallerani" unit was tested in the Jordan Badia on 95 ha land with slopes ranging from 1-8 % and with different spacing (4, 6, 8, and12 m) between successive contour ridges. The operation was successful in that the ridges were constructed right on the contour lines (as checked by conventional topography survey instrument), and the operator was able to easily acquire the guiding skills within one or two passes.

The parameters **B** and **C** were determined for different slopes and different spacing between

ridges (Table 1). For example, with slope of 4% and contour spacing of 8 m (which is equal to a 9-m effective working width), the operator needed to adjust the receiver each pass (**B** = 1) and the elevation of the transmitter every fifth pass (**C** = 4). Assuming that the average length of the passes in such a case was 500 m, the area covered, therefore, was 500 m x 9 m x 4 passes, which is equal to 1.8 ha. This area was doubled with slope of 2% and contour spacing of 4 m (**C** = 15) . This can be considered a quite acceptable system efficiency and appropriateness to the application.

Table 1. Numbers of ridges that can be made on – the – go before adjusting the receiver (B), and before adjusting the transmitter (C) as calculated at different slopes and spacings between contour ridges

	Slope							
Ridges spacing	to 2%		to 4%		to 6%		to 8%	
	B	C	B	C	B	C	B	C
4m	4	15	2	7.8	1.2	5	1	3.4
6m	2.3	10	1.2	5	1	3.4	1	2.3
8m	1.2	7	1	3.4	1	2.3	1	1.2
12m	1	5	1	2.3	1	1.2	1	1

It is quite clear from Table 1 that the number of adjustments increased with increasing both spacing between ridges and slope. Fortunately, wider spaced ridges, in water harvesting system, are usually not applied on steep slopes. Therefore, shaded figures of **B** and **C**, shown in Table 1, describe techniques that are not followed.

The CLG system devices, ordered and used in this work, are similar to those used in land leveling applications, where slopes are usually mild or do not exist. Therefore, the relatively frequent adjustment and relocation of the transmitter and the receiver (low numbers of **B** and **C**) indicate, somehow, a weakness in the guiding system. Nevertheless, such a weakness can be overcome by: a) Using longer receiver and taller mast specially manufactured for contour ridging. b) Using electro-adjustable mast, so the operator can relocate the receiver while driving, and c) Planning the field works in a way that perform long contour ridges rather than short ones by switching from one hill to another adjacent, and choosing proper locations for the transmitter to cover long fields of similar sloping.

The implementation of the CLG on the "Vallerani" unit was successful in that the operation was accurate along the contour and the cost of contour layout was reduced drastically. The surveying works were completely eliminated from WH operation. The potential capacity of the mechanized contour ridging was, therefore, achieved by the possibility to lay out the contour lines *on-the-go* for 15- 20 hectares per day. Following are some of the additionally achieved advantages in comparison with conventional surveyed contour ridging:

a) Time and effort saving: In large scale implementation of water harvesting structures it's critical to start and finish up land preparation before the first rain. This will help in timeliness and hence improved WH systems management.

b) Cost reduction: Traditional land surveying cost (surveyors and equipment) is higher if compared with the cost of CLG, especially if considered over many years, and

if bearing into mind that the targeted areas of interventions are considered as low productive areas.

c) Ease of operation: While traditional surveying needs at least two skilled surveyors, the CLG can be operated by one man with minimum training.

d) High accuracy: Tractor driver usually moves between marks pigged by the surveyors in straight lines, which affects the accuracy of tracing the contour lines , while in CLG the operator is guided to trace the contours continuously all the time. This assures even elevation inside the catchments and thus assures even distribution of harvested water along them. Moreover, it happens in some incidents that tractor driver was confused by close adjacent surveyors' marks and drove toward the wrong mark.

e) The Laser guidance system can be used as surveying equipment with even farther range of coverage than traditional surveying equipment, and it can give guidance to as many surveyors or receivers as wanted.

4. Conclusion

The adaptation and implementation of the CLG system to the micro-catchment water harvesting mechanical unit (Vallerani) increased the system efficiency of not less than three times, and reduced the cost of implementation substantially. The improved system, after full evaluation, is recommended for the large-scale rehabilitation of rangelands development projects in the Badia and similar dry rangelands worldwide. Furthermore, testing and evaluation revealed that the performance of CLG system, with cooperation with manufacturers, can be further enhanced with minor changes to the specifications of the used devices to suit the contour ridging.

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3. Impact of micro-catchment water harvesting on plant diversity in Jordan Badia rangelands

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Abstract

Water scarcity is the limiting factor in plant establishment and growth. Microcatchment water harvesting systems provide an opportunity for plants regeneration and improved vegetation. A field experiment was conducted at Mharib village about 65 km south-east of Amman in the Jordan badia (latitude 31.672358°, longitude 36.21763°) to evaluate the effect of micro-catchment water harvesting technique on the native vegetation. The experiment consisted of two main land slopes, <5%), and 8-12%) and the sub-treatments in each slope were: T_1: Water harvesting with Vallerani intermittent contour ridges, within catchment area (VIC); T_2: Water harvesting with Vallerani intermittent contour ridges, within the ridges (VIR); T_3: Water harvesting with Vallerani continuous contour ridges, within catchment area (VCC); T_4: Water harvesting with Vallerani continuous contour ridges, within the ridges (VCR); T_5: water harvesting with traditional contour ridges, within catchment area (TPC); T_6: Water harvesting with traditional contour ridges, within ridges (TPR); T_7: barley plantation (BP); and T_8: control, with no intervention and no grazing (CIG). The average vegetation cover for within contour ridges treatment increased from 20% in December 2006 to 52% in April 2007. The highest total number of plants was recorded for *Poa bulbosa* L., followed by *Torularia torulosa* (Desf.) O.E.Scultz, Species richness values in April 2007 was 58% higher than that reported in December 2006; it ranged from 33 species to 5 species, from which 74% are annuals. The mechanized contour ridges intervention recorded the highest plant number whereas; the traditional ridges recorded the lowest. On the other hand, mechanized intermittent contour ridges recorded slightly higher number of plants per square meter compared with mechanized continuous contour ridges within contours. Barley plantation recorded the lowest plant per square meter compared with the other interventions with no significant difference with the control treatment.

1. Introduction

Natural rangeland in Jordan is an important resource for livestock feed. The area of natural rangelands is about 8 million ha and it constitutes about 90% of the total area of Jordan. The rangelands are distributed over three agro-ecological regions: 1) Badia rangelands, located within areas that receive less than 100 mm of rain per year, and cover about 7 million ha. This area is mostly government-owned land. 2) The Steppe rangelands, located in areas that receive annual rainfall between 100200 mm and cover about 1 million ha. About 90% of these lands are privately owned, the remaining 10% is government owned and characterized by rough terrain, which makes it difficult to develop. 3) The Highland rangelands, located in areas that receive annual rainfall of over 200 mm and cover about 45,000 ha. These lands consist of small plots scattered around villages (The National Strategy for Agricultural Development 2003).
The Badia and steppe rangelands have the largest water basins in the kingdom and possess high

potential for water harvesting in addition to important wildlife biodiversity. The most significant use of Badia (arid lands, as defined by Dutton and Clarke 1997) is pastoral. Sheep and goats graze the natural vegetation produced on the rangelands during the short time following rainfall episodes.

Jordan's grazing lands have suffered a continuous deterioration over time and this has resulted in the disappearance of vegetative cover (Al-Jaloudy 2001). The main causes for degradation are the environmental factors such as the dry climatic conditions leading to droughts and the depletion of soil nutrients. Socioeconomic factors also exert a serious degrading effect on rangelands. Overgrazing, too early grazing, and overuse of natural resources are causing a decline in the native vegetation in the Badia region and loss of indigenous plants. Uprooting of bushes for firewood by pastoral communities, uncontrolled arbitrary movement of vehicles in grazing lands; and increasing livestock density are further causes of degradation (Al-Jaloudy, 2001). Other reasons can be related to ploughing of marginal lands to exert property rights over the land (Abu-Zanat 1997). Policy factors also play a vital role in the process of degradation: for example there is lack of regulations for rangeland use, poor coordination between institutions and projects working in the field of range, and scattered efforts among the various institutions. Rangeland degradation severely affects the biodiversity of plants and other living organisms, and in many cases palatable plant species have been entirely eliminated from the plant communities. Many species which were previously common have now become scarce or have altogether disappeared.

Understanding the biodiversity status of the rangeland and its degradation levels will help scientists and planners to develop technical and socio-economic solutions aiming at restoration of the vegetation and the sustainability of rangeland. The decline of species and habitat diversity will continue unless there are major changes in policy based on improved technology and scientific knowledge (Bainbridge 2003).

In Jordan rangelands, water is the most limiting resource for improved agricultural production. Maximizing water productivity is an important strategy for dry farming systems (Oweis and Hachum 2006). Shaping the ground to concentrate available rainfall has been very effective for vegetation establishment in these areas. Microcatchments have been used successfully with domesticated crops for centuries, but have only recently been used to supplement rainfall for native vegetation (Ehrler et al. 1978). Micro-watersheds management systems can be built using hand labor, thus less expensive and more adapted to re-vegetation projects (Bainbridge 2003). Construction of micro-catchments alterations in the topography of a site to direct precipitation runoff offers a low cost, "passive" means of increasing the amount of water available to plants (Fidelibus and Bainbridge 1994). Indigenous practices of rainwater harvesting provide a sound basis for improved resource management. Moreover, innovative techniques such as mechanized construction of microcatchments for water harvesting built on traditional knowledge can reduce cost and provide people with tools for improving the rangelands as well as their income and livelihoods (Oweis and Hachum 2003).

This research was conducted with the objective to evaluate the effect of microcatchment water harvesting (MCWH) on the native vegetation regeneration and potential improvement.

2. Materials and methods

The experimental site is located at Mharib village about 65 km south-east of Amman-Jordan (latitude 31.672358 o, longitude 36.21763o). Site altitude ranges between 820-846 meters a.s.l. Land use is mainly rangeland and barley cultivation. The grazing period extends from 2 to 5

months (March to August) depending on rangeland situation. Average annual rainfall is 152mm. Rainfall is sporadic and it mostly occurs in short intense storms. Surface runoff efficiency ranges from 6% and 20% (ICARDA 2007). The steppe grassland produces a tough turf, which protects the soil surface from wind and water erosion, and frequent grazing keeps vegetation growth close to the soil surface. About 13 small and medium gullies exist within the watershed (ICARDA 2007).

The experimental site has two slopes, gentle (< 5%) and moderate (8-12%). Both slopes have shallow (40-60cm deep) to medium soils depth (80-199cm deep) and embrace a gently undulating valley of deep soil. The soil structure is friable, fragile, and highly calcareous forming a thick surface crust when wetted and highly affected by erosion. The infiltration rate measured using the double ring method ranged from 20-42mm/hr. The native vegetation cover ranged from 11% to 25% and concentrated at the banks of waterways (ICARDA 2007).

The Vallerani machine (Antinori and Vallerani, 1994; Malagnoux, 2006; Prinz, 2001) was used for constructing the water harvesting structures in the different sub-treatments. Two main ridge shapes were constructed by the machine: continues ridges (along the contour ridge of each treatment site) and the intermittent ridges (2m long) along the contour ridge. The traditional farmer's furrows method was also included using the mold board plough. *Atriplex halimus* was planted in the contour ridges constructed by both the Vallerani machine and the traditional furrows with fixed distance (6m for all treatments). Barley was planted in the site using farmer's traditional method with 50kg seed/ha. A control area was distributed randomly between the treatments with no contour

To study the effect of different water harvesting techniques on the native vegetation, a survey of the flora was carried out on three consecutive dates: December 2006, April 2007 and April, 2008. The survey was carried out using the Belt Transect Method (Schmutz et al. 1982). One transect had been laid down per land slope per sub-treatment. Five quadrates were placed along each transect at 10m interval. A total of 48 transect and 240 quadrates for the experimental site were surveyed. On April, 2007 the native vegetation was cut to the ground level, weighed to get fresh weight and then dried to determine dry weight. An estimation of some vegetation communities of high conservation value - those areas that make a significant contribution to the conservation of biodiversity (that is the species mostly adapted to the site and give higher percentage of survival and biomass) - was obtained.

The experiment was conducted in randomized complete block design with three replicates. The treatments consisted of two main land slopes, slope 1 (S_1: <5%), and slope 2 (S_2: 8-12%), and the sub-treatments in each slope were: T_1: Water harvesting with Vallerani intermittent contour ridges, within catchment area (VIC); T_2: Water harvesting with Vallerani intermittent contour ridges, within the ridges (VIR); T_3: Water harvesting with Vallerani continuous contour ridges, within catchment area (VCC); T_4: Water harvesting with Vallerani continuous contour ridges, within the ridges (VCR); T_5: water harvesting with traditional contour ridges, within catchment area (TPC); T_6: Water harvesting with traditional contour ridges, within ridges (TPR); T_7: barley plantation (BP); and T_8: control, with no intervention and no grazing (CIG).

Data were analyzed using the SAS program version 9 applying the repeated measure arrangement (SAS Institute 2002), for the following measurements: 1) Effect of slopes, water harvesting methods, and sampling dates on the vegetation cover, and the biomass production of the native plants, and 2) Biodiversity indices (Species Richness (SR), Relative Density (RD), Species Abundance (SA), Shannon – Wiener Diversity Index (SDI), and Shannon's equitability (E_H).

3. Results

3.1. Total number of plant species

Results (Table 1) showed that mechanized intermittent contour ridges intervention resulted in the highest plant number within the ridges. This was followed by mechanized continuous contour ridges, and traditional contour ridges interventions. As for sampling date, the highest plant number was recorded in April 2007, followed by December 2006 in moderate slope, then in April 2008, whereas the lowest plant number was recorded in December 2006 . The mechanized contour ridges intervention recorded the highest plant number (58%-66%) from the total plant recorded in the area, whereas, the traditional ridges recorded (11%-21%) of the plants. Mechanized contour ridges within the ridges intervention recorded higher plant number per square meter (42%-52%) compared to mechanized catchment area (23%-31%). On the other hand, mechanized intermittent contour ridges recorded higher plant number per square meter (15%-29%) compared with mechanized continuous contour ridges within contours (20%-26%). Barley plantation recorded the lowest plant per square meter (4%-6%) compared with the other interventions with no significant difference with the control treatment (5%-6.6%).

The highest total plant number (284 plants m^{-2}) was recorded within the ridges of the mechanized intermittent contour ridges treatment, in samples collected in April 2007 in the moderate slope (8-12%), whereas, the lowest total plants number was recorded in the barley plantation (27 plant m^{-2}) treatment in samples collected on April, 2008 in the gentle slope.

Table 1. Effect of slope, sampling date and WH intervention on number of native plants per square meter

WH interven-tion	Number of plants m^{-2}					
	Slope <5%			Slop 8-12%		
	December 2006	April 2007	April 2008	December 2006	April 2007	April 2008
T1: VIC	61 klmno*	I50 defg	30 no	60 klmno	130 fghi	60 klmno
T2: VIR	87 ijklm	231 ib	210 bc	184 bcde	284 a	212 bc
T3: VCC	80 ijklmn	71 jklmno	59 klmno	97 hijkl	60 lmno	108 ghijk
T4: VCR	148 efgh	202 bcd	162 cdef	163 cdef	228 b	164 cdef
T5: TPC	33 no	87 ijklm	114 fghij	35 mno	62 jklmno	67 jklmno
T6: TPR	109 ghijkl	162 cdef	82 ijklmno	161 cdef	218 b	85 jiklm
T7: BP	32 no	60 klmno	27 o	42 mno	60 klmno	32 no
T8: CIG	30 no	68 jklmno	37 mno	32 no	66 jklmno	37 mno
Total	580	1031	721	774	1108	765

** Values having the same letter are not significantly different at p≤ 5% using SAS analysis version*

3.2. Vegetation cover percentage

Analysis of variance for the effect of water harvesting interventions and sampling dates on the vegetation cover shows significant interaction between slope and sampling date, and between sampling date and WH interventions. The highest vegetation cover percentages (42%) across interventions were estimated for April 2007 in the moderate slope, followed by gentle slopes (35%) of the same date (Table 2). The lowest vegetation cover percentages were for samples collected on December, 2006 at both slopes.

The two way interaction between sampling dates and interventions is shown in Table 3. The highest vegetation cover (58%) was measured within the ridges of the mechanized continuous contour ridges intervention sampled in April 2007. However, this was not significantly different ($p<0.05$) from those measured within the ridges of the mechanized intermittent contour ridges, and within the ridges of the traditional contour ridges, in the same sampling date (Table 3).

Table 2. Effect of slope and sampling dates on vegetation cover percentages

Date	Vegetation cover per percentage	
	slope <5%	**8-12% slope**
December 2006	18 e*	21 de
April 2007	35 b	42 a
April 2008	24 cd	25 c

** Values having the same letter are not significantly different at p≤ 5%*

Table 3. Two way interaction effect of the eight WH interventions, and sampling dates on vegetation cover.

WH Intervention	% Vegetation cover		
	Date		
	December 2006	**April 2007**	**April 2008**
T1: VIC	16 ghij*	28 cdef	26 def
T2: VIR	25 defg	55 a	38 b
T3: VCC	19 fghi	37 bc	26 de
T4: VCR	29 bcdef	58 a	27 cdef
T5: TPC	20 efgh	38 b	26 def
T6: TPR	26 def	50 a	30 bcde
T7: BP	15 ghij	30 bcd	15 hij
T8: CIG	8 i	12 hij	9 ij

** Values having the same letter are not significantly different at p≤ 5%*

The mechanized interventions recorded 12% higher average vegetation cover than the traditional plough, while the mechanized within contour ridges recorded 40% higher average vegetation cover percentage compared to the catchment area. Mechanized continuous contour ridges recorded higher average vegetation cover percentages of only 5%, even with no significant difference, compared with mechanized intermittent. Barley plantation recorded higher average vegetation cover (60%) than the control with no intervention and no grazing treatment.

Table 4. Two way interaction effect of the eight WH interventions, and two slopes on dry weight (gm m^{-2})

WH Intervention	Dry weight (gm m^{-2}).	
	slope <5%	8-12% slope
T1: VIC	6 cd*	6 cd
T2: VIR	7 cd	21 a
T3: VCC	5 d	4 d
T4: VCR	16 ab	12 bcd
T5: TPC	5 d	4 d
T6: TPR	17 ab	14 abc
T7: BP	10 bcd	9 bcd
T8: CIG	5 d	6 cd

** Values with the same letter are not significantly different at p≤ 5% using SAS analysis version 9*

3.3. Biomass production

The highest dry weight (Table 4) was recorded for mechanized intermittent contour ridges, within the ridges intervention, however this was not significantly different from dry weight values obtained from other interventions such as the traditional contour ridges, within ridges, mechanized continuous contour ridges, within the ridges, and water harvesting with traditional contour ridges, within ridges at moderate slope (at slope <5%).

3.4. Biodiversity indices

High species diversity was found for plants within the ridges in the mechanized intermittent contour ridges intervention (Table 5), with high species evenness within the site (EH = 0.81) as well as high SR (52 species) in the gentle slope. For the moderate slope, the high diversity values (SDI= 2.89, EH= 0.73 and SR = 52 species) was measured for plant species found within the ridges in the mechanized intermittent contour ridges intervention Plant species within the ridges of the mechanized continuous contour ridges, intervention show high average diversity in the two slopes, compared with the control.

The average SDI in the mechanized contour ridges were higher by 15% in gentle slope and 9% in the moderate slope compared with the traditional ridges, while the increment in E_H was 11% for mechanized contour ridges in gentle slope and 4% in moderate slope compared with

the traditional ploughing. The plant SR was higher by 19% in the gentle slope and 2% in the moderate slope for mechanized contour ridges compared with the traditional ploughing.

The control had higher SDI and E_H and SR compared with barley planting in the gentle slope. However in the moderate slope, barley planting intervention recorded higher SDI, E_H and SR compared with the control.

3.5. Vegetation communities of high conservation

From previous results of this study (Table 5) it was found that the area with contour ridges mechanized intermittent had the highest diversity values (SDI=3.21). A total of 54 plant species were recorded in this site, with species richness (SR) ranging from one species to 15 species (Table 6). The highest SR was recorded in gentle slope (<5%) and was for Bromus madritensis sub sp. Delilei, Catapodium rigidum (L.) C.E. Hubb., Ceratocepahala falcata (L.) Pers., Eremopyrum bonaepartis (Sprengel) Nevski, Filago Desertorum Pomel, Hordeum glaucum Steud., Poa bulbosa L., and Schismus barbatus L. In moderate slope (8-12%) the highest SR (15) was recorded for Ceratocepahala falcata (L.) Pers., Filago Desertorum Pomel, Herniaria hirsuta L., Lasiopogon muscoides L., Poa bulbosa L., Schismus barbatus (Loefl. ex L.) Thell and Torularia torulosa (Desf.) O. E. Schulz.

Table 5. Shannon-Wiener Diversity Index (SDI), Shannon's equitability (E_H) and species Richness (SR) of the different interventions in the two slope recorded for April, 2007

WH Intervention	Gentle slope <5%			Moderate slope 8-12%		
	SDI	E_H	SR	SDI	E_H	SR
T1: VIC	1.7	0.6	17	2.25	0.68	28
T2: VIR	3.21	0.81	52	2.89	0.73	52
T3: VCC	1.83	0.64	17	1.59	0.55	18
T4: VCR	2.36	0.71	28	2.37	0.67	34
T5: TPC	1.53	0.53	18	1.83	0.62	19
T6: TPR	2.33	0.71	27	2.31	0.65	34
T7: BP	1.73	0.57	21	2.31	0.72	25
T8: CIG	2.06	0.66	23	2.14	0.69	22

Discussion

Native vegetation cover (vegetation cover, plant number, and biodiversity parameters such as SDI and SR values) was found to be the highest under mechanized contour ridges and the treatment within ridges. The mechanized plough produces contours that are deep enough to

collect more moisture than other treatments (Suleman et al. 1995). Wetted soil depth increased under mechanized continuous and intermittent contour ridges by 3.5 to 4 times than under the control treatment. The main effect here is that the ripper part of the plough loosens the soil to deeper depth (over 60 cm) without disturbing soil structure significantly. The ridges intercept runoff and allow the water to stay over the surface long enough to infiltrate into soil profile. This causes large differences in the wetted soil depth that exceeded 100cm under mechanized contour ridges (continuous or intermittent) compared to 20–25cm depth under the control treatment (BBM 2007). The availability of more moisture is the major reason behind having higher vegetation cover, taller plants or higher biodiversity values. Also, the presence of shrubs can improve the natural vegetation.

Table 6. List of plant species, their Species Richness (SR) and Relative Density (R.D) recorded in contour ridges mechanized intermittent within contours intervention

Plant Species	Gentle slope		Moderate slope	
	SR	R.D	SR	R.D
Aaronsohinia factorovshyi Warb. & Eig	8	1.03	4	0.33
Adonis dentata Del	10	0.86	4	0.24
Allium desertorum Forssk	4	0.38	5	0.28
Alyssum damascenum Boiss. & Gaill	10	1.12	4	0.24
Anabasis syriaca Iljin Iljin	5	0.30	4	0.19
Androsace maxima L.	13	2.10	10	1.86
Anthemis haussknechtii Boiss. & Reut.	8	0.62	3	0.14
Astragalus cruciatus Link.	3	0.21	2	0.09
Astragalus spp.	3	0.21	1	0.05
Atriplex halimus L.	11	0.89	4	0.33
Bassia muricata (L.) Asch.	5	0.24	2	0.12
Biarum anguotifol L.	2	0.09	0	0
Bromus madritensis sub sp. Delilei	15	4.04	6	1.13
Capsella bursa-pastoris (L.) Medik	0	0	2	0.12
Catapodium rigidum (L.) C.E. Hubb.	15	5.17	5	0.73
Ceratocepahala falcata (L.) Pers.	15	3.04	15	8.67
Colchicum tunicatum Feinbrum	1	0.06	0	0
Dipoltaxis erucoides (L.) DC.	11	1.00	4	0.19
Erodium hirtum Willd	9	0.62	14	1.10
Erucaria spp.	6	0.50	11	0.78
Eruca sativa Miller	7	0.50	2	0.12
Eremopyrum bonaepartis(Sprengel) Nevski	15	4.55	5	1.20
Evax contracta Boiss.	7	0.53	3	0.17
Filago desertorum Pomel	15	4.96	15	9.99
Gagea chlorantha (Bieb) Schult. fil.	6	0.65	3	0.19
Gagea reticulate (Pallas) Schult. fil.	9	0.62	9	0.78
Gymnarrhena micrantha Desf.	12	9.27	14	7.12
Gynandiris sisyrinchium (L.) Parl	12	2.21	11	0.61
Hammada eigii Iljin	8	2.66	13	14.08
Helianthemum ledifolium (L.) Miller	9	0.74	13	2.52
Herniaria hirsuta L.	13	5.43	15	9.26

Hirschfeldia incana (L.) Lagr.-Foss	10	0.74	4	0.21
Hordeum glaucum Steud.	15	3.72	14	2.47
Lasiopogon muscoides (Desf.) DC.	10	1.92	15	7.12
Lappula spinocarpos (Forssk.) Asch.	1	0.12	1	0.02
Bellevalia spp.	10	0.62	6	0.24
Leopoldia longipes (Boiss) Losinsk.	12	2.90	8	1.22
Malcolmia conringiodes Boiss.	7	0.59	4	0.31
Poa bulbosa L.	15	13.17	15	5.81
Raphanus aucheri Boiss.	2	0.09	1	0.05
Rhagadiolus stellatus (L.) Gaertner	4	0.24	7	0.35
Roemaria hybrida (L.) DC.	11	0.89	8	0.61
Rostraria berythea L.	8	0.83	8	0.80
Salsola vermiculata L.	2	0.09	2	0.07
Schismus barbatus (Loefl. ex L.) Thell.	15	6.61	15	3.62
Scorzonera schweinfurthii (Boiss) Thiébaut	5	0.35	3	0.16
Silene conoides L.	8	0.50	5	0.28
Sinapis arvensis L.	5	0.27	4	0.16
Sisymbrium irio L.	7	0.39	4	0.16
Spergularia rubra (L.) J. & C. Presl.	4	0.27	4	0.21
Stipa capensis Thunb.	5	0.35	1	0.05
Torularia torulosa (Desf.) O. E. Schulz	15	10.69	15	12.88
Trigonella stellata Forskal	*2*	*0.089*	*2*	*0.07*
Vaccaria pyramidata Medik.	0	0	5	0.52

The use of traditional plough showed a higher vegetation cover (60%), fresh weight (50%) and dry weight (30%) over the control treatments. This is significant as it shows that it is better to plough the land in contours than cultivating barley or leaving the land unused. Contours form a suitable habitat for the plants to grow for longer time as they form structure permiting better water harvesting from the catchment area of the intervention. Barley cultivation disturbs the whole soil surface where the soil is mixed and the seeds are buried in the deep layer of the soil adversely affecting barley germination. Competition between the barley and the native plants for the moisture and soil nutrient also occurs and causes lower plant species number than under the control treatment.

Under arid conditions the native vegetation is sparse and characterized by short plant stems where plants develop as individuals not as a community. Organic matter accumulates slowly and often imperceptibly. Badman (2006) mentioned that good environmental conditions result in good vegetation cover. The significant difference in vegetation cover within the contour treatments (12% higher in mechanized than traditional ploughing and 40% in within contour ridges than the catchment interventions) (Table 4) can be attributed to the fact that the contour ridges with suitable structure can capture rainwater 3-4 times of that under the other treatments (BBM 2007) and store it for longer times. Plants then use the moisture in the spring for better establishment, growth, seed production and create a better microhabitat for the plant growth in dry areas. This is in agreement with Rice (2004) who indicated that the desert water harvester (as the microcatchment contours in our study) can be used to concentrate and collect water from precipitation. ACSAD (2003) reported that the microcatchment water harvesting resulted in improving vegetative cover and fodder shrubs stand and led to the restoration of the rangelands

in semi-arid and arid regions in West Asia**.** Shrubs that are planted in these contours play an important role in storing moisture that provides a suitable habitat for the other plants to grow **(**Facelli and Temby 2002; Holzapfel and Mahall 1999; Tielbörger and Kadmon 1997).

In the treatment "between the contour ridges", family Gramineae was more dominant than other plant families (Table 6). Rapid growth of the annual species gives the plants enough time to complete their life cycle and they produce more seeds than other plant species resulting in more grass growth when moisture is available. The mechanized intermittent contour ridges structure maintains more uniform moisture distribution than that maintained under the mechanized continuous contour ridges or the traditional ploughing. Thus relative density (R.D) for grasses was higher in the mechanized intermittent interventions than other interventions.

In conclusion, results showed that microcatchments water harvesting has a significant effect on improving the native vegetation of the area under study. The mechanized intermittent contour ridges intervention was the most effective treatment in improving the moisture supply and thus the natural vegetation in term of species richness and total number of plants.

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4. Assessing the suitability and location of water harvesting and supplemental irrigation using SWAT model

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Abstract

Rainfall in the arid and semi arid areas is limited with high spatial and temporal variability resulting in low water productivity. Rainwater harvesting (RWH) and supplemental irrigation (SI) can improve water productivity, control erosion and contribute to adaptation to climate change and variability. The possibility of implementing RWH and SI depends on climate, hydrology, vegetation, agriculture practices, and soils. One common reason for low adoption of improved land and water management practices is the lack of systematic knowledge on potential areas and suitable locations for these interventions. This study aimed to identify areas within watersheds that are most suitable for RWH and SI, to maximize the benefits from their implementation. SWAT (Soil Water Assessment Tool) was used to identify suitable areas in four watersheds in eastern and western Libya. The paper presents a methodology that enables water managers to assess the suitability for RWH and SI for large watershed areas (87-900 km^2). GIS layers including digital elevation model (DEM), soil data, and land use were used to characterize the watershed for modeling. Data from eleven weather stations for eleven years (2000-2010) were used for simulation. Model output was used to assess hydrological process by estimating runoff coefficient (rainfall: runoff) in each sub-watershed and hydrologic response unit (HRU).

Introduction

Libya is one of the arid and semiarid countries that face very severe water scarcity. Although rainfall is an extremely valuable resource in the country, its productivity is often low. At least 80 percent of agricultural production in Libya depends on irrigated agriculture; however, yields from rainfed as well as irrigated agriculture are generally low. Irrigation potential has been estimated at 750, 000 ha, but when considering renewable water resources, it is estimated that a maximum of 40, 000 ha could be irrigated in the coastal areas (FAO 2005).

Rainwater harvesting (RWH) and supplement irrigation (SI) systems are important in managing scarce rainfall, these are among the most promising and efficient-proven technologies for optimizing the use of the limited water available from renewable resources in rainfed areas, and for improved farmer income in drier environment (Oweis and Hachum 2003). Success of RWH and SI systems mainly depends on identification of suitable potential sites and technologies. However, the selection of appropriate sites for these technologies on a large scale presents great challenge due to lacking the necessary data and complexity of watershed variables.

Rainwater harvesting and supplemental irrigation technologies have shown an enormous impact

on the livelihoods of smallholders in the rainfed cropping systems and steppe environments of West Asia and North Africa (WANA) (Oweis and Hachum 2006). RWH can improve the productivity of rainwater and maintain productive and sustainable agro-pastoral systems in marginal environments (Abu-Awwad and Shatanawi 1997; van Wesemael et al. 1998; Prinz et al. 1998). Additionally, it can control soil erosion and reduce the impact of drought (Samuel and Mathew 2008). The potential of RWH to mitigate the spatial and temporal variability of rainfall has brought about its revival during the last two decades (Mwenge Kahinda et al. 2008).

The selection of appropriate sites and the determination of suitable methods for RWH are very important for ensuring its sustainable implementation. Often one can achieve high runoff efficiency (defined as the ratio of runoff volume collected at the target area to the volume of rainwater falling on the catchment area), but water may be lost in deep percolation in the target area, due to improper selection of the catchment size relative to target area under the given soil and climatic conditions (Oweis and Hachum 2006).

Oweis et al. (1998) also indicated that improper selection of sites and matching the practice with its technical and socio-economical requirements can results in failure of RWH projects and adoption of RWH techniques. A major knowledge gap exists concerning the identification of those parts of the drylands in which the chances for impact and adoption of RWH techniques are high and to which further studies could be targeted (De Pauw et al. 2006). Specifically, for planning and implementation purposes, it is critical to be able to identify suitable areas for RWH (Mwenge Kahinda et al. 2008). Therefore, there is a need for approach to identify areas that are suitable for RWH and SI technique, which can be used to assess the potential for implementation these techniques (Patrick 1997).

Suitability of an area for RWH depends on hydrological characteristics of the watershed and farming practices. Therefore, appropriate data must be available on the climate, soil, crops, topography, and socioeconomics of the targeted area. These data can be collected through a combination of field visits, site inspections, topographic and thematic maps, aerial photos, satellite images, etc. Geographical Information Systems (GIS) can facilitate this task for large areas and permit rapid and cost effective site survey. For relatively small areas, a field survey can be conducted by experienced people. However, for larger areas, the application of modeling integrated with Remote Sensing (RS) and GIS could be the most relevant means (Prinz et al. 1998; Holme and Tagg 1996; De Pauw et al. 2007). In fact, planning for large scale implementation requires quantitative information and spatial distribution of land characteristics, which are often not available for arid environments (Prinz et al. 1998). Because of the large extent of these environments and the relatively low population density, it is very expensive to inventory them using traditional survey methods (Patrick 2002). Therefore, the use of available data should be optimized to provide solid basis for site selection.

The Soil and Water Assessment Tool (SWAT) is one of the most widely used watershed-scale water quality models in the world. Nearly 600 peer-reviewed SWAT-related journal articles have been published and hundreds more have been published in conference proceedings and other formats. The SWAT model has proven to be a very flexible tool for investigating a range of hydrologic and water quality problems at different watershed scales, as well as very adaptable for applications requiring improved hydrologic and other enhanced simulation needs. This paper presents a methodology that enables water managers to assess the suitability of rainwater harvesting and supplement irrigation for different watersheds of Libya. The objective was to develop a methodology for identifying areas where RWH and SI can maximize beneficial use of water.

Materials and methods

The study was conducted in Libya (25 00 N, 17 00 E), which has a total land area of 1,76 million km². The average annual precipitation is less than 400 mm. Rainfall occurs during the winter months, but with great variability from place to place and from year to year. Four watersheds, named with the following codes 37 (Samalous), 83 (Ghadama), 416 (Ganeimah) and 416 (Turghut), were selected in the eastern and western parts of Libya. The watershed area varied from 87 to 986 km² (Table 1, Fig. 1). They were selected in Al-Jablal Al-Gharbi and Al-Jabal Al-Akhdar, with characterization and baseline information. The selection of these watersheds included matching of the selection criteria assigned by multi-disciplinary team of researchers with existing biophysical and socioeconomic conditions of the watersheds. This included analyzing information on rainfall, cropping systems, communities (rural settlements), accessibility and visibility, topography and soil. The watersheds were identified as suitable for targeting rainwater harvesting and supplement irrigation techniques (Ziadat et al. 2010).

Table 1. Selected watersheds and their hydrological properties

Watershed site	Watershed area (km²)	Number of sub basins	Average precipitation (mm)	Average surface Q (mm)	Average runoff coefficient.	Maximum RC
37 (Samalous),	896.368	23	285.89	24.34	0.08	0.12
83 (Ghadama)	986.069	29	268.70	4.59	0.02	0.15
416 (Ganeimah)	87.25	41	363.04	40.87	0.11	0.23
416 (Turghut)	239.537	42	373.97	35.54	0.09	0.14

ArcSWAT 9.3 (Soil and Water Assessment Tool) interfaced with GIS was used to characterize the hydrology of the selected watersheds. The model is used to evaluate the impact of land characteristics on the hydrological outputs. SWAT is a physically based, river-basin scale, deterministic, continuous simulation model that operates on a daily time step (Arnold et al. 1998; Di Luzio et al. 2002; Di Luzio et al. 2004). It can predict the impact of land-management

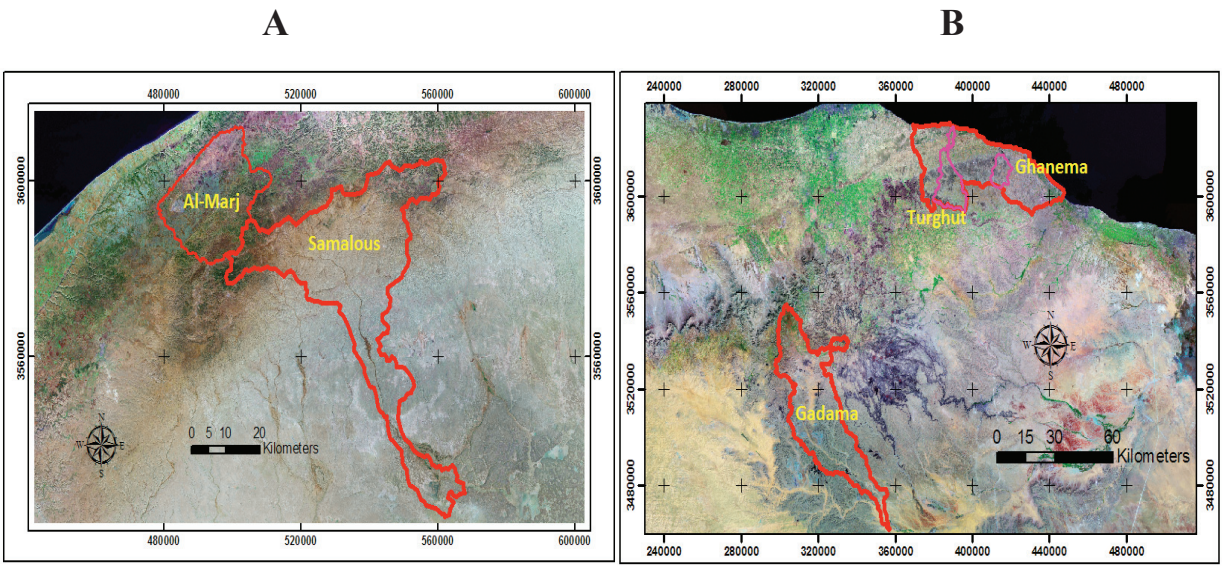

Figure 1. Selected watersheds in the eastern area (A) and in the western area (B).

practices on water, sediment, nutrient and pesticide yields from large watersheds. The SWAT interface delineates watershed sub-basins based on topography and specified threshold drainage area. Soils and land use maps are overlaid to result in hydrologic response units with unique soil/ land use combinations.

Watersheds were delineated based on DEM (digital elevation model), sub basins distribution, and stream outlets. Model simulation was done for 11 years from 2000 to 2010 to identify the most active hydrological areas for runoff. Watershed delineation process consists of five sections namely: DEM setup, stream delineation, outlet and inlet definition, watershed outlet(s) selection and definition. The output of the model shows the amount of rainfall and surface runoff (Q) from which the runoff coefficient and runoff volume for each sub-watershed are estimated. The model calculates runoff using curve number method. The geographic coordinates of eleven weather stations in and around the targeted watersheds were derived from various sources and were used to create map that shows the distribution of these stations (Fig. 2). A map of rainfall isohyets based on long-term average rainfall (more than 30 years) was received from the department of meteorology (Fig. 3). The available land use map was used to derive land use / land cover layers. The scale of this map was 1:50,000 and was derived using the legend of the FAO land cover classification system (LCCS). Land use data was interoperated from field work, satellite images (scale 1:50,000), and collection of ground-truthing observations using GPS (accuracy 5-10 m) (Fig. 4).

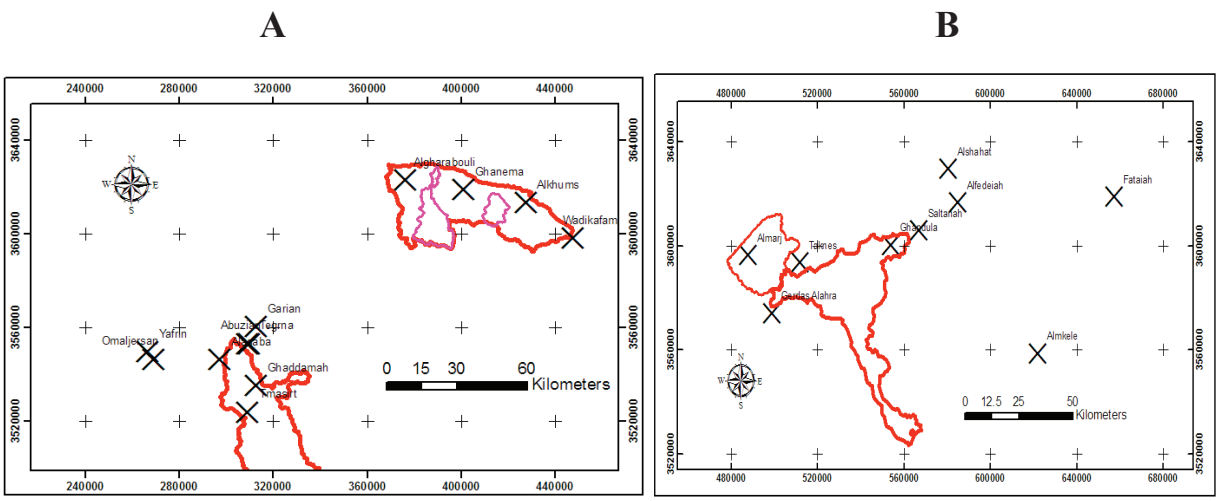

Figure 2. Distribution of weather stations over the eastern area (A) and the western area (B).

For topography and slope, data were derived from digital topographic layers prepared previously for part of Al-Jamahiriya (mapping the natural resources for agriculture use and planning (Fig. 5). These topographic maps (scale 1:50,000) provided the contour lines (at 20 m vertical intervals and in some cases at 10 m vertical intervals (Fig. 6). These layers were used to derive digital elevation model (DEM) using standard command in ArcGIS. From this DEM, slope grid was derived to cover the four watersheds. The soil data were derived from the Russian study that was conducted in 1984. The scale of the map is 1:50,000 and the soil mapping units recorded many soil characteristics. An example for soil depth is shown for the eastern area and western area (Fig. 7).

Result and discussion

Runoff coefficients at hydrologic response units (HRUs) varied from zero to 0.23, with significant variation among the four watersheds (Fig. 8). In watershed 37, sub basins 12, 13

and 19 have high runoff coefficient (0.12) compared with the other sub basins, runoff volume also can be illustrated for sub catchment (Fig. 9). For watershed 83, sub basin 1 generates high runoff (0.15) compared with downstream sub basins. However, the other two watersheds in eastern part generated more runoff than western part (see sub basins 9 and 11 in Ghanemah with runoff coefficient of 0.23), which indicated the value of implementing RWH and SI on these sub basins. Other sub basins in Turghut watershed have less runoff coefficient (range between 0.12 and 0.14). Areas where RWH and SI can be implemented were identified based on runoff coefficient at field scale; large dams can be placed on the stream network where high runoff is generated. Hydrologic response varies within a watershed as a function of topography, soil, land cover and climatic conditions. Spatial and temporal data from targeted watersheds may provide information on where, when, how, and why the response varies. General classes of watershed characteristics attributed to the differences in hydrological response to rainfall are watershed size, local climate, vegetation cover, soil properties; geology anthropogenic activities, slope, and drainage characteristics (Black 1997; Uhlenbrook et al. 2003; Sivapalan 2005). Because the suitability of certain location for RWH and SI depends not only on the predicted runoff amounts but also on other biophysical and socio-economic factors, these results were integrated with GIS layers of land use, soil and community distribution to identify potential sites for RWH and SI techniques. The results of suitability analyses indicated that different watersheds are containing variable areas that are suitable for various RWH systems.

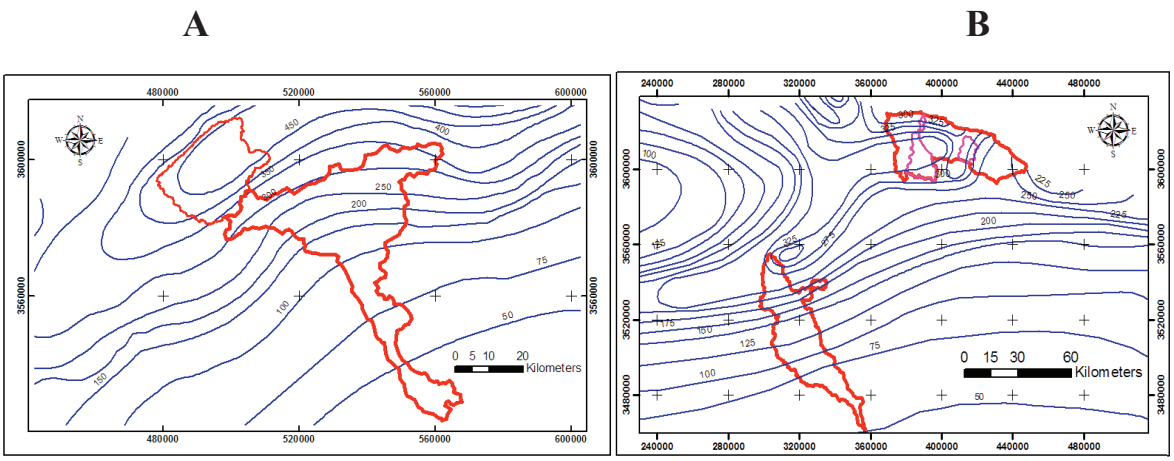

Figure 3. Isohyets based on long-term average rainfall for the eastern area (A) and the western area (B).

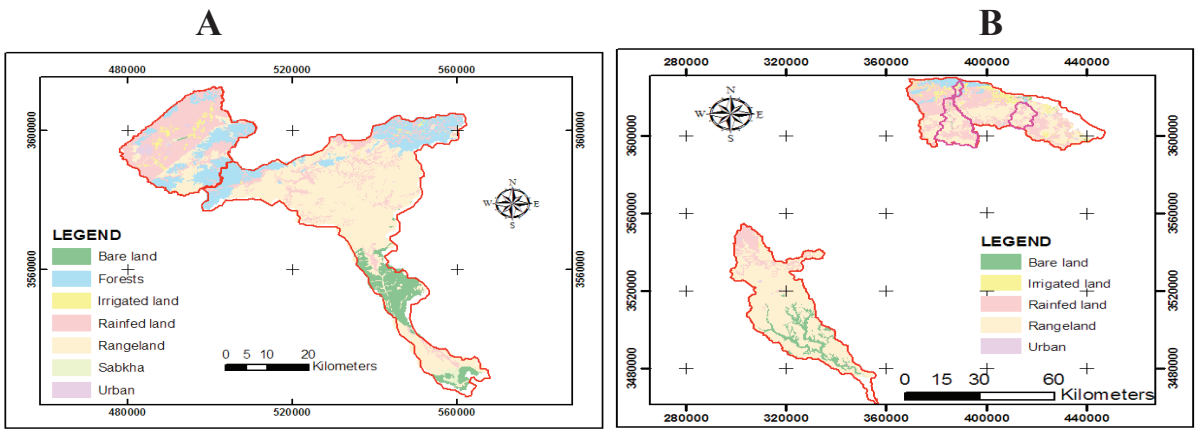

Figure 4. Land cover / land use map of the eastern areas (A) and the western area (B).

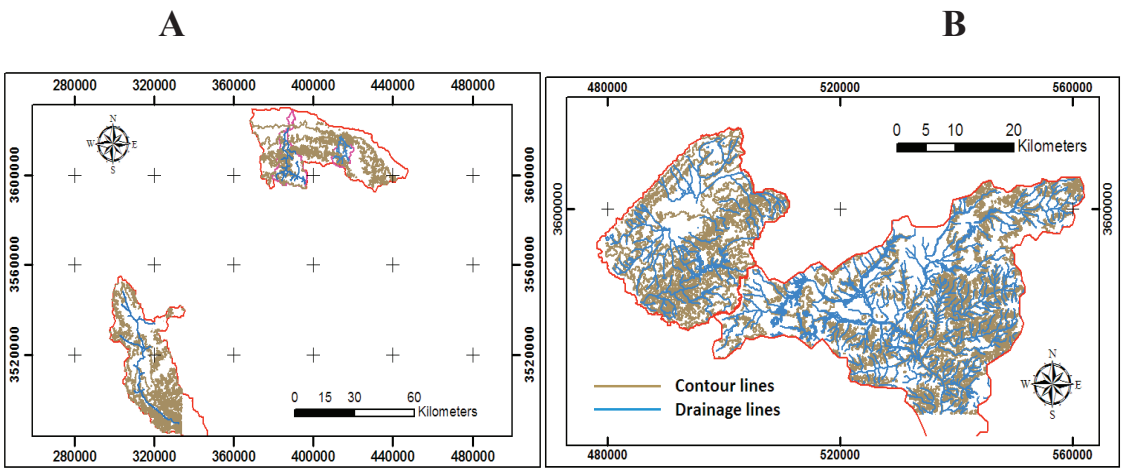

Figure 5. Contour lines and drainage system for the eastern area (A) for the western area (B).

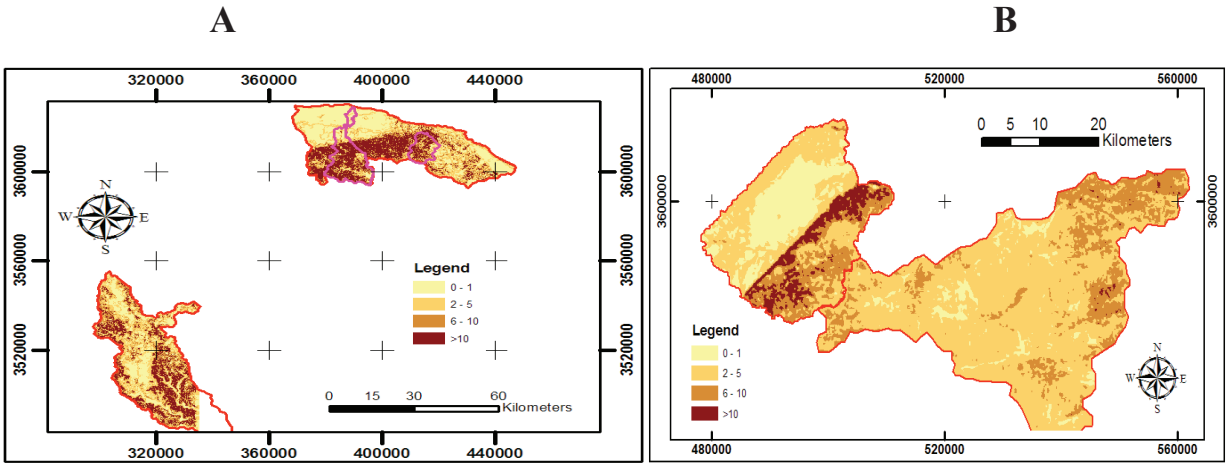

Figure 6. Slope grid for the eastern area (A) and the western area (B).

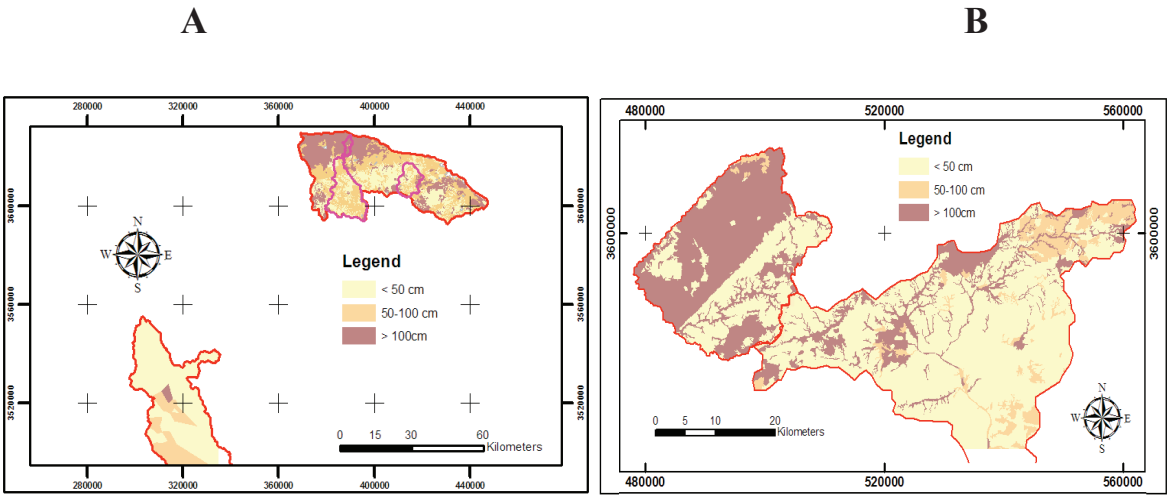

Figure 7. Soil depth for the eastern area (A) western area (B) extracted from 1:50,000 soil map.

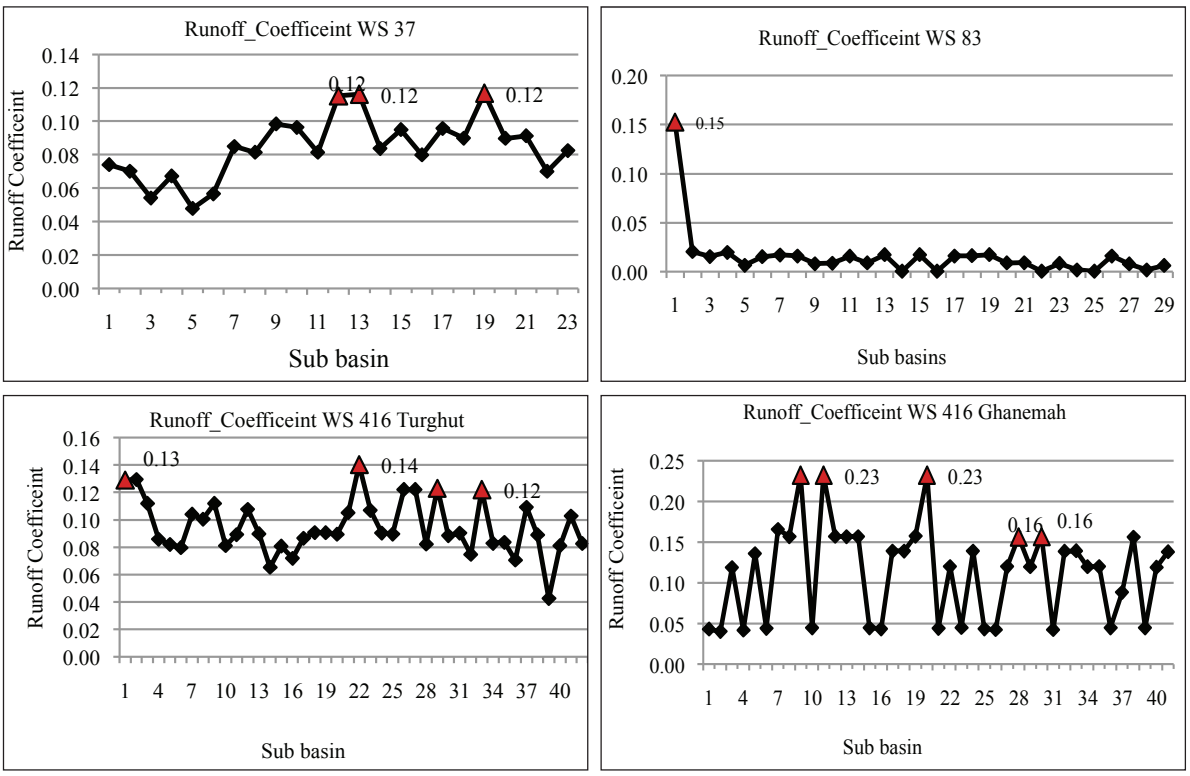

Figure 8. Runoff coefficient for each watershed's sub basin (Triangle red colored shapes are indicated identified sub basins with high runoff coefficient.

The runoff coefficient is the proportion of total flow to rainfall. Variations in spatial and temporal efficiencies of watershed-scale rainfall-to-runoff conversion have led to stream flow generation concepts such as variable source- area (Hewlett 1961) and partial-source-area (Dunne and Black 1970). Therefore, differences in runoff coefficient values within four watersheds are results of variation of the amount of runoff that each sub basin can generate (see Table 1 for hydrological characteristics of the four watersheds).

These results were discussed with hydrologists from Libya and were compared with some measured runoff amounts at certain locations. The results are generally accepted outputs given the scale of the input data and the purpose for which these results are going to be used. It is anticipated that these results will be used only to determine potential sites for RWH and SI. However, the study outputs will not be used to design the structures of RWH and SI interventions. In fact, more measurements and detailed information are required for such in suite implementation. In addition, variability of seasonal precipitation over Libya are more strikingly experienced from 1976-2000 than from 1951-1975 indicating a growing magnitude of climate change in more recent times (Fig. 10).

To decide a suitable location for SI, the most important criterion is the availability of sufficient water for irrigation mainly by runoff to be harvested and stored in dams for later use. This criterion was explored by overlaying the layer that shows the predicted runoff coefficient and runoff volume for each sub-watershed within the selected watersheds. This provides an idea about the expected amounts of runoff to be harvested at the outlet of these sub-watersheds. Three layers of information were overlaid and examined: runoff amount from each sub-watershed, land use / land cover maps and the distribution of communities for Turghut watershed (Fig. 11) to define the potential sites for supplemental irrigation techniques. The layer which shows

the runoff volume was overlaid with the land use / land cover map to identify areas where both criteria are satisfied.

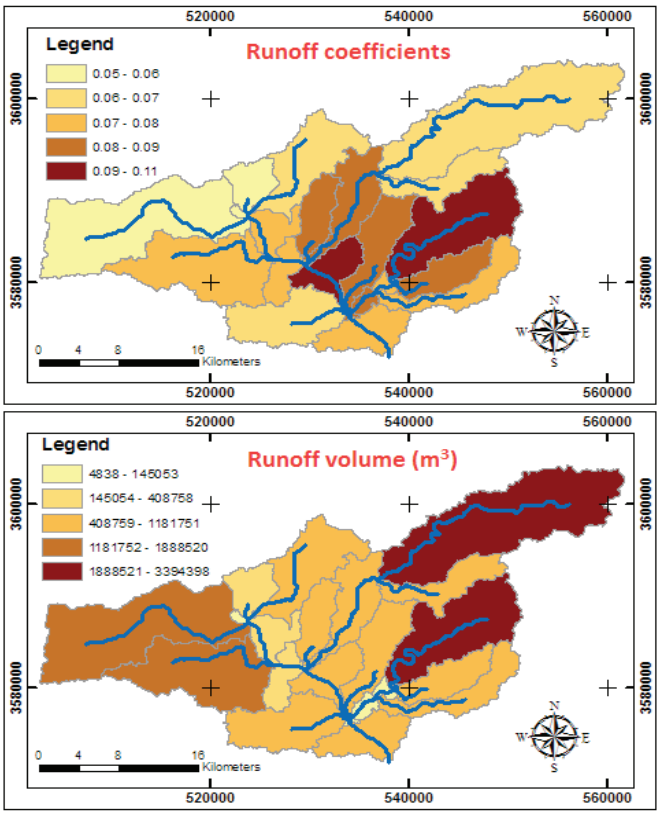

Figure 9. GIS layers of watershed 37 to show varied runoff coefficient within sub basins.

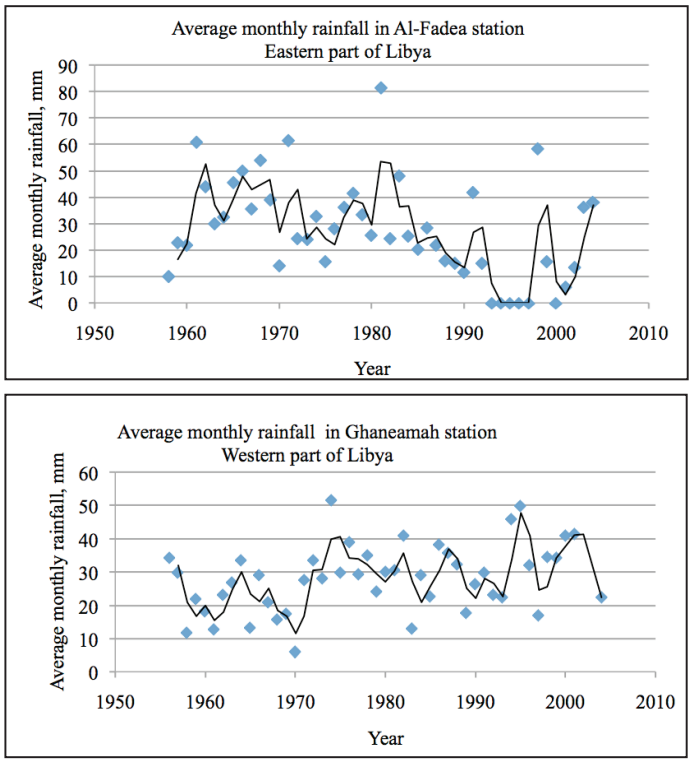

Figure 10. Trend of average monthly rainfall from 1950-2010 for two stations in eastern and western parts of Libya.

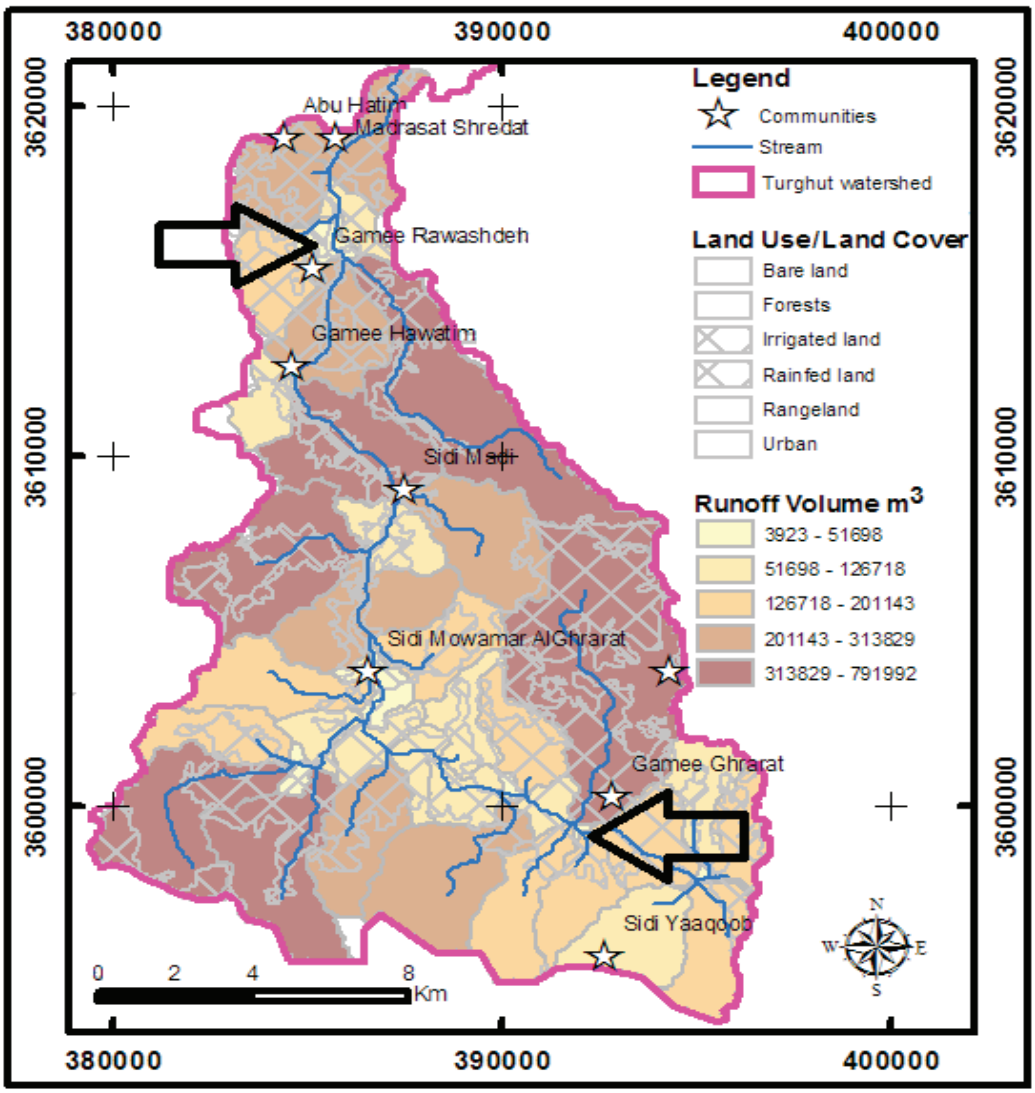

Figure 11. Potential sites for supplemental irrigation; an overlay of runoff volume for sub-watersheds, rainfed and irrigated lands, and distribution of communities for Turghut watershed.

Although many sub-watersheds might generate reasonable amounts of runoff at their outlets, only two of these are potential sites for supplemental irrigation (Figure 11). This is because only those two sites (pointed by arrows) satisfy the above criteria; the outlets of these sub-watersheds indicated reasonable amount of predicted annual runoff, and they were close to community and surrounded by irrigated and rainfed lands, where harvested water could be distributed by gravity. The results of SWAT indicated that in some cases the runoff was too small to ensure sufficient amount of water to be harvested and in other cases the cumulative amount of runoff for successive sub-watersheds provided a very large body of water that would need a very large structure to be held, which is beyond the scope of this study. However, in each watershed there were a number of possible sites with reasonable volume of runoff.

Conclusion

The analyses indicated that a small percentage of a watershed (< 30%) was directly contributing to storm flow generation. Even in these hydrologically active areas, rainfall-to-runoff conversion rates varied with the type of runoff generation process: infiltration excess or saturation excess.

Construction of large hydrological structures such as dams can be more effective practice at sub-catchment scale specially at stream network where high runoff is generated. Results showed that the methodology provides approach that can be used for identifying potential areas for rainwater harvesting and supplemental irrigation. It can be concluded that integration of watershed modeling and GIS techniques with limited field survey is useful for identification of potential sites for RWH and supplemental irrigation.

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5. Effects of simulated rainfall amount and frequency on seed germination and seedling emergence of two desert shrubs

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Abstract

In seriously degraded Minqin desert-oasis ecotone, coppice dunes that protect the oasis are being degraded. To restore the degraded coppice dunes, favorable seed germination conditions and a successful development of plants to a mature, seed-producing individual are necessary. *Reaumuria songarica* (Pall.) Maxim and *Nitraria tangutorum* Bobr. are the two major species growing on the coppice dunes. We conducted experiments to investigate the effect of simulated rainfall amount and frequency on seed germination, seedling emergence and seedling dry weight of the two species. Three simulated rainfall patterns: 5 mm per day, 10 mm every two days, and 20 mm every four days were employed. Seeds of the two species were placed at the optimal depth in the dune sand. Germination of the two species was not influenced by rainfall pattern and germination percentage of the *N. tangutorum* was higher than that of *R. songarica* at all the three water treatments. Seeding emergence was significantly affected by simulated rainfall pattern and seeding emergence was higher at 5 mm per day and 20 mm every four days water treatments. Seedling emergence percentage of *N. tangutorum* was higher than that of *R. songarica* at 5 mm per day treatment but no difference was observed at 10 mm every two days and 20 mm every four days. Rainfall pattern significantly influence seedling dry weight. Both the species had the maximum seedling dry weight at 10 mm rainfall every two days. The increasing extremely heavy rainfall events in Minqin are conducive to the seedling emergence but not favorable for seedling establishment, which might decrease the restoration of coppice dunes.

Introduction

In desert-oasis ecotone, coppice dunes serve very important ecological functions, such as decreasing wind velocity, trapping sands, and protecting the oasis from moving sand dunes (Wang et al. 2007; Du et al. 2008). About 1 km wide coppice dunes are present around the Minqin oasis (Chang and Zhao 2006), which consititute shelter belt for the oasis. The most common species growing on coppice dunes are *Reaumuria songarica* (Pall.) Maxim and *Nitraria tangutorum* Bobr. Yet, the dunes in Minqin desert-oasis are facing degradation and finally aeolian desertification (Wang et al. 2002; Wang et al. 2008; Ma et al. 2009). Water table is descending due to over exploitation by agricultural use, which is considered to be the main force leading to the death of shrubs growing on coppice dunes (Ma 1997; Ma and Wei 2003).

The dry grassland restoration largely depends on favorable conditions for successful development of plants to a mature, seed producing individual (Willems and Bik 1998). There are several periods during plant establishment when water availability is critical (Frasier et al. 1987). Wilson and Briske (1979) found that *Bouteloua gracilis* requires 2 to 4 days of wet soil conditions to successfully establish. Frasier et al. (1987) evaluated the effect of various wet-dry water

sequences on seed germination and seedling establishment. Downs and Cavers (2000) concluded that some seeds were induced into a dormant state through exposure to the cycles of wetting and drying and the dormancy may prevent the seed germination in unapproriate condition. Zheng et al. (2006) found one time large amount of water is conducive to germination and seedling emergence of desert annuals. Tobe et al (2005) found that dependence of germination on rainfall after a cold and dry cycle determines the seasonal emergecne of different species in deserts of China. Simulated rainfall amount and frequency influences seed germination and seedling emergence throught regulating soil moisture availability in various dry-wet periods.

From 1960, no significant change in precipitaion amount has occurred in Minqin (Zhao et al. 2005) but frequency of extremely heavy rainfall events has increased (Zhao et al. 2005; Zhang et al. 2008). Rainfall events with precipitation of less than 5 mm and 5-10 mm had no clear trend but rainfall events with amount greater than 10 mm have significantly increased ($p = 0.034$). The objective of this study is to determine the effects of simulated rainfall patterns on the germination, emergence, seedling dry weight so as to provide an overview on the future of coppice dunes.

Materials and method

Seed collection

Mature seeds were collected from natural habitats of the two species in Minqin desert oasis ecotone (Fig. 1), the lower reaches of Shiyang River, one of the three longest inland rivers, in northwestern China. Annual mean precipitation is 116 mm with 70 % occurring from July to September. Annual mean temperature is 8.2 C. Monthly mean temperature below 5 C is from November to next March, and above 20 C is from June to August. Prevailing winds in the area are northwest and mean annual wind velocity is 2.35 m s^{-1}. Sandstorm frequents the area, 25.8 d every year. Mature seeds of the two species were collected from late October to early November, 2009. Seeds were stored in the freezer compartment of a refrigerator at 4 C from mid-November 2009 to January 10th, 2010.

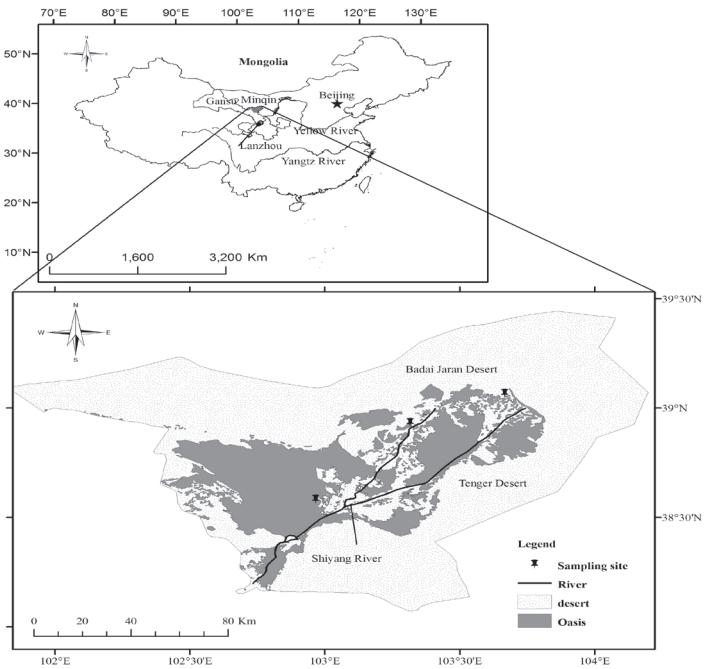

Figure 1. Location of seed collection sites.

Experimental procedure

Germination experiments were carried out in an automatic temperature and light controlled growth chamber (Cold Desert Simulator, Espec Corp., Osaka, Japan) in Arid Land Research Center, Tottori University, Japan. The chamber was set for daily cycle (14 h light, 10 h dark) using metal halide lamps. The temperature was set to 15/25 C (night/day) under 600 μmol m^{-2} s^{-1} light density. This temperature cycle was set because it is preferable for germination of many desert species (Tobe et al. 2005; Zheng et al. 2004). Relative humidity (RH) was 45 % , which was consistent with RH in Minqin from May to July. The sand utilized in this study was collected from Tottori sand dunes, washed several times with tap water, dried naturally and sifted through sieves with 0.85 mm openings to remove debris. Plastic pots (8 cm in diameter and 11 cm in height) were filled with prepared sand to a specific depth where the seeds were placed. Then the pots were filled with additional sand to get a final height of 10 cm. The drainage outlet at the bottom of the pots was covered with nylon mesh to prevent loss of sand but allowing drainage of excess water. An earlier study showed that the optimal burial depth for *N. tangutorum* and *R. songarica* was 1.5 cm and 0.5 cm respectively. Twenty randomly selected seeds were planted to each pot. Three water management treatments were utilized: 5 mm per day, 10 mm every two days and 20mm every four days. Emerged seedlings were counted daily, seedlings emergence was defined as appearance of a seedling on the surface. Symbol of germination was the appearance of radical and cotyledons out of the seed coat. The experiment lasted for 35 days since no seedling emergence occurred in the successive two days. Finally the seedlings were harvested and dried in an oven at 75 C for 72 h.

Statistical analysis

Germination percentage, emergence percentage, and seedling mass were arcsine transformed before the data were analyzed using SPSS 16.0 one-way ANOVA analysis. Tukey multiple comparison test was used to determine differences among treatments.

Results

Effects of water treatments on germination

Germination was not significantly influenced by treatments (p = 0.78). Under the three water treatments, not all the seeds of the two species germinated and germination percentage of *N. tangutorum* was higher than that of *R. songarica* under each water treatment (Fig.2).

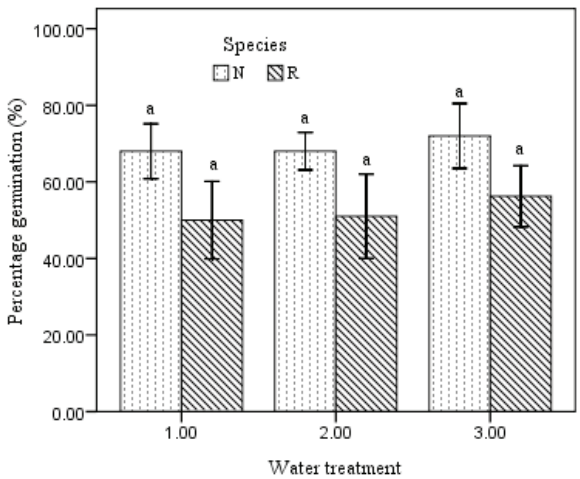

Figure 2. Germination percentage of the two species (N. tangutorum and R. songarica under three water treatments. Same letters above the standard error bar represent no significant differnce p = 0.5, n = 5.

Effects of water treatments on seedling emergence

Seedling emergence was significantly affected by species (p = 0.04), water treatments (p = 0.002) and interaction between species and water treatments (p = 0.013). *N. tangutorum* seedling emergence was significantly less than *R. songarica* when water treatment was equivalent to 5 mm per day, while no significant differences were observed under 10 mm every two days and 20 mm every four days water management. Seedling emergence of *R. songaric*a was higher at 5 mm per day and 20mm every four days treatment and lower at 10 mm every two days treatment. *N. tangutorum* seedling emergence was promoted as one time water supply amount increased (Fig.3).

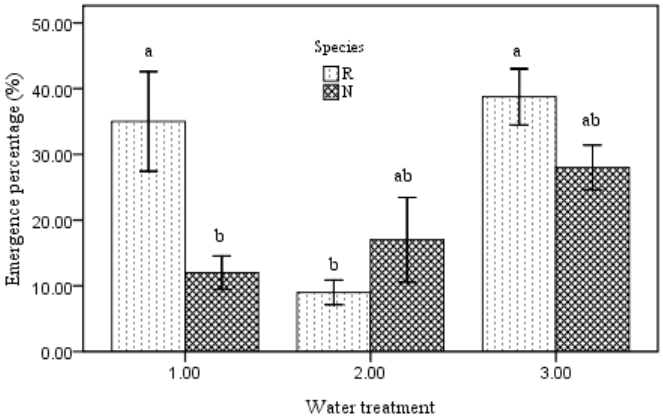

Figure 3. Emergence percentage of the two species under three water treatments. Different letters above the standard error bar represent significant differnce among treatments p = 0.5, n = 5.

Effects of water treatments on time to first emergence

Time to first emergence was significantly affected by water treatments (p = 0.015) and species (p < 0.0001). Number of days to first emergence was longer when treated with 5 mm per day and 10 mm every two days than when treated with 20 mm very four days for *R. songaric*a. It took almost 15 days for seedling to emerge the surface when watered with 5 mm per day and 10 mm every two days, while it only took 10 days for seedling to emerge when watered with 20 mm very four days. And no difference was observed for *N. tangutorum* (Fig.4).

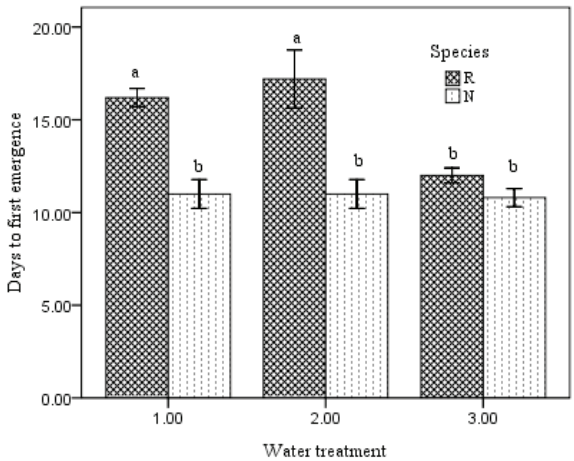

Figure 4. Days to first emergence of the two species under three water treatments. Different letters above the standard error bar represent significant differences among treatments p = 0.5, n = 5.

Effects of water management on seedling dry mass

Seedling dry weight was significantly affected by water treatments ($p = 0.005$) and species ($p < 0.001$) and interaction between them ($p = 0.039$). When provided 10 mm water every two days, both the species had the greatest seedling dry weight and no significant differences of seedling dry mass between 5 mm and 20 mm water treatment were observed. Seedling dry weight of *N. tangutorum* was several times higher than that of *R. songaric*a (Fig.5).

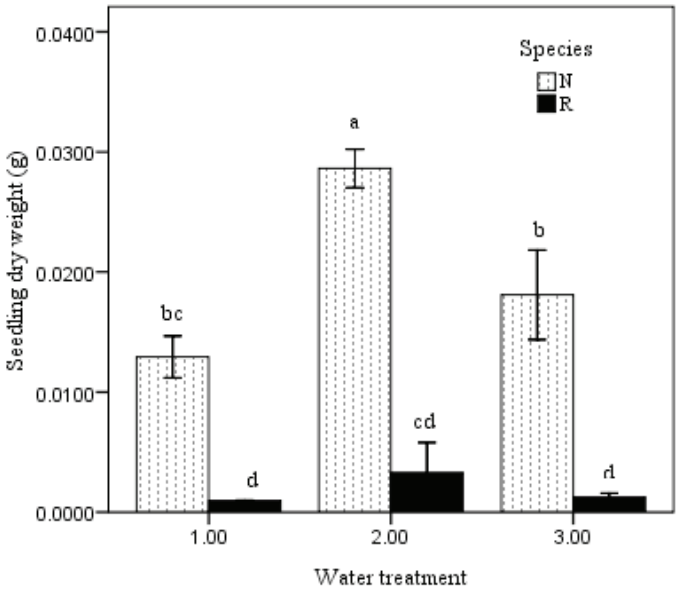

Figure 5. Seedling dry weight of the two species under three water treatments. Different letters above the standard error bar represent significant difference among treatments p = 0.5, n = 5.

Discussion

No significant differences of germination of the two species under the three water treatments were observed. Almost half R. songarica seeds and 80 % of N. tangutorum germinated under the 5 mm water treatment. Germination responses are reported to be related to rate of water uptake by seeds from sand (Wilson and Thurling 1996). The amount of water necessary to start germination was proportional to seed mass. Small seeds absorbed water more rapidly than large ones (Kikuzawa and Koyama 1999). However, rapid water uptake can cause imbibition damages to the embryos of germinating seeds. In our study, seed mass of R. songarica is smaller than that of N. tangutorum. The relative smaller germination percentage of R. songarica might have resulted from imbibition damages as the small seeds quickly absorb water. Downs and Cavers (2000) found that some seeds would be induced to domancy under wet-dry cycles. In this study, the vitality of the un-germinated seeds was not tested. Soil moisture of 0.5 and 1.5 cm soil depth 24 h after irrigation with 5 mm supply was less than 1 % and near 1 % (Fig.6) which suggests that short-period of water stress is not limiting seed germination. In Minqin, from 1960s to 2000, rainfall events with precipitation greater than 10 mm account for about 55 % of total 184 rainfall events, which indicates that in the natural habitat germination could not be impeded by precipitation.

Seedlings need to elongate enough to emerge from the surface. During this process, seedlings have to overcome adverse conditions such as mechanical impedance (Tobe et al. 2005), light deficiency (Maun 1998), insufficient aeration(Maun 1994) and water shortage, which affect

metabolic activities. One day after irrigation, soil moisture in 0.5 and 1.5 cm soil depth irrigated with 5 mm is smaller than 2%, the wilting point of the experimental sand(Tsuji et al. 2005). Under the 5 mm water supply, seedlings suffer from temporary drought and under 10 mm water supply every two days, seedlings suffer longer water stress. In this study, both higher frequency of small amount of water (5 mm per day) and lower frequency of large amount of water (20 mm every four days) enhance the seedling emergence of *R. songaric*a, which indicates that short period of water stress could not affect elongation of *R. songaric*a seedling but longer water stress decrease emergence. *N. tangutorum* seedling emergence increased as one time water supply amount increased irrespective of the frequency. The larger seeds have the ability to absorb and store more water to pass through dry conditions. Increased emergence percentage of *N. tangutorum* with one time water supply suggests that water stress impeded the elongation of germinated *N. tangutorum* seeds and 20 mm water supply each time did not cause imbibition damage.

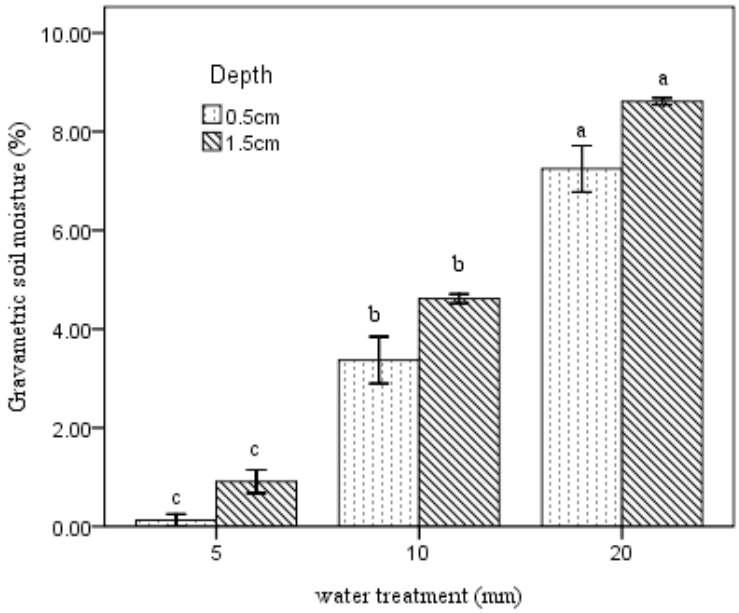

Figure 6. Soil moisture at two depths under three different water treatments 24 h after irrigation. Different letter denote significant difference among treatments p = 0.5, n = 5.

Both the species had the largest dry matter under 10 mm water supply every two days. Dry weight of seedlings affects the possibility of their survival. As the results showed, 10 mm precipitation provides the favorable condition for the buildup of plants. However, in real condition, rainfall is not as regular as in the experimental setup and the recorded meteorological data show that rainfall events with precipitation amount greater than 10 mm increased in the past fifty years. If the changing pattern is strong and persistent, emergence of desert plant seedlings will increase after one time rainfall events but the lower dry weight and long time drought will decrease the possibility for the seedlings to grow up to become adult plants. What is more, higher germination and emergence percentage after one time rainfall with precipitation greater than 10 mm would consume the seed bank thus shrubs in coppice dunes might decrease and the dunes would degrade.

Conclusion

One time precipitation amount is not the limiting factor for germination for the two species; however, the emergence is significantly affected by the rainfall pattern. Emergence percentage of

R. songarica is promoted by 5 mm water supply every day and 20 mm water supply every four days. But increase in the onetime water supply amount proved detrimental to the emergence of *N. tangutorum*. Seedling dry weight was significantly higher at 10 mm water supply every two days. Increased rainfall events with precipitation amount greater than 10 mm would promote the possibility of higher emergence of seedlings but would result in lower seedling dry weight, which would reduce the survival. One time large germination and emergence would deplete the soil seed bank, which would threaten the sustainability of coppice dunes.

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6. Deficit irrigation as an alternate option to adapt with climate variability and change under water supply shortage conditions in Egypt's Delta

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Abstract

Future water supply in Egypt will largely depend on the severity of impacts from climate change which are still uncertain. However, it is clear that water will be the most critical constraint to sustainable agriculture. In addition, it is likely that the ET of various crops will change. Deficit irrigation is a useful option for improved on-farm water management. This research was conducted at Zankalon Water Research Station, Water Management Research Institute, Egypt, during three successive growing seasons, 2007/08 to 2009/10, to study the effect of deficit irrigation on water consumptive use, yield and yield attributes of two wheat cultivars ('Gemmieza-9' and 'Sakha-93') for the purpose of developing a decision tool for managing irrigation applications under water-deficient conditions in the Nile Delta. Three treatments with five, four and three irrigation events (designated as I1, I2 and I3) were used. I1 represents the common farmer practice. Each irrigation event for the three treatments delivered the same quantity and quality of irrigation water. Total water delivery was 5,793 $m^3.h^{-1}$ in I1, 4,693 $m^3.h^{-1}$ in I2 and 3,564 $m^3.h^{-1}$ in I3. Averaged across the three seasons, I1 gave the best yield attributes and yield and I3 the poorest. There was insignificant difference in grain and straw yields between treatments I1 and I2. Cultivar Gemmieza-9 significantly surpassed Sakha-93 in all studied parameters. Treatment I_2 could reduce water applied by farmers, as compared to their traditional practice (I_1) by 1100 $m^3.h^{-1}$ per season, or 19 %. To maximize wheat yield of Gemmieza-9 and Sakha-93 cultivars in the Nile Delta, where irrigation water is not a limiting factor, I_1 (five irrigations) is appropriate. However, in case of low water supply, I_2 (four irrigations) might be adequate. This finding could help adapt to water shortages at the end of the canal, which is a longstanding problem in the Nile Delta. The average of actual evapotranspiration values were 39.1, 32.4 and 26.7 cm for I_1, I_2 and I_3 respectively. Gemmieza-9 consumed more water than Sakha-93, with average water consumptive use of 33.6 versus 31.9 cm. Wheat plants take up about 73.7 % and 26.3 % of their water needs from the 0-30 cm and 30-60 cm layers, respectively for treatment I_3. Treatment I_1 resulted in increasing the water uptake by roots from the 30-60 cm layer, to 29%. The highest water productivity was observed for treatment I_3 (1.88 kg cm^{-1}) followed by treatments I_2 (1.83 kg cm^{-1}) and I_1 (1.64 kg cm^{-1}). Gemmieza-9 utilized water more efficiently than Sakha-93. A linear regression between water consumptive use, grain yield, and water productivity were 97.11 and negative 30.28 for Sakha-93; and 116.88 and negative 52.63 for Gemmieza-9. The correlation coefficient between consumptive use of water and grain yield was positive (0.96 for Sakha-93 and 0.97 for Gemmieza-9) and correlation with water productivity was negative (-0.77 and -0.82 for the two cultivars).

Introduction

Bread wheat (*Triticum aestivum* L.) is one of the most important cereal crops in Egypt. But the local production of wheat is not sufficient to meet the annual demand of the increasing

population. Water management is considered as one of the most important factors affecting production of high yielding varieties of wheat. Many investigators have studied the effect of irrigation treatments on wheat yield, yield components, water requirements, water consumptive use and water productivity. Ibrahim et al. (1988) found that in Eastern Nile Delta the irrigation for wheat at 50 % of field capacity was most common and the water consumptive use ranged between 400 to 491 mm. El-Refaie et al. (1988) reported that at Middle Delta the seasonal water consumptive use was 378 mm and monthly rates of water consumptive use 22.4, 55.3, 53.5, 90.7, 85.3 and 70.7 mm, from December to May. Yousef and Eid (1994) found that water consumptive use of wheat in the calcareous soil of Fayom was 397 mm.

Ghanem et al. (1990) found that the optimum irrigation frequency (five irrigations) increased grain yield per hectare by 20 % over three irrigations and by 17.27 % over four irrigations. Mosaad et al. (1990) found that the total water use and grain yield generally decreased as the number of irrigation decreased. Chouhan (1991) indicted that the mean grain yield was 2.60, 3.90 and 4.10 ton ha^{-1} with 2, 4 and 6 irrigation events, respectively. Abd El-Gawad et al. (1993), showed that decreasing the number of irrigation events (skipping an irrigation at tillering, heading, milk-ripe or dough-ripe stage) reduced yield and its components.

El-Menoufi and Harb (1994) reported that water stress during flowering, milk stage, flowering and dough-ripe stage led to gradual but significant reduction in grain yield. Eid and Yousef (1994) showed that skipping one irrigation event at milk or booting stage reduced grain yield by 13.4 and 18.25 % respectively. El-Rafaie and Hamada (1994) reported that the highest water productivity was recorded when wheat crop was subjected to drought stress. In North Nile Delta, Gad El-Rab et al. (1995) obtained maximum grain and straw yields with six irrigations. Osman et al. (1996) indicated that there was no significant difference in grain and straw yields with 5 irrigations (I5) and 4 irrigations (I4) in North Delta, and the consumptive use was 361 and 401 mm, respectively. Water productivity decreased by increasing the number of irrigations and varied from 1.59 $kg.m^{-3}$ for treatment I_5 to 2.92 $kg.m^{-3}$ for irrigation treatment I_4.

In the Middle Nile Delta, Abdel-Monem et al. (1997) found no significant difference in the yields obtained from four and five irrigations. Khater et al. (1997) reported that the seasonal water consumptive use was 360 mm for treatment of 100% of field capacity and water productivity was 1.93 kg m^{-3} in Middle Delta and the number of spikes per m^2, straw yield and grain yield per hectare were significantly decreased with decreasing amount of available soil moisture.

El-Sabbagh (1998) found that crop water requirements of wheat was 592 mm at Sakha (Northern Delta) with 5 irrigations events, which gave the highest grain yield; the crop evapotranspiration rate ranged from 357 to 431 mm.

Atta (2002) reported that the seasonal water consumptive use value of wheat crop in East Delta was 392 mm and water productivity 1.63 kg m^{-3} while the water applied was 588 mm. Nahla et al. (2002) found that water requirements of wheat was 577 mm at Zankalon (East Delta) when it gave highest yield. The consumptive use was 395 mm. and water productivity was 1.75 kg m^{-3}. They also determined the crop coefficient (Kc), using Class A pan method, for Gemmieza-7 cultivar.

With regard to the effect of wheat cultivars, Kheiralla et al. (1993), El-Kalla et al. (1994), and El-Banna (1995) found significant differences in grain and straw yields. Khater et al. (1997) found that Gemmieza-I surpassed all other cultivars (Sakha-8, Giza-163, Giza-164 and Sakha-69) in

response to irrigation at 100, 80, 60 and 40 % of field capacity. Nahla et al. (2002) indicated that Sakha-69 cultivar surpassed Sakha-8 in plant height, number of spikes per m^2, grain weight per spike, 1000-grain weight, grain yield per hectare and straw yield per hectare. Hamada et al. (2001) showed that Gemmieza-9 was superior to the other cultivars (Sakha-93, Gemmieza-7 and Giza-168) in number of spikes per m^2, grain yield and straw yield.

The objective of this work was to study the effect of deficit irrigation (achieved by reducing the number of irrigations as compared to the traditional farmer practice) on applied water, yield and some its attributes of two wheat cultivars as well as their water relations in order to set the proper management tool for managing water under shortage of water supply conditions.

Materials and method

Two experiments were conducted during three successive seasons (2007/08 to 2009/10) at Zankalon Water Research Station, Water Management Research Institute. This site is representative of East Nile Delta region. Soil of experimental site was clay in texture. Soil samples were collected to determine the soil physical and chemical properties of the experimental site. The average values of these measurements at different soil depths down to 60 cm are presented in Table 1.

Table 1. Some soil physical and chemical properties of the experimental site

Depth (cm)	Sand %	Silt %	Clay %	Texture	Bulk density g/cm^3	Field Capacity %	Wilting point %	Available water %	E.C $dS.m^{-1}$	pH
0-15	25.80	28.90	43.51	Clay	1.25	43.51	23.55	19.96	1.40	8.10
15-30	25.12	30.10	42.50		1.27	40.50	21.06	19.44	1.22	8.00
30-45	26.90	31.50	40.50		1.35	37.12	17.59	19.53	1.25	8.01
45-60	29.78	31.50	37.12		1.41	36.25	16.64	19.61	1.05	8.01

Wheat was sown at rate of 166 kg ha^{-1} on November 19, 20 and 13 and the crop was harvested on May 11, 10 and 3 in the three seasons, respectively. The preceding crop was rice. Recommended cultural practices were applied. Nitrogen (as ammonium nitrate 33.5 % N) was applied at the rate of 178 $kg.h^{-1}$ in two doses, one-third at planting and the other two thirds before the first irrigation. Phosphorous (as single superphosphate 15.5 % P_2O_5) at a rate of 238 kg ha^{-1} and potassium (in the form of potassium sulfate, 48 % K_2O) at a rate of 119 $kg.h^{-1}$ were applied as one dose at field preparation.

A split-plot design with four replicates was used where three irrigation treatments were the main plots and two wheat cultivars (Sakha-93 and Gemmieza-9) were the sub-plots. The experimental plot was 150 m^2 (12 12.5 × cm) consisting of 80 rows of 12.5 m length and spaced 15 cm apart. There was a border of 1.5 m between plots. Three irrigation treatments were tested. They included I_1 (five irrigations, one each at sowing, tillering, heading, milk stage, and dough stage, which is the conventional practice), I_2 (four irrigations, with no irrigation at dough stage), I_3 (three irrigations, with no irrigation at milk and dough stages).

Growth, yield attributes and yield

An area of 30 m^2 from the center of each plot was harvested to estimate grain and straw yields. The following crop parameters were measured: 1. Plant height at harvest (cm); 2. Grain weight per spike (g); 3. 1000-grain weight (g); 4. Number of spikes per m^2; 5. Grain yield (ton ha^{-1}); 6. Straw yield (ton ha^{-1}).

Actual evapotranspiration (ETc)

The ETc was measured using weighing lysimeter (2 m width, 4 m length and 2 m depth), installed at the experimental site and it was surrounded by 200 m canopy cover (wheat crop). The lysimeter was calibrated by gravimetric soil moisture determination of the sample taken at 15 cm intervals down to 60 cm at sowing, two days before and two days after every irrigation event as well as at harvest. The ETc was determined using the equation given by Israelsen and Hansen (1962).

Applied water

The irrigation water had the typical water quality for the region with EC of 0.34 dS/m. The amount of water applied in each irrigation event was determined on the basis of raising the soil moisture content (60 cm depth) to its field capacity. Irrigation water was delivered to each plot through polyethylene pipes of eight inch diameter with a calibrated flow meter and a valve in front of each plot.

Water productivity (WP)

Water productivity based on grain yield and actual evapotranspiration was calculated according to the following equation given by Jensen (1983):

$$WP = \text{Grain yield (ton ha}^{-1}\text{)} / \text{Actual evapotranspiration (cm)}.$$

Reference evapotranspiration (ETo)

ET_O was estimated from daily weather data using a modified version of the Penman-Monteith equation (Allen et al. 1998):

$$ET_O = \{0.408\ D\ (R_n\ D\ G) + g\ (900/T+273)\ u_2\ (e_3\ D\ e_a)\} / \{D+g\ (1+0.34\ u_2)\}$$

where D (kPa $^oC^{-1}$) is the slope of the saturation vapor pressure curve at mean air temperature, R_n and G are the net radiation and soil heat flux density in MJ $m^{-2}d^{-1}$, g (kPa $^oC^{-1}$) is the psychrometric constant, T (^oC) is the daily mean temperature, U_2 (m s^{-1}) is the mean wind speed, *es* (kPa) is the saturation vapor pressure calculated from T, and *ea* (kPa) is the actual vapor pressure calculated from T_d (^oC), which is the mean daily dew point temperature. For a complete explanation of the equation, see Allen et al. (1998).

Crop coefficients

While ET_O is a measure of the 'evaporative demand' of the atmosphere, crop coefficients *(Kc)* account for the difference between the crop evapotranspiration (ET_C) and the reference evapotranspiration (ET_O). Crop coefficient was calculated: $Kc = ETc/ETo$.

Statistical analysis

Analyses of variance were conducted for each experiment as well as the combined analysis (for the three seasons) according to Snedecor and Cochran (1980). The differences between the mean values were compared by using the least significant different (L.S.D.) method. Values of regression and correlation between crop evapotranspiration (cm), grain yield ($kg.h^{-1}$) and water productivity ($kg.cm^{-1}$) were calculated for each wheat cultivar (Snedecor and Cochran 1980).

Results and discussion

Growth

Plant height (Table 2) decreased significantly as the number of irrigations decreased in all the three seasons and combined. Such decrease may be attributed to the decrease in the activity of meristematic tissues responsible for elongation. These results are in agreement with those obtained by Khater et al. (1997), Nahla et al. (2002), and Atta (2002). Gemmieza-9 was significantly taller than Sakha-93 as also observed by above workers.

Table 2. Plant height, grain weight per spike, number of spikes per m2 and 1000-grain weight as affected by number off irrigation for two wheat cultivars in the three growing seasons and combined.

Treat	plant height (cm)				grain yield (g per spike)				number of spikes per m^2				weight of 1000-grain (g)			
	S1	S2	S3	comb	S1	S2	S3	comb	S1	S2	S3	comb	S1	S2	S3	comb
I3	94.7	96.8	96.6	96.0	2.10	2.10	2.16	2.12	292.4	299.0	306.8	299.4	50.0	51.5	50.8	50.7
I2	100.2	102.6	103.3	102.0	2.39	2.19	2.29	2.29	336.4	366.2	375.2	359.3	52.6	54.1	53.6	53.4
I1	102.4	105.4	106.5	104.8	2.42	2.24	2.30	2.32	349.9	388.4	387.3	375.7	54.0	55.6	54.7	54.8
L.S.D at 0.05%	2.96	2.40	3.86	2.10	0.15	0.05	0.07	0.04	12.96	15.60	10.58	7.56	1.24	1.38	1.18	0.8
Sakha-93	98.15	98.4	100.1	90.0	2.24	2.08	2.22	2.18	324.3	339.6	350.9	338.3	50.9	51.4	53.8	52.0
Gem 9	102.4	102.4	104.1	103.0	2.39	2.28	2.35	2.34	328.1	362.8	361.9	351.3	53.4	56.1	52.4	54.0
L.S.D at 0.05%	3.15	3.86	3.77	3.64	0.09	0.17	0.08	0.11	3.22	5.80	4.09	4.13	2.36	3.55	1.28	1.80
Interac-tion I x C	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S

S1: first season (07/08), S2: second season (08/09), S3: (09/10), N.S: Indicates not significant

Yield attributes

Deficit irrigation had significant effect on number of spikes per m^2, grains weight per spike, and 1000-grain weight in all the three seasons and combined (Table 2). The highest values were obtained from I_1 (5 irrigations) followed by the I_2 treatment (4 irrigations), and the lowest were with treatment I_3 (3-irrigations). These results indicated that subjecting wheat plant to moisture stress during the reproductive phase (I_2 and I_3) led to significant reduction in yield components. These results agree with those obtained by El-Menoufi and Harb (1994); Khater et al. (1997) and Nahla et al. (2002). Gemmieza-9 had higher grain weight per spike, number of spikes per m^2 and 1000-grain weight than Sakha-93 by 6.84, 3.71 and 3.63 %, respectively. These results are in harmony with those obtained by Hamada et al. (2001), and Nahla et al. (2002).

Grain and straw yields

Grain and straw yields (Table 3) were highly significantly affected by deficit irrigation. Applying I_1 treatment (5irrigation events) resulted in the highest yields of grain and straw as there was no water stress on the plants at any critical stage of yield formation. Treatment I_3 (3 events) gave the lowest yields. There was no significant difference in average grain and straw yields between treatments I_1 and I_2. The grain and straw yields for treatment I_3 were 21.59 and 23.12 % and for treatment I_2 7.44 and 10.25 % less than those treatment I_1 respectively. Thus, under water shortage deficit irrigation I_2 treatment is recommended as the yield reduction is rather low as compared to full irrigation. These results agree with those of Ghanem et al. (1990), Mosaad et al. (1990), Chauhan (1991), Eid and Yousef (1994), El-Menofia and Harb (1994), Abd El-Gawad et al. (1993), Gad El-Rab et al. (1995), Osman et al. (1996), Abdel Monem et al. (1997), Nahla et al, (2002) and Atta (2002).

Table 3. Grain and straw yields as affected by number of irrigations of two wheat cultivars in the three growing seasons and combined

Treat	Grain yield (ton.h^{-1})				Straw yield (ton.h^{-1})			
	S1	S2	S3	Comb.	S1	S2	S3	Comb.
I3	4.849	5.066	5.166	5.027	12.571	12.910	13.340	12.940
I2	5.861	5.939	6.002	5.934	14.643	15.300	15.378	15.107
I1	6.461	6.338	6.434	6.411	16.619	16.510	17.370	16.833
L.S.D at 0.05%	0.560	0.360	0.40	0.430	1.75	1.03	1.89	1.46
Sakha-93	5.376	5.620	5.788	5.595	13.071	13.394	14.095	13.520
Gem. 9	6.071	5.942	5.947	5.985	16.051	16.420	16.631	16.400
L.S.D at 0.05%	0.61	0.30	0.13	0.33	2.88	2.96	2.34	2.66
Interaction I x C	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S

Gemmieza-9 had the higher grain and straw yields per hectare and it out-yielded Sakha-93 by 6.51 and 17.58 % respectively as an averages of the three seasons. Similar results were obtained by Kheiralla et al. (1993), El-Kalla et al. (1994), El-Banna (1995), Khater et al. (1997), Hamada et al. (2001) and Nahla et al. (2002). The interactions between irrigation treatments and cultivars were not significant in the three seasons and combined for all traits (Tables 2 and 3).

Actual evapotranspiration (ETc)

The results (Table 4) indicate that average water consumptive use values were 26.74 cm, 32.42, and 39.08 cm for irrigation treatments I_3, I_2 and I_1 respectively. These results are in harmony with those obtained by El-Rafaie et al., (1988), Ibrahim et al., (1988), Yousef and Eid (1994), Osman et al., (1996), Khater et al., (1997), Elsabbagh (1998), Nahla, Abo El-Fotouh et al. (2002) and Atta (2002). Gemmieza-9 had higher Etc (33.62 cm) than Sakha-93 (31.87 cm) as averages of the three growing seasons.

The results indicated that there was no significant difference in grain yield between the I_3 and I_2 treatments (Table 3) while they differed significantly in their water consumptive use (Table 4). Using deficit irrigation treatment I_2 saved about 11.0 cm of water applied without significant reduction in grain yield. Thus in the case of low water availability or when it is necessary to save water, use of I_2 treatment can result in saving of about 1,102 m^{3}ha^{-1} (19.0 %) without significant

reduction in grain yield. These results are in agreement with those by Ainer et al. (1993) and Osman et al. (1996) who stated that frequent irrigation provides chance for more water use and higher evaporation rate from a wet soil surface than a dry one.

Table 4. Amount of water applied, water consumptive use and water productivity as affected by number of irrigations for two wheat cultivars in the three growing seasons and combined

Treat	Applied water (mm)				Water consumptive use (mm)				Water productivity ($kg.cm^{-3}$)			
	S1	S2	S3	comb	S1	S2	S3	comb	S1	S2	S3	comb
I3	356	348	365	356	265	254	283	267	1.83	1.78	1.82	1.88
I2	487	442	479	470	334	328	316	324	1.76	1.81	1.93	1.83
I1	584	578	576	579	388	392	392	391	1.91	1.62	1.64	1.64
Sakha-93	476	456	474	468	319	316	321	319	1.70	1.78	1.80	1.76
Gem. 9	476	456	474	468	339	334	336	336	1.98	1.77	1.79	1.81

Table 5 presents the average monthly and daily consumptive use values as affected by number of irrigations and wheat cultivars as average of the three growing seasons. The values indicated that highest water consumptive use during February for treatment I_3 and March for treatment I_2 then tended to decrease with advancing of the crop to the maturity stage. While I_1 irrigation treatment had highest water consumptive use values in March then dropping during maturity stage in May. Similar results were obtained by El-Refaie *et al* (1988), Atta (2002) and Nahla *et al.,* (2002).

Table 5. Monthly (M), daily (D) and seasonal water consumptive use (mm) as affected by number of irrigations and wheat cultivars as an average of the three growing seasons

Treat.	Cultivars	Nov.		Dec.		Jan.		Feb.		Mar.		Apr.		May		Sea-sonal (mm)
		M	D	M	D	M	D	M	D	M	D	M	D	M	D	
I_3	Sakha-93	9.56	0.90	32.9	1.06	54.0	1.70	60.2	2.20	63.6	2.10	23.2	0.80	13.2	1.30	257
	Gem 9	9.56	0.90	35.6	1.15	56.1	1.80	62.4	2.20	71.8	2.30	28.4	1.00	14.2	1.40	278
Mean		9.56	0.90	34.2	1.11	55.0	1.80	61.3	2.19	67.7	2.19	27.3	0.86	8.72	1.37	267
I_2	Sakha-93	9.6	0.90	32.9	1.10	54.0	1.70	60.2	2.20	85.6	2.80	55.8	1.90	20.3	2.00	318
	Gem 9	9.6	0.90	35.6	1.20	56.1	1.80	62.4	2.20	88.1	2.80	57.6	1.90	20.8	2.10	330
Mean		9.6	0.90	34.2	1.10	55.0	1.80	61.2	2.20	86.8	2.80	56.7	1.90	20.6	2.20	324
I_1	Sakha-93	9.6	0.90	32.9	1.10	54.0	1.70	60.2	2.20	106.2	2.40	94.1	3.14	24.3	2.43	381
	Gem 9	9.6	0.90	35.6	1.20	56.1	1.80	62.4	2.20	109.8	3.50	99.9	3.33	27.0	2.70	400
Mean		9.56	0.90	34.2	1.10	55.0	1.80	61.3	2.10	108.0	3.50	97.0	3.20	25.6	2.60	391

Reference evapotranspiration (ETo)

Table (6) presents monthly average ETo values in $mm.d^{-1}$ determined by the Class ***A*** pan method.

The results indicated that ETo was 2.24 mm in November then decreased to 1.75 mm and 1.94 mm in December and January, respectively. ETo increased gradually to reach the maximum value of 6.17 mm in May due to the increase in air temperature. However, the average monthly actual consumptive use (Etc) increased from 0.87 mm in November and reached a maximum of 3.49 mm in March then decreased to reach 2.57 mm in May (Table 5).

Table 6. Actual evapotranspiration (ETc), potential evapotranspiration (ETo) and crop coefficient (Kc) for the two wheat cultivars as an average of the three growing seasons

Month	ETc ($mm.day^{-1}$)		ETo ($mm.day^{-1}$)	Kc	
	Sakha-93	Gemmieza-9		Sakha-93	Gemmieza-9
Nov.	0.87	0.87	2.24	0.39	0.39
Dec.	1.20	1.15	1.75	0.69	0.66
Jan.	1.74	1.81	1.94	0.90	0.93
Feb.	2.15	2.23	2.33	0.92	0.96
Mar.	3.43	3.54	3.08	1.11	1.15
Apr.	3.14	3.33	4.49	0.70	0.74
May	2.43	2.70	6.17	0.39	0.44

Crop coefficient (Kc)

Crop coefficient (Kc) values were calculated (Table 6) based on the daily actual evapotranspiration (ETc) derived from the irrigations treatment (I_1) for two wheat cultivars which produced the maximum wheat grain yield and the reference evapotranspiration (ETo). Kc was low at the start of the growing season, and then increased and reached its maximum value in March, then decreased again when plants started to mature in May. Similar results were obtained by Doorenbos and Kassem (1986). Thus, the updated empirical value of Kc to calculate consumptive use of Gemmieza-9 and Sakha-93 wheat cultivars for East Delta region.

Water productivity (WP)

WP of two wheat cultivars as affected by irrigation treatments as an average of the three growing seasons is presented in Table 4. The WP increased with decreasing the number of irrigations. The highest productivity occurred when plants were subjected to water stress treatment I_3 (3-irrigations) while the lowest WP (1.64 $kg.cm^{-3}$) was obtained from the treatment I_1 which received five irrigation events (typical farmer practices). Such a result indicates the importance of giving proper amounts of water at the proper physiological stages of growth to maximize crop production per unit of water. Similar results were also reported by Abd El-Gawad et al. (1993), El-Refaie and Hamada (1994), Osman et al. (1996), Khater et al. (1997), Nahla et al. (2002) and Atta (2002). In respect of the studied cultivars, Gemmieza-9 had higher WP value than Sakha-93.

Water uptake from different soil layers

Data of soil moisture extraction percentages in the soil layers (upper 60 cm soil depth) as average of the three growing seasons for irrigation treatments and two cultivars are presented in Figure 1. The most of the consumed water by wheat was removed from the surface soil layer. The rate of soil moisture uptake decreased with the soil depth.

The highest average percentage values of moisture uptake were 70.92, 72.33, and 73.73% for the upper 30 cm soil layer of the irrigation treatments I_3, I_2, and I_1 respectively. While the respective values were 29.08, 27.67 and 26.27 % obtained from the lower 30-60 cm. These values indicate that when exposing wheat plants to water stress (I_2 and I_3 irrigation treatments), plants tended to extract more water from lower depth (30-60 cm) in spite of less root distribution at the lower layers of the soil. Israelsen and Hansen (1962) reported that in arid regions more water was extracted from the first layer of the soil, whenever it is kept moist by frequent irrigation.

Gemmieza-9 removed considerably more water from the second layer than Sakha-93. Sakha-93 used higher quantity of water from the first layer than Gemmieza-9.

Table 7. Regression and correlation between water consumptive use (ETc) and grain yield (GY) and water productivity (WP) for the two wheat cultivars as an average of the three growing seasons

Dependent variables (Y)	Independent variable (X)	Regression equations	Correlation value (r)
		Sakha-93	
GY (kg.h^{-1})	ETc	*Y = 2500.1 + 97.11 x…….. (1)*	0.96**
WP (kg.cm^{-1})	ETc	*Y = 10971.4-30.28 x……..... (2)*	-0.77*
		Gemmieza-9	
GY (kg.h^{-1})	ETc	*Y = 2055.5 + 116.88 x…….. (3)*	0.97**
WP (kg.cm^{-1})	ETc	*Y = 15420.7-52.63 x …….. (4)*	-0.82*

Regression and correlation coefficients

Regression and correlation coefficients values between water consumptive use (ETc), grain yield (GY) and water productivity for all irrigation treatments and two wheat cultivars are shown in Table 7. The data revealed that ETc is positively correlated to GY and negatively to WP. Also, the data showed that increasing ETc by one centimeter enhanced the grain yield by 97.11 and 30.28 kg ha^{-1} for Sakha-93 and Gemmieza-9 respectively (equations 1 and 3). WP decreased by 52.63 kg cm^{-1} of water consumed in case of Gemmieza-9 as against 30.28 kg ha^{-1} in case of Sakha-93 (equations 2 and 4). There was a positive correlation between ETc and GY (r = 0.96 and 0.97for Sakha-93 and Gemmieza-9) and negatively to WP (r = -0.77 and -0.82 for the same cultivars respectively).

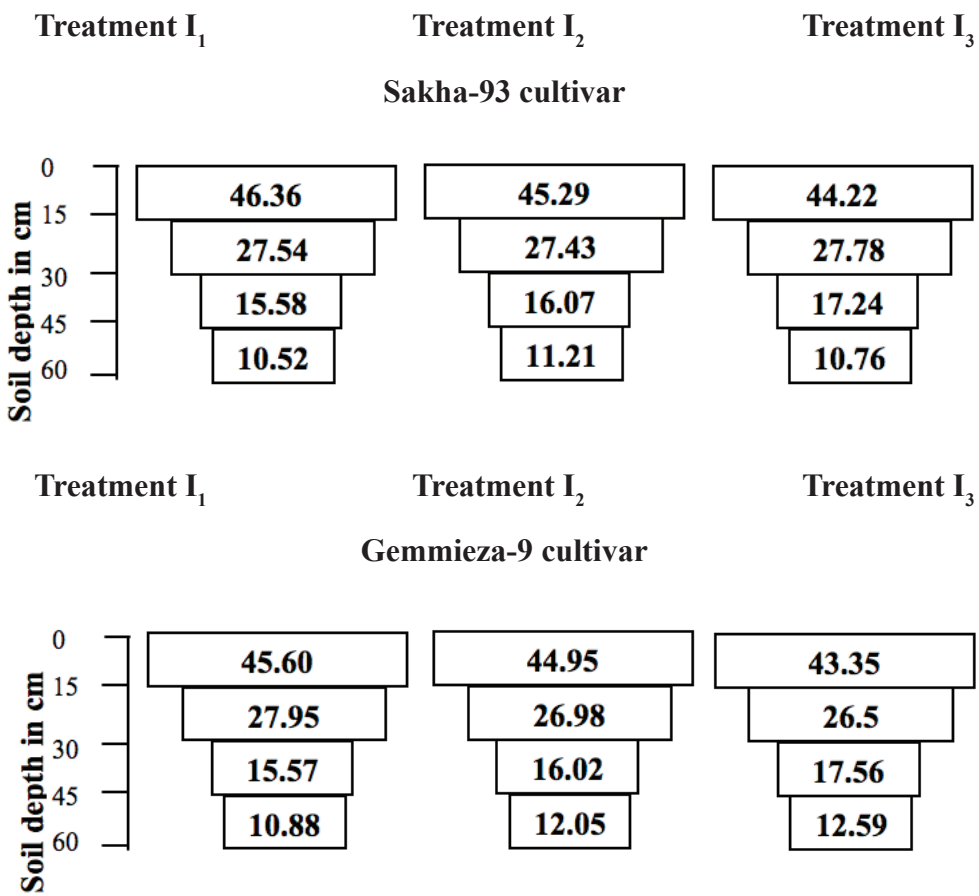

Figure 1. Water uptake percentage by wheat roots from soil layers as affected by number of irrigations for two wheat cultivars as an average of three growing season.

Conclusions

Options to reduce the gap between water supply and demand are essential for dealing with water scarcity coupled with rapid population growth and the potential negative impacts of climate change on agriculture production systems. This research attempted to find solution to the problem faced by users of canal ends in Delta where water supply is becoming an increasingly serious problem. The aim was to study the effect of deficit irrigations on water consumptive use, growth and yield attributes and yield of two important wheat cultivars recommended for the area in order to set the management tool for managing water under water shortage conditions. The results indicated that the number of irrigation events could be decreased with only slight, insignificant decrease of 7 and 10 % in the grain and straw yield. This means that applying four irrigations instead of conventional five could save about 19 % of the water commonly applied. However, for maximizing the yield five-irrigations should be applied under East Delta conditions. In general Gemmieza-9 cultivar gave higher grain and straw yields and was more efficient in using water than Sakha-93. Hence it is recommended for use in this region. The crop coefficient values (Kc) were calculated based on reference evapotranspiration (ETo) and the daily actual evapotranspiration (ETc) derived for the irrigation treatment that produced the highest wheat grain yield. It is recommended that this updated empirical value of the crop coefficient should be used to calculate consumptive water use of Gemmieza-9 and Sakha-93 wheat cultivars in the East Delta Region.

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7. Magnetic water technology, a novel tool for improving crop production

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Abstract

The technology of magnetized water has been widely studied and adopted in agriculture in many countries (Russia, Polanda, Australia, USA, China and Japan), but in Egypt studies on the use of magnetized water in agriculture are very limited. Therefore, the present work was carried out to study the response of growth, yield components and yield and some chemical constituents of wheat and flax (monocotyledonous) and chick pea and lentil (dicotyledonous plants) to irrigation with magnetized and tap water under green house condition. Magnetized water exhibited marked increases in the vegetative growth and the content of photosynthetic pigments (chlorophyll a, chlorophyll b and carotenoids), total phenols and total indole acitic acid and the yield and yield components of all crops. The increases in seeds yield/plant were 10.0, 33.3, 26.9, and 46.6%, for flax, wheat, lentil and check pea, respectively. This preliminary study shows that magnetized water can be promising for improving the crop productivity and quality under Egyptian conditions.

Introduction

Till 1980 a little was known about how the magnetic field can stimulate plant growth or prevent it. Wojcik (1995) reported that in the beginning of 1980s Fujio Shimazaki working in Shimazaki Seed Company in Japan was the first who reported that stationary magnetic fields can improve the germination of seeds and speed up the growth of plants.

The magnetic field (MF) influence on the seeds of various crops and trees species increased the germination of seeds and improved their quality (Aladjadjiyan 2002). The reason of this effect can be searched in the presence of paramagnetic properties in chloroplast which can cause an acceleration of seeds metabolism by magnetic treatment (Aladjadjiyan and Ylieve 2003). It was also shown that, MF affected various characteristics of plants like germination of seeds, root growth rate, seedlings growth, reproduction and growth of the meristem cells and chlorophyll quantities (Namba et al. 1995; Atak et al. 1997 and Reina et al. 2001). In addition, there were magnetic field studies done with yield and yield parameters of crops like cereal, sunflower and soybean. In these studies the crop yield was increased (Özalpan et al. 1999; Yurttas et al. 1999 and Oldacay 2002).

The effect of magnetic field on the productivity of different crops has been studied by many authors (Phirek et al. 1996; Pietruszewski 1999 a, b and c; Aladjadjiyan 2002). It has been established that the proper combination of magnetic field induction and exposure accelerates the early stages of plant development and improves the productivity. Consequently, the magnetic field effect can be used as an alternative to the chemical methods of plant treatment for improving the production efficiency (Aladjadjiyan 2003). Investigations of MFs on biological systems have

demonstrated generalized increases in gene transcription and changes in the levels of specific mRNAs (Celik et al. 2008).

Material and methods

A pot experiment was conducted in the screen house of the Agronomy Department of the National Research Centre, Dokki, Giza, Egypt during to study the response of growth, yield and some chemical constituents of some plants to irrigation with tap and magnetized water. Seeds of monocotyledonous crops [wheat var. 'Sakha-93 186' and flax var. 'Sakha 2'] and dicotyledonous crops [check pea var. 'Giza-4' and lentil 'var. Sena-1'] were obtained from field Crop Research Department, Field Crops Institute, Agriculture Research Centre, Giza, Egypt. Selected seeds were planted in ten pots (30 cm in diameter and 50 cm depth) containing a mixture of clay and sandy soil (2:1). Half of the pots were irrigated twice on a week interval with tap water, while the other 5 pots were irrigated with the tap water after magnetization through a one inch Magnetron (U.T. 3). The recommended NPK fertilizers for each crop were applied through the period of experiment (120 days).

After 60 days from sowing plant height, fresh and oven dry weight of 6 plants from each crop were determined. Photosynthetic pigments (chlorophyll a, chlorophyll b and carotenoids) of leaves were determined spectrophotometrically (Moran 1982). Total indole acetic acid (IAA) (Larsen et al. 1962) and total phenol (Malik and Singh 1980) contents were estimated in the fresh shoots. Electrophoresis protein profile of leaves was analyzed by sodium dodocylsulphate polyacrylamide gel electrophoresis (SDS-PAGE) technique (Sheri et al. 2000). Molecular protein markers, percentage of band intensity and molecular weight of each polypeptide were related to standard markers using gel protein analyzer version 3 (MEDIA CYBERNE TICE, USA).

Statistical analysis was conducted using SPSS program Version 16. A student test (independent t-test) was done to find the significant differences between magnetic and nonmagnetic water treatments.

Results and discussion

Growth parameters

The changes in plant height, fresh and dry weight per plant and water content of plants because of the exposure to magnetic field are shown in Table 1. Magnetic treatment increased growth significantly over the untreated plants of both monocotyledonous and dicotyledonous type. The increase in fresh weight/plant of monocotyledonous plants ranged between 15.9 and 52.61% and the dry weight/plant increased between 8.26 and 43.21%. The increases in fresh and dry weight/plant of dicotyledonous plants ranged between 11.36 – 17.86% and 4.28 – 15.94% in chick pea and lentil plants, respectively. Water content was the least affected parameter in both types of crops; the percent increase ranged between 0.66 and 2.63 in all four crops. Monocotyledonous plants (wheat and flax) surpassed dicotyledonous plants (chick pea and lentil) in their response to magnetic treatments.

The stimulatory effect of magnetic water may be attributed to some role in increasing absorption and assimilation of nutrients and consequently plant growth. These results are in good harmony with observations on positive effects on growth in tissue culture and field regeneration percentage (Yaycılı and Alikamanoğlu 2005). Alikamanoğlu et al. (2007) suggested that, magnetic water

treatment improved seed imbibition, vigor and germination rate, and seedling treatment promoted NPK absorption and increased root number, stem thickness, dry weight/100 plants and tillers number. Celik et al. (2008) and Nasher (2008) concluded that, magnetized water increased growth and was an important factor for inducing plant growth. The stimulatory effect of MW on growth in our study may be also attributed to the increase in photosynthetic pigment, endogenous promoters (IAA), total phenol (Table 2) and increase in protein biosynthesis (Table 4). In this connection, Shabrangi and Majd (2009) concluded that, biomass increase needs metabolic changes particularly increased protein biosynthesis.

Table 1. Growth response of some monocot and dicot plants at 60 days after sowing for irrigation with magentic water

Treatment	Monocot						Dicot					
	Wheat			Flax			Chick-pea			Lentil		
Character	Magnetic water	Tap water	P-value	Magnetic water	Tap water	P-value	Magnetic water	Tap water	P-value	Magnetic water	Tap water	P-value
Plant height (cm)	29.200	26.200	**0.013**	25.000	24.000	**0.406**	26.200	24.200	**0.131**	18.400	15.200	**0.013**
Fresh weight/plant (g)	1.210	0.793	**0.001**	0.709	0.612	**0.001**	1.731	1.554	**0.001**	0.660	0.560	**0.001**
Dry weight/plant (g)	0.294	0.205	**0.001**	0.163	0.150	**0.227**	0.382	0.374	**0.016**	0.194	0.167	**0.001**
Water contents (%)	75.600	74.040	**0.177**	77.073	75.470	**0.282**	77.928	75.934	**0.001**	70.568	70.107	**0.534**

Chemical constituents

Photosynthetic pigments (Chlorophyll a, Chlorophyll b, total Chlorophyll a+b and carotenoids), total phenols and total indole contents in plant shoots exhibited great alterations in response to the irrigation with magnetized water than the controls (Table 2). The magnitude of increments in total pigment content ranged from 15.25 – 31.45 % in monocot and from 16.64 – 21.4 % in dicot. Total phenol content was increased by 18.2 – 33.59 % in monocot and by 20.0 – 39.02 % in dicot. The total indole acetic acid content of monocot plants increased by 33.35 – 233.5 %, and of the dicot plants by 8.66 – 148.19 %.

These results may be due to the effect of MT on alteration in the key of cellular processes such as gene transcription. It also may be due to the increase in growth promoters (IAA, Table 2). Tian et al. (1991) and Atak et al. (2000, 2003) also found an increase in chlorophyll content specifically after exposure to a magnetic field for a short time. Atak et al. (2003) suggested that increase in all photosynthetic pigments was through the increase in cytokinin synthesis which is induced by MF. They also added that cytokinin plays an important role in chloroplast development, shoot formation, axillary bud growth, and induction of number of genes involved in chloroplast development and nutrient metabolism. Atak et al. (2003) showed that the increase in shoot regeneration, chloroplast rate, root formation and fresh weight were accompanied by the increase in auxin synthesis by MF treatment in soybean plants. Goodman et al. (1995) and Atak et al. (2003) described the role of MF in changing the characteristics of cell membrane, affecting the cell reproduction and causing some changes in cell metabolism. So the increase in total phenol under this study may be attributed to the role of MT in changing the cell membrane properties. Carimi et al. (2002) and Celik et al. (2008) conclude that MF stimulates protein synthesis via increase in cytokinins and auxins and they can promote the maturation of chloroplast. Growth, development and plants productivity are usually affected by the activity of photosynthetic pigments. Magnetic fields are known to induce biochemical changes and could be used as a stimulator for growth related reactions including affecting photosynthetic pigments (Dhawi and Al-Khayri 2009).

Table 2. Effect of magentic water on chemical constituents of some monocot and dicot plants at 60 days after sowing

Treatment		Monocot						Dicot					
		Wheat			Flax			Chick-pea			Lentil		
Character		Magnetic water	Tap water	P-value	Magnetic water	Tap water	P-value	Magnetic water	Tap water	P-value	Magnetic water	Tap water	P-value
Photosynsetic pigments (mg/100 g fresh weight)	Chlorophyll a	9.684	8.235	**0.001**	7.200	6.130	**0.001**	7.239	5.720	**0.001**	4.215	3.711	**0.017**
	Chlorophyll b	5.539	4.973	**0.121**	3.960	2.360	**0.002**	3.741	3.071	**0.001**	1.804	1.247	**0.013**
	Chlorophyll a+b	15.223	13.208	**0.008**	11.160	8.490	**0.001**	10.980	8.791	**0.001**	6.019	4.958	**0.015**
	Carotoneiods	5.844	5.672	**0.455**	4.993	4.600	**0.135**	4.502	4.483	**0.745**	4.902	4.773	**0.569**
	Total pigments	30.446	26.417	**0.008**	22.320	16.980	**0.001**	15.482	13.274	**0.001**	12.038	9.916	**0.015**
Total phenol (mg/100 g fresh weight)		288.051	215.619	**0.001**	246.073	208.190	**0.001**	434.130	312.287	**0.003**	215.017	179.177	**0.002**
Total Indols (µg/100 g fresh weight)		9.796	2.937	**0.001**	1.594	1.195	**0.001**	1.367	1.258	**0.009**	2.055	0.828	**0.001**

Protein electrophoretic pattern

The changes in protein electrophoretic pattern of plant leaves treated with magnetic water was analyzed (Table 3). In the control leaves the separation of 12, 13, 15 and 11 protein bands appeared in wheat, flax, chick pea and lentil, respectively. Their molecular weights ranged between 346 K Da. and 20 K Da. Magnetic water treatment (MWT) showed an increase in the number of protein bands to 16, 21, 22 and 16 in wheat, flax, chick pea and lentil, respectively. These results indicate that the leaves of plants treated with magnetic water characterized by disappearance of certain bands and the appearance of new ones as compared with that of the control plant (Table 3). Six new protein bands appeared in wheat at molecular weights 340, 194, 116, 88, 57 and 22 KDa. The nine new protein bands appeared in flax at molecular weights 301, 267, 223, 210, 113, 107, 98, 59 and 45 KDa. New protein bands appeared in chick pea at molecular weights 314, 248, 235, 226, 192, 135, 49 and 32 KDa. In lentil, the new protein bands appeared at molecular weights 332, 307, 301, 93, 75, 55 and 38 KDa. On the other hand, the protein bands at molecular weights 51 and 37 K Da in wheat, at 56 K KDa in chick pea and at 127 and 20 K Da in lentil disappeared in response to magnetic water treatment.

The induction of new protein bands in response to MWT may be a result of the effect of MF in increasing proliferation, gene expression and protein biosynthesis (Tenford 1996). Celik et al. (2008) concluded that investigations of MF on biological systems have demonstrated generalized increases in gene transcription and changes in the levels of specific mRNAs. Shabrangi and Majd (2009) concluded that biomass increase needs metabolic changes particularly increase in protein biosynthesis. They also added that magnetic field is known as an environmental factor which affects gene expression. Therefore, by augmentation of biological reactions like protein synthesis, biomass would increase.

Yield and yield component

Data in Table 4 showed that MWT increased all yield characters in all crops over the untreated controls. The percentage of increase in seed yield /plant reached to 10 to 33.33 % in

monocotyledonous crops and to 26.92 – 46.62 % in dicotyledonous crops over the untreated controls. Chick pea and lentil surpassed monocotyledonous plants (wheat and flax) in their response to magnetic treatments. The percent increase in photosynthetic pigment and growth promoters (total IAA) in monocot was higher than in dicot plants (Table 2).

Table 3. The relative area percentage of protein bands in leaves at 60 days after sowing of some monocot and dicot plants irrigated with magnetized and normal water

M wt. K.Da.	Monocot				Dicot			
	Wheat		Flax		Chickpea		Lentil	
342	4.54	2.24					1.76	1.83
339		5.28	2.54	3.58				
327	5.07	4.16			3.54	2.51		2.44
323					3.61	1.47	2.72	2.58
322					16.97	1.46		
316			4.49	3.03		2.32		
307				3.42				2.00
301								1.27
286	8.73	8.21	2.43	3.03				
267				3.22				
253	8.21	7.34	2.37	3.26				
245						7.80	10.23	12.75
233			4.61	3.15		1.31		
224				3.65		2.51		
204		10.32		2.40		2.68		
189					2.32	2.32		
146	13.79	6.80	7.40	7.60	4.23	5.38	8.60	4.97
135						1.99	4.55	2.15
125					2.06	2.06	6.17	
114		6.11		3.86				
107				2.56				
95				5.49				10.35
87		4.55	15.70		4.27	5.24		
73			6.21	2.75				7.85
66	9.67	9.81			6.89	7.70	17.32	2.85
56		3.92		6.77	6.15			6.05
52	8.08		10.61	6.03	2.76	5.69	8.11	4.73
47			11.22	10.44		5.08	13.30	14.96
45	15.47	12.84		5.96	10.45	7.76		
41			11.36	4.75	8.80	7.17		
37	5.16		7.26	2.45	8.79	6.15		6.59
35					5.34	2.25		
33	11.67	9.23	13.80	12.60		10.68	18.31	16.63
30					5.60	8.47		
22		4.24						
20	9.61	4.95					8.93	
Band number	**11**	**15**	**13**	**21**	**15**	**22**	**11**	**16**
Number of new band		**6**		**9**		**8**		**7**

Table 4a. Effect of magentic water on yield and yield components of some monocot plants

Treatment	Monocot						
	Wheat			Character	Flax		
Character	Magnetic water	Tap water	P-value		Magnetic water	Tap water	P-value
Plant height (cm)	47.00	39.80	**0.012**	**Plant height (cm)**	58.20	56.80	**0.029**
Spike length (cm)	6.60	5.00	**0.004**	**Tecenical length (cm)**	48.80	43.40	**0.012**
Spikeletes no./spike	12.00	9.00	**0.001**	**Based branches no/plant**	2.80	2.40	**0.242**
Spike weight (g)	0.75	0.64	**0.004**	**Fruit Branches. no/plant**	6.00	5.60	**0.347**
Seed yield (g/plant)	0.40	0.30	**0.001**	**Cabsules no/plant**	10.80	9.20	**0.024**
Straw yield (g/plant)	0.80	0.59	**0.001**	**Seed no/cabsula**	8.40	8.00	**0.524**
Biological yield (g/plant)	1.20	0.89	**0.001**	**Cabsules weight/plant (g)**	0.53	0.44	**0.008**
HI (%)	33.80	33.76	**0.984**	**Seeds no/plant**	79.60	66.00	**0.046**
CI (%)	51.33	51.28	**0.993**	**Seed yield (g/plant)**	0.35	0.32	**0.046**
				100 seed weight (g)	0.70	0.68	**0.116**

Table 4b. Effect of magentic water on yield and yield components of some dicot plants

Treatment	Dicot					
	Chick-pea			Lentil		
Character	Magnetic water	Tap water	P-value	Magnetic water	Tap water	P-value
Plant height (cm)	41.800	32.400	**0.001**	20.600	16.400	**0.001**
Branches no./plant	4.400	3.200	**0.005**	3.600	2.710	**0.010**
Pods no/plant	11.500	7.600	**0.001**	6.400	4.780	**0.001**
Pods weight (g/plant)	2.755	1.964	**0.001**	0.720	0.630	**0.011**
Seed no/plant	10.200	7.132	**0.001**	10.500	8.750	**0.001**
Seed yield (g/plant)	2.104	1.435	**0.001**	0.660	0.520	**0.002**
Starw yield (g/plant)	2.946	1.985	**0.001**	1.366	1.056	**0.004**
Biological yield (g/plant)	5.050	3.420	**0.005**	0.706	0.536	**0.001**
Harvest index (%)	41.977	41.956	**0.995**	48.379	49.301	**0.745**
Crop index (%)	74.536	72.374	**0.839**	94.872	98.497	**0.756**
100 seed wt (g)	19.174	19.130	**0.901**	5.620	5.200	**0.001**

Generally, the stimulatory effect of magnetic treatment may be attributed to the increase in growth (Table 1), and photosynthetic pigment and growth promoters (Table 2). This is in agreement with the results of Tian et al. (1991) who indicated that MW increased yield of rice by 13.23%, which

was accompanied by the stimulation effect of MW on leaf chlorophyll content. Kordas (2002) found that the exposure of green tops and root systems of wheat plant to MF increased yield of coarse grain by 10.6% and 6.3% respectively. In this connection, Dodlesny et al. (2004, 2005) suggested that, the gain in seed yield resulting from the pre-sowing treatment of seeds with MF for broad bean and pea was due to the higher number of pods per plant and the fewer plant losses in the unit area in the growing season. Souza et al. (2006) showed that MWT of tomato increased significantly the mean fruit weight, the fruit yield/plant, the fruit yield per area and the equatorial diameter of fruits in comparison with the controls. MF was shown to induce fruit yield per plant and average fruit weight (Celik et al. 2008).

Exposure of plants to MW is highly effective in enhancing growth characteristics. This observation suggests that there may be resonance-like phenomena which increases the internal energy of the seed. Therefore, it may be possible to get higher yield (Vashisth et al. 2008; Shabrangi and Majd 2009) on chickpea and lentil respectively.

Conclusion

Growth parameter and yield components of monocotyledonous (wheat and flax) and dicotyledonous (chick pea and lentil) plants increased when plants were treated with magnetic water through increased photosynthetic pigment, endogenous total indole acetic acid, total phenol and protein synthesis. The variation in the response of plants should encourage continuous efforts from researchers to explore the mode of magnetic treatment action in monocot and dicot crops.

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8. Sustainable development: Optimization of the water use management using sap flow as a sensitive indicator of water stress in olive tree (*Olea europaea* L.)

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Abstract

Water stress is the most important factor limiting plant growth and production. In this study, trunk sap flow and stomatal conductance was characterised in an experimental olive orchard, located in the center of Tunisia, for irrigated and rain-fed olive trees (*Olea europaea* L.). Physiological parameters responded diurnally to variations in tree water status. Water deficit caused a decrease in leaf stomatal conductance, and a decrease in sap flow (stronger in rain-fed than irrigated trees), probably attributable to modifications in hydraulic properties at the soil-root interface. Our results confirm that olive trees are economical and sparing users of soil water, with an efficient xylem sap transport, and maintenance of significant gas exchange even during drought stress.

Introduction

Tunisia is next to Spain, Italy and Greece in the world olive oil sector regarding the number of trees and olive oil production; Tunisia produced 144,500 T per year between 2000 and 2006 (Codex Alimenarius Commission 2007), accounting for ~5.2% of world production. However, most of the Tunisian olive plantations are growing in arid zones (in the centre and the south of the country) and face harsh environmental conditions, especially drought that affects severely the olive production. Moreover, in the south Mediterranean countries the climate change shows that global warming is occurring at a rate higher than the global average. Indeed, the rise in global temperatures during the 20th century was 0.75 ° C, where as that of the Maghreb was between 1.5 and 2 ° C depending on the region. Precipitation,decreases are between 10 and 20%.

The olive tree (*Olea europaea* L.) is considered as one of the hypostomatous species best adapted to the semi arid Mediterranean environment, and is traditionally grown under dry conditions (Gimenez et al. 1997).This species is characterized by low hydraulic conductivity (Bongi and Palliotti 1994), which is responsible for a high degree of variation in leaf water potential in response to changing environmental factors (Lakso 1985

A common response of plants to water deficit is a reduction in the conductivity to water flow along the soil–plant–atmosphere pathway. Stomatal control and root conductivity are considered as the main factors regulating the water flow in plants (Jones 1992). Several approaches have been used to monitor the plant water status and its physiological responses to external factors like local atmospheric demand for water and soil water availability. One such approach that has been successfully used for olive trees is the heat-pulse method (HP) to monitor tree sap flow and transpiration (Green and Clothier 1988; Fernández et al. 2001; Green et al. 2003). In the past, sap flow data have been used to calibrate and test a range of micrometeorological methods to

estimate tree transpiration (Green 1993; Pereira et al. 2006). These measurements are also being suggested as suitable means for automatic control of orchard irrigation systems (Fernández et al. 2001; Jones 2004; Tognetti et al. 2004; Dragoni et al. 2005).

The aim of this work was to evaluate the effects of irrigation on the trunk sap flow and leaf staomatal conductance (g_s) in the olive trees. Studying these parameters in field grown olive trees may provides a powerful tool to assess the sensitivity to drought and irrigation. Through gaining an understanding of temporal variations in these parameters, we will be better able to schedule water supply, allowing the olive trees some resilience against water stress in arid regions of Tunisia.

Material and methods

Plant material and experimental conditions

Research work was conducted during 2007 in olive orchards (having cv. 'Meski' and cv. 'Chemlali') located in Kairouan and Jemmel Centers of Tunisia. The climate of the study area is Mediterranean with an average annual rainfall of 350 mm, mostly distributed outside a 4-month summer drought period. Olives were planted in 1990 in Kairouan and 1988 in Jemmel. The two olive tree groves were subjected to identical fertilisation regime and to all common olive cultivation practices. Two treatments were used in Kairouan : T1: rain-fed plus a moderate level of supplemental irrigation; and T2: trees were irrigated with 100 % of crop evapotranspiration (Et_c). The soil under both treatments had the same texture. Each treatment block consisted of a row of six trees. Climatic conditions at the experimental site were recorded by a weather station. For Jemmel experimental plot, four planting densities were tested in rain fed conditions (156 trees/ha: 8x8m; 100 trees/ha:10x10 m; 70 trees/ha: 12x12 m and 50 trees/ha: 14x14 m trees/ha). Each treatment area had the same soil texture and each treatment block consisted of a row of six trees.

Gas exchange measurements

Stomatal conductance (g_s) was measured on two leaves per tree with six replicates per treatment with a portable system (Li-Cor 6400, Nebraska, USA) under saturating light conditions (PAR at leaf surface was up to 1050 µmol m^{-2} s^{-1}).

Sap flow measurements

Sap flow was measured using the Granier system (Granier 1985), based on the temperature differences between two cylindrical probes with a diameter of 2 mm and a length of 15 mm, which were installed radially into the semi-trunk of each tree, at a height of about 50 cm. Sap flow was measured on three selected trees for each treatment. Each probe included a 0.2 mm diameter copper–constantan thermocouple. The two thermocouples were joined at the constantan leads, so that the voltage measured across the copper leads provided the temperature difference between the heated upper probe and the lower reference. Measurements were taken at 60 s intervals and their average was stored every 5 min on a data logger.

Results and discussion

In Kairouan, sap flow diurnal patterns showed, for both treatments, a steep morning increase leading to the maximum rates achieved at about midday, followed by a sustained gradual decrease

until late in the afternoon (Figure 1). Rain-fed trees showed lower daytime sap flow rates than irrigated plants. It is likely that roots of irrigated trees supplied additional water. Moreover, the presence of roots in dry zones explored by the root system might provide sufficiently strong signals for trees to begin adopting prudent strategies to limit water usage in rain-fed trees (Tardieu and Davies 1993). Sap flow measurements provided useful information on the dynamics of tree transpiration and for determining effects of meteorological conditions and soil water status on olive tree water use (Fernández & Moreno 1999).

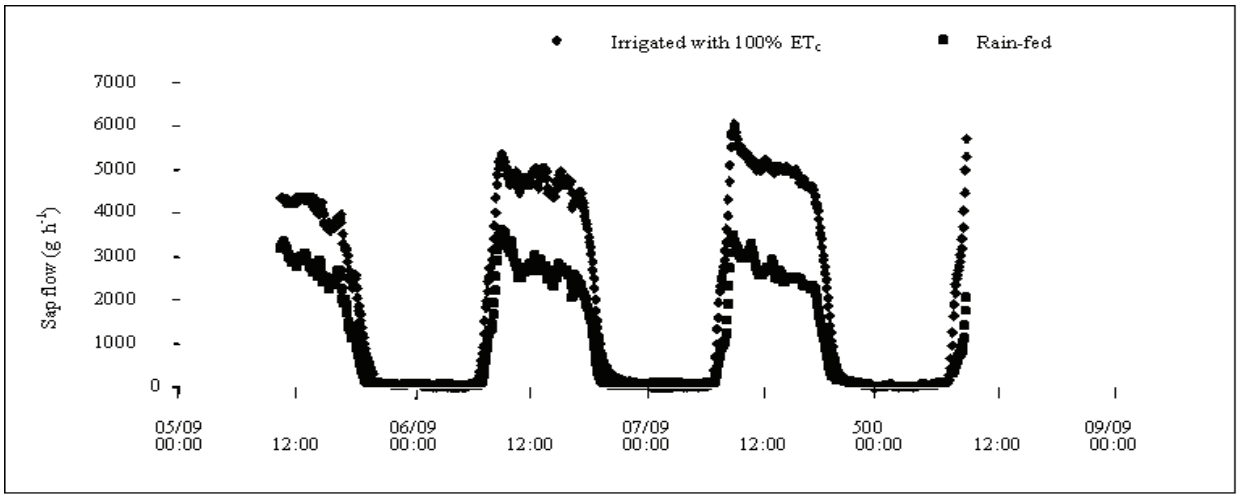

Figure 1. Diurnal patterns of sap flow of olive tress under two treatments: rain-fed, or irrigated with 100 % ETc during the period from 05/09 to 08/09 in 2007 in Kairouan.

Integration of information on hydraulic behaviour of olive trees and interpretation of the diurnal sap flow dynamics might be used to infer the onset, or severity of water stress in olive orchards (Fernández et al. 2001). Despite the limitation due to the considerable heterogeneity of the conductive area in mature olive trees, Giorio & Giorio (2003) showed the feasibility of estimating the transpiration rate of many olive trees (cv. Kalamata) by monitoring sap flow in single trees by the use of a sole heat-pulse gauge.

Diurnal patterns of leaf conductance showed a progressive reduction in daily values in rain-fed trees (Fig. 2). Leaf conductance values being generally higher in mid morning hours in rain-fed tress compared to irrigated ones. In addition, our results show that an increase in relative humidity seemed to lead to stomatal closure and thus reducing sap flow of rain-fed tress (Fig. 3). Stomatal closure in response to increasing relative humidity; might be an effective strategy to avoid excessive water loss under drought conditions and prevent leaf water potential from falling to dangerous levels (Tyree and Sperry 1988). However, the physiological mechanisms of stomatal response are very complex and not fully understood. Hypotheses involving hydraulic and/or biochemical signals have been proposed and verified in many studies (Stoll et al. 2000; Davies et al. 2002).

Figure 3 shows that an increase in daily air temperature leads to an increase in sap flow by inducing stomatal opening. Stomata are integrators of many environmental factors affecting plant growth (Morison 1998). In addition to physiological and environmental variables, endogenous factors (hydraulic and chemical signals) appear to affect stomatal conductance in olive trees (Moriana et al. 2002).

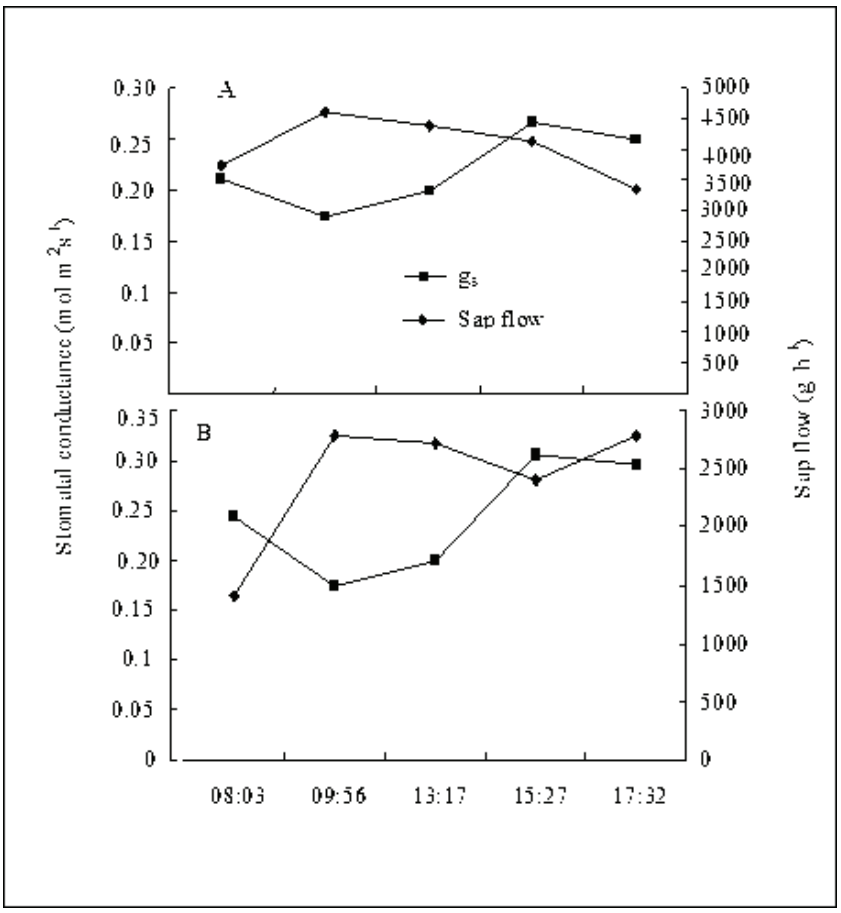

Figure 2. Diurnal patterns of sap flow and stomatal conductance of olive trees under two treatments: Irrigated with 100 % ETc (A) or rain-fed (B).

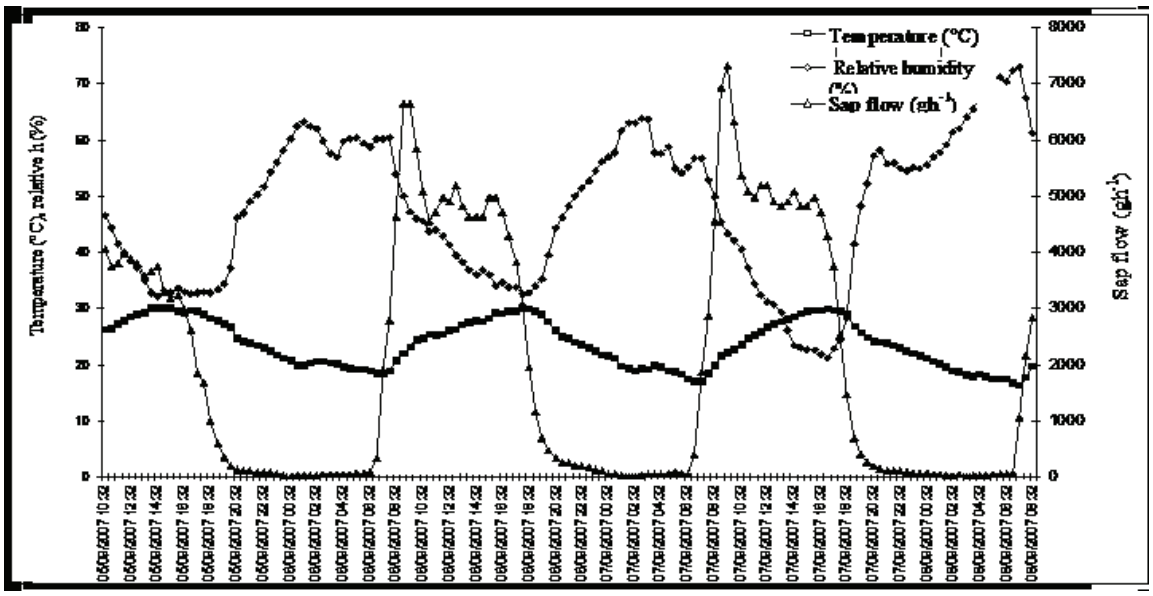

Figure 3. Daily sap flow of rain-fed tress, daily temperature and daily relative humidity as recorded by a weather station during the experimental period nearby Kairouan olive plantation.

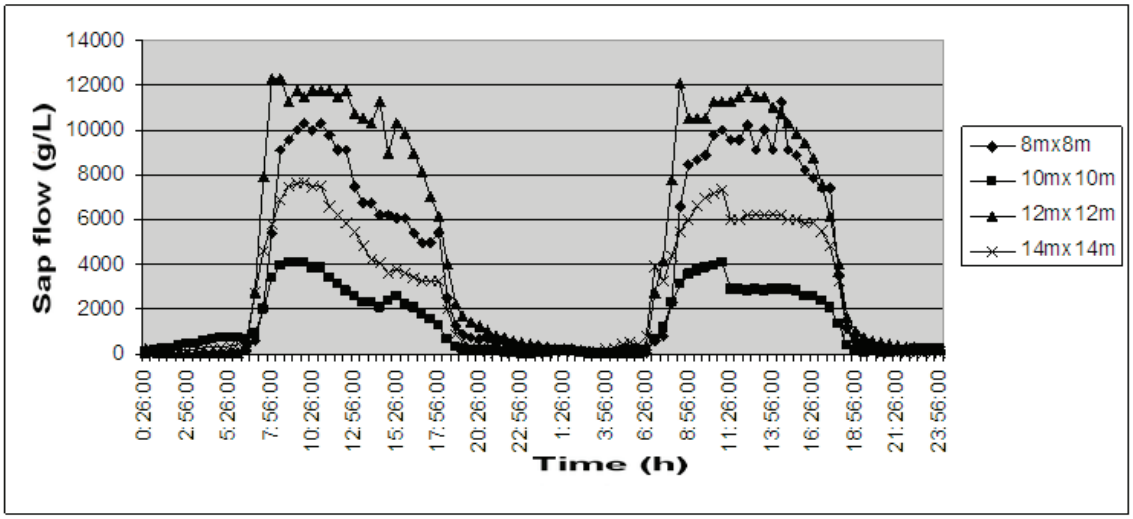

Figure 4. Diurnal patterns of sap flow of olive tree on two consecutive days during the summer under four densities in the experimental plot of Jemmel.

In Jemmel, the application of the sap flow technique for monitoring flow of sap in rain fed conditions shows (Fig. 4) that in summer the sap flow was higher in tree densities of 50 and 100 trees/ha than in density of 70 and 156 trees/ha. This reflects that the difference in transpiration may not be due to changes in tree density and confirm the ability of the variety to provide its water needs during the driest period. In autumn, we recorded a heavy rainfall, the diurnal variation of the sap flow in this period was similar in the trees for all the densities, and this proves the high hydratation potential of the plant. In winter the sap flow record showed that the water consumption in this period was not negligible. The maximum sap flow level was seen in the trees at the lowest densities. These results show the importance of the water in this period for the tree to conserve nurtients.

Conclusion

Our results confirm that sap flow represents a reliable indicator of olive tree water status. Water supply can directly improve the tree water state and the sap flow data gives accurately and instantaneously the water status of the tree that can be used to reduce the negative effect of the water shortages by giving irrigation. Moreover, the close relationship between this parameter and the stomatal conductance could be used in developing a sap flow based technique for automatically controlling the irrigation system in field grown olive tree.

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9. Impact of water stress and nitrogen fertilizer levels on cotton under high temperatures in Upper Egypt

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Abstract

This work was carried out at El-Mattana Agricultural Station, Luxor Governorate, Egypt, during 2007, 2008 and 2009 seasons to study the impact of water stress and nitrogen fertilizer levels on growth, yield and fiber quality of 'Giza 90' cv. under high temperatures in Upper Egypt. Two irrigation intervals (15 and 21 day) and three levels of nitrogen (30, 45 and 60 kg N/fed.) were used. Obtained results revealed that the years affected significantly all characters under study due to the variation in total amount of heat units, which were higher in 2008 growing season and which led to a significant increase in growth (plant height and number of fruiting branches per plant) and caused decrease in seed-cotton yield and fiber quality. Prolonging the irrigation interval to 21 day resulted in significant reduction in vegetative growth, no. of open bolls per plant, boll weight, seed cotton yield and gave low fiber quality. The increase of N level to 60 kg N /fed significantly increased the vegetative growth, number of open bolls per plant, boll weight, seed cotton yield and gave good fiber quality. Well-watered plants responded more favorably to N supply than water-stressed plants. The interactions between years, irrigation intervals and N levels were significantly in affecting growth, yield and fiber traits. Prolonging the irrigation interval and increasing stress of water under high temperature on cotton plant gave the lower values of traits under studied. Positive and significant correlation was found between cotton growth and heat units but seed cotton yield and its components were negatively and significantly correlated with heat units. Under El-Mattana conditions, therefore, proper N level was 60 kg N /fed and the irrigation interval was 15 day to assure high yield and quality and to avoid adverse effects of high temperature in some seasons.

Introduction

Crop growth and yield are controlled by environmental factors. Temperature plays a dominate role in controlling growth and developmental rates of cotton plants. Roussopoulos et al. (1998) found that fibers were shortest in the high temperature regime where fiber strength and micronaire values were at maximum compared with low temperature regime. Sawan et al. (1999) reported that air temperature governed flower and boll production during the fourth period of their growth. Oosterhuis (2002) reported that high day and particularly night temperatures may be detrimental to the yield of cotton. Reddy et al. (1996) also indicated that high night temperatures are detrimental for yield of cotton and they cause yield variability due to their effects on respiration and the carbon balance of the plant whereby more carbohydrates are lost by the high respiratoration rates at the expense of cotton plant growth. Mohamed (1993) found that the correlation between heat units and plant height was positive and highly significant. Elayan et al. (2006) found that the correlations between number of opened bolls/plant or boll weight or seed cotton yield/fed or micronaire value were positive and significant with air temperature and hence heat units under Giza condition.

Water stress is considered the most important variable affecting cotton crop production. Water deficiency particularly during fruiting stage markedly restricts plant growth, fruit retention and seed cotton yield (El-Shahawy and Abd EL-Malik 1999; El-Sayed 2005; Hamed 2007). Regardless of water availability, even irrigated cotton plants usually experience some degree of water stress, particularly at midday time, due to poor timing of irrigation or due to high evapotranspirative conditions, like those prevailing in Upper Egypt, where short-duration mild water stress could damage cotton yield (Reddy et al. 1998). Thus, there is the need for enhancing cotton tolerance to water stress. Ahmed and Kassem (2008) found that irrigation interval of three weeks resulted in significant reduction in plant height, number of fruiting branches/plant, number of open bolls/plant and seed cotton yield/fed.

The management of fertilizer nitrogen (N) is a very important component of any cotton production program. Water and N are normally the most limiting inputs to successful cotton production. Efficient and balanced nutrition has proved to be a means for improving plant tolerance to various environmental stresses including drought. Plants receiving proper nutrients supply exhibit better performance and productivity under stressful conditions (Szezpaniak and Grzebisz 2007). Balanced fertilization improves water use efficiency (Marchand 2007). Thus, more efficient nutrient management strategies are needed to maximize the use of all available recourses in cotton production (Reiter and Krieg 2000). Samy (1997) found that increasing nitrogen fertilizer up to 80 kg N/fed increased final plant height, boll weight and seed cotton yield /fed., but reduced earliness.

Next to irrigation, nitrogen fertilization is the variable that exerts profound effects on cotton growth and productivity. Nitrogen supply may affect cotton response to drought via promoting root growth and antioxidant activities in roots (Liu et al. 2008). Also, Cadena and Cothren (1995) reported that N supply improved water use efficiency, which was positively correlated with the N status of cotton plant. A complementary effect of N and water in cotton yield was also reported by Grimes et al. (1969) indicating that the addition of N may substitute for a lack of water. However, some research results indicated that cotton response to N supply is usually diminished by water stress (Reiter and Krieg 2000; Silvertooth et al. 2007) and excessive N supply had a deleterious effect on cotton plant resistance to drought (Liu et al. 2008). The main objective of this investigation was to study the impact of water stress (through prolonging the irrigation interval) and nitrogen levels on growth, earliness, yield and fiber quality of cotton under high temperatures to explore the possibility of planting cotton in Upper Egypt and to determine the relationship between cotton yield and heat units accumulated during the growing season.

Materials and methods

Field experiments were conducted at El-Mattana Agricultural Research Station in Luxor Governorate during three growing seasons (2007, 2008 and 2009) to investigate the response of 'Giza 90' cotton to two irrigation intervals (irrigation every two weeks or three weeks starting after the first irrigation) and three levels of nitrogen (30, 45 and 60 kg N/fed) under high temperature conditions in Upper Egypt. The experimental design was a split plot with four replications. Cotton seeds were planted on 22nd, 23rd and 24th of March in the 2007, 2008 and 2009 growing seasons. Nitrogen fertilizer in the form of ammonium nitrate (33.5 % N) was applied as per the treatments in two equal doses, immediately before the first and the second irrigations. Standard agricultural practices were followed throughout the growing seasons. All samples were taken randomly from each sub plot. At harvest, 6 guarded plants in the central row were randomly selected to determine plant height, no. of fruiting branches/plant, no. of open bolls/plant, boll weight, lint % and seed index. Seed cotton yield /fed was estimated as the weight of seed cotton from the five middle rows in sub plot collected in two picks, then converted to yield/fed in kentar (1 kentar = 157.5 kg.). Earliness (E %) was determined as percent of seed cotton yield of first pick to total seed cotton yield. Upper

half mean length (UHM mm.), fiber strength (g/tex.) and micronaire value were measured by using High Volume Instrument (HVI).

The soil was clay loam low in nitrogen content but moderate to rich in available P and K. Maximum and minimum air temperatures (°C) were recorded at 10-day intervals from March to September in all the three seasons (Fig 1). Heat units (HU) were calculated (Young et al. 1980) as follows: HU= (Mean of the daily minimum and maximum temperatures) – K , where K is the temperature at which no growth occurs (K = 12.8 °C). The heat units (HU) were calculated in 30-day intervals (Table 1).

The combined analysis over the three years was done. Simple correlation coefficient was computed between cotton traits and heat units. All collected data were subjected to statistical analysis (Gomez and Gomez 1984) and means were compared by LSD.

Table 1. Monthly heat units (HU) during a six month cotton growth period in El-Mattana Agricultural Station 2007, 2008 and 2009 growing seasons

Years	Monthly heat units						Total HU (190 day)
	sowing to 30 day	31-60 day	61-90 day	91-120 day	121-150 day	151-180 day	
2007	302.00	490.00	549.00	598.50	592.50	555.50	3236.00
2008	370.00	475.50	578.00	611.00	580.00	599.50	3391.00
2009	288.00	413.00	510.00	582.00	576.00	526.50	3057.00

Results and discussion

Growth, yield and fiber quality

Cotton plants were exposed to different air temperatures through the different growing seasons. Data in Table 1 indicated that the temperatures in Upper Egypt are very high. The total heat units received by cotton plants in the 2008 planting season were higher than in the 2007 or 2009 seasons. In the 2009 season the lowest heat units were accumulated in the beginning of the season. The diurnal air temperature figures showed (Fig. 1) that the night temperature seldom surpassed 20°C during the first month of the growing seasons. This was reflected in a low heat unit accumulation, particularly in the 2009 season. The heat units progressively increased with the advance of the growing season reaching the maximum during the period from 91 to 120 days, which coincides with peak of flowering and early boll development.

Significant seasonal effect was observed on cotton growth, earliness, yield and quality attributes. It is quite evident from Table 2 that cotton plants were forced to a vegetative growth as was

expressed in earliness and plant elongation on the expense of fruiting or was expressed in lower number of open bolls/plant in 2008 season compared with 2007 or 2009 seasons. This clearly was due to the higher air temperature and hence the larger heat units in 2008 than in the other two seasons. Since the very early growth stage, cotton plants experienced higher heat units averages in four out of the six recorded periods of growth. The total heat units amounted to 3391 in 2008 season compared with averages of 3236 and 3057 in 2007 and 2009 seasons in respective order. In cotton, plants with heavier boll load are always shorter due to the lower photosynthates available for elongation and vice versa. This effect was quite clear in the first and third growth seasons where plants were shorter and carried larger number of open bolls/plant than those of the second season. This refers to younger boll shedding in 2008 than in 2007 or 2009 seasons. This, also, was certainly, reflected in the seed cotton yield due to the higher number of bolls/plant and the heavier boll weight (Table 2). Finally, fiber quality was also affected by the seasonal changes of air temperature. Fibers were shorter and of less strength in 2008 than in the 2007 or 2009 seasons. This probably could be attributed to their lighter seed index and higher lint index which might have had played a negative role in fiber elongation and therefore fiber strength.

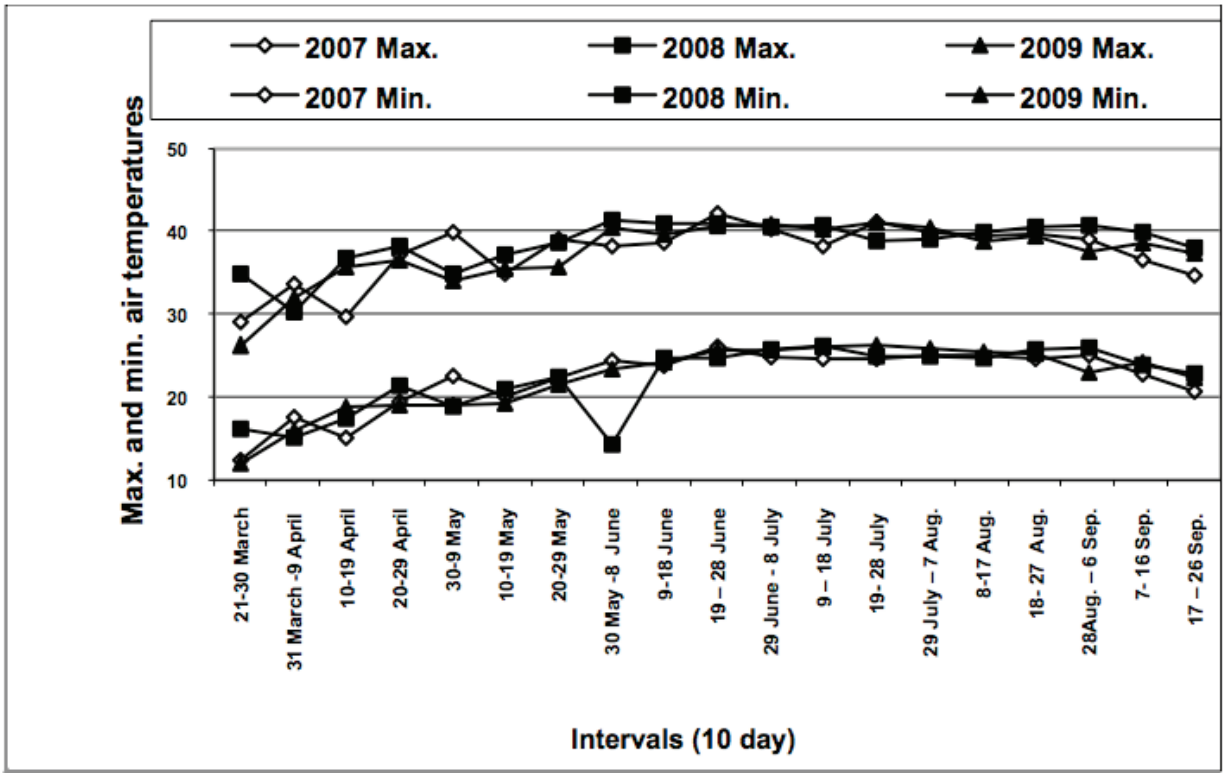

Figure 1. Maximum and minimum air temperatures, as a mean every 10 days, in El-Mattana Agricultural Station during the 2007, 2008 and 2009 growing seasons.

The daily and seasonal thrmoperiodicity played an active role in governing cotton plant growth and development, which in turn governed yield and fiber quality. Higher heat units lead to increasing vegetative growth. But this increase in vegetative growth does not necessarily lead to higher cotton yield; instead, it reduced the yield. With increase in heat units, cotton yield always reaches a plateau and then declines.

Data shown in Table 2 reveal that the irrigation every 15 day increased plant height and no. of fruiting branches/plant. The reduction in plant growth in case of longer irrigation cycles could be in

part due to limiting the plant ability to absorb nutrients needed for optimal growth and development of the plant. Also, it is well recognized that water is not only required for different biochemical activities of all cells, but also water-generated turgor pressure is a driving force of cell expansion (Xiong and Zhu 2002). Thus water deficit disrupts normal cellular activities and restricts plant growth. Many research results indicated that vegetative growth of cotton plant is closely related to the quantity of irrigation water applied (EL-Sayed 2005; Hamed 2007). Prolonging irrigation interval to 21 day significantly decreased plant height, no. of open bolls /plant, boll weight, seed index and seed cotton yield, while earliness and lint % were significantly increased. The reduction in yield and its components owing to extending irrigation interval may be due to the reduction in nutrient uptake, photosynthesis and vegetative growth. Similar results were obtained by EL-Shahawy and Abd El-Malik (1999) and EL-Sayed (2005). Irrigation every 21 day decreased fiber length and strength, this effect may be due to water stress under high temperatures.

Table 2 Seasonal changes of years (Y), irrigation intervals in days (I. int.), nitrogen levels in kg/fed (N) and their interactions effects on growth parameters, yield and yield components and fiber quality

Treatments		Plant height (cm)	Growth parameters		Yield and yield components						Fiber quality		
			.Fruit branch per plant	Boll weight (g)	Open bolls per plant	Seed index (g)	Lint %	Seed cotton yield fed/	Earli-% ness	Length U.H.M	Strength (g/tex)	Micro-naire value	
Year	2007	b 135.2	b 12.9	b 2.56	b 23.9	b 10.1	b 37.5	b 11.9	70.8a b	b 30.79	b 38.82	4.18 b	
	2008	a 142.8	a 13.6	c 2.47	c 20.3	c 9.8	a 38.6	a 10.5	a 75.4	c 30.53	c 35.43	4.01 c	
	2009	c 131.5	c 12.3	a 2.62	a 27.0	a 10.3	b 37.3	c 12.5	c 66.3	a 31.04	a 42.15	4.29 a	
.I. int	15	a 137.4	a 13.3	a 2.63	a 25.5	a 10.2	b 37.6	a 12.7	b 70.0	a 30.94	a 39.36	4.27 a	
	21	b 135.6	b 12.6	b 2.47	b 21.9	b 9.9	a 38.0	b 10.6	a 71.7	b 30.64	b 38.24	4.06 b	
N	30	c 133.7	c 12.3	c 2.43	c 21.8	c 9.9	a 38.0	c 10.8	a 72.8	c 30.31	c 37.70	4.04 c	
	45	b 137.0	b 12.8	b 2.57	b 23.8	b 10.1	b 37.7	b 11.5	b 71.3	b 30.75	b 38.50	4.16 b	
	60	a 138.8	a 13.7	a 2.65	a 25.6	a 10.3	b 37.6	a 12.7	c 68.5	a 31.31	a 40.20	4.29 a	

Increasing N levels from 30 to 60 kg N /fed exhibited a significant increase in plant height and no. of fruiting branches/plant. N is known for its major role in building up the plant tissues and stimulating its growth. Cotton plant, owing to its indeterminate growth habit, responds favorably to increasing N rate and its growth is linearly correlated with N supply (Silvertooth et al. 2007). Decreasing N levels significantly decreased no. of open bolls /plant, boll weight, seed index and seed cotton yield/fed. It is well established that increasing N level increase vegetative growth but may not necessarily lead to higher cotton yield. With increasing N level, cotton yield always reaches a plateau then it declines. These results are in harmony with those of EL-Shahawy and Abd El-Malik (1999). Higher N fertilized plant had better fiber quality than low N fertilized ones.

The interaction between season and irrigation interval significantly affected earliness %, boll weight and seed cotton yield due to increasing stress of water under high temperature. The interaction between seasons and nitrogen levels significantly affected all studied characters. The interaction of irrigation intervals × N levels had significant effect on plant growth parameters, yield and yield components and fiber characters. The effect of such interaction on plant growth revealed that growth of well-watered plants responded more favorably to N supply than that of water-stressed plants. Similar results were obtained by Cadena and Cothren (1995) who reported that N supply increased growth of well-watered cotton plants greater than that of water-stressed plants because of poor N uptake under inadequate water supply since enough water availability in soil is essential for fertilizer dissolution in soil and nutrient uptake by roots. Also, Silvertooth et al. (2007) reported that N uptake by cotton plant is usually diminished under water stress conditions because of the drought–induced stomatal closure which limits the transpirational stream and thus the upward flow of N solutes to the leaves. The interaction of seasons x irrigation intervals x nitrogen levels had significant effects on plant height, no. of fruiting branches/plant, boll weight, no. of bolls/plant, seed index and seed cotton yield/fed.

Table 3. Simple correlation between heat units (HU) and the some characters of cotton in different planting seasons (2007, 2008 and 2009)

Cotton properties		r values
Growth characters	Plant height (cm)	0.855*
	No. of fruiting branches/plant	0.595*
Yield and its components	No. of open bolls /plant	- 0.740*
	Boll weight (g)	- 0.441*
	Seed index (g)	- 0.601*
	Lint percentage	0.632*
	Seed cotton yield/fed	- 0.512*
	Earliness percentage	0.850*
Fiber properties	Fiber length (UHM) (mm)	- 0.412*
	Fiber strength g / tex	- 0.911*
	Micronaire value	- 0.577*

** indicates significant at 0.01 level of probability.*

Simple correlation between heat units and some cotton growth, yield and quality characters

Data in Table 3 show the correlation between heat units and some growth, yield and quality characters of cotton. Positive and significant correlation was found between cotton growth (plant height and no. of fruiting branches/plant) and heat units. These results are in harmony with

those of Mohamed (1993). On the other hand, no. of open bolls /plant, boll weight, lint % and seed cotton yield /fed were negatively and significantly correlated with heat units. These results clearly indicate that the large heat units, though favoring plant elongation and the number of fruiting branches and lint percentage, decreased seed index and the seed cotton yield/fed, the last one due to the decrease in the number of open bolls /plant and as well as boll weight. The negative effect was also observed on fiber quality (UHM, fiber strength and micronaire value).

Conclusion

The daily and seasonal thrmoperiodicity played an active role in governing cotton plant growth and development. Increasing temperature in Upper Egypt increased vegetative growth but at the cost of seed cotton yield. Well-watered plants responded more favorably to N supply and these plants were more tolerant to high temperature than water-stressed plants. Plants receiving proper N supply exhibited better performance and productivity under stressful conditions. The results show that under Upper Egypt conditions, the proper N level was 60 kg N/fed and the irrigation interval was 15 day for cotton to assure high yield and quality and to avoid adverse effects of high air temperature.

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10. Improving growth, yield and quality of pea (*Pisum sativum*) on sandy soil by phosphorus fertilizer and biological seed treatments to control root rot and damping off

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Abstract

One of the important methods to combat the current climate changes in the dry areas is to use agronomical practices to produce healthy plants under such conditions. On the other hand, producing plants with a healthy strong root zone increase the efficiency of irrigation water usage. Two field experiments were conducted in newly reclaimed sandy soil for two successive winter seasons of 2007/08 and 2008/09 at El-Nobaria region, Beheira Governorate, Egypt, to study the effect of phosphorus fertilization (0, 25, 50 and 75 kg P_2O_5 per feddan (feddan= 4200m^2)) in combination with different seed treatments (untreated seeds, seeds, priming with 1% carboxymethylcellulose (CMC), bio-priming with1% CMC plus 3x10^6 cfu/ml *Trichoderma harzianum*, and finally seed coating with 3x10^6 cfu/ml *T. harzianum*) on the control of damping–off and root rot diseases and improving of growth, yield and quality of pea plants variety Master P. the obtained results indicated that inoculation of pea seeds before sowing by bio-priming treatment combined with adding the mineral phosphorus at the rate of 50 kg P_2O_5/fed resulted in the highest significant increase in vegetative growth, green pods yield and quality. Likewise, the results indicated that combined effect of bio-priming plus 50 and/or 75 units phosphorus fertilizer rates has the highst efficacy in reducing root rot disease on pea plants at both pre and post emergence stages. In all the measured parameters control seeds (without treatment) combined with 0 Kg P_2O_5 resulted in the lowest values.

Introduction

Pea (*Pisum sativum* L.) is one of the most important leguminous crops for both local consumption and export in Egypt. Growing pea in desert areas in Egypt has been facing a lot of problem. The current climate changes have resulted in a reduction of water availability and increased temperature during the main growing period of the crop. Some of these areas are also naturally infected by root rot pathogens. Damping off and root rot diseases on pea are caused by single or combination of various soil borne fungi e.g., Fusarium solani, F. oxysporium, Rhizoctonia solani, Sclerotium rolfsii, Pythium spp. and Phytophthora cactorum. These pathogens attack roots during in the growing season causing a substantial loss in yield and quality (Abda et al. 1992; Persson et al. 1997; Ragab et al. 1999 and Rauf 2000). Healthy and vigorous root zone could help overcoming this problem. This could be achieved by controlling root rot diseases through fungicidal treatments. However, fungicidal application causes hazards to human health and environmental pollution. Therefore, there is a need to find a viable alternative to fungicidal seed treatment.

Few studies have examined the possible utilization of some agricultural practices such as fertilizer application or soil amendments for controlling soil-borne plant pathogens. Graham (1983) found that moderate phosphorus levels tend to decrease disease incidence in some fungal diseases

such as powdery mildew and Pythium root rot, whereas very high or low levels tend to increase disease incidence.

Phosphorus is one the essential elements and a major nutrient, especially for plant growth of pea. In spite of considerable addition of phosphorus to soil, the amount available for plant is usually low because it gets fixed in arid and semi-arid soils (El-Gizawy and Mehasen 2009). Generally, phosphorus plays a significant role in several physiological and biochemical plant activities like photosynthesis, transformation of sugar to starch and increasing root growth. Sharma (2002) reported feeding plants with phosphorus creates deeper and more abundant roots leading to early ripening of the plant and improving crop yield and quality. Several other researchers have showed positive effect of phosphorus fertilization on pea yield and quality (Gubbels 1992; Karamanos et al. 2002; Nadeem, et al. 2003; Murat et al. 2009).

Several researchers have tried to use biological seed treatment alone or in combination with other disease control measures such as fungicide, soil amendments and seed priming (Harman and Taylor 1988; El-Mohamedy 2004; El-Mohamedy et al. 2006). Ragab et al. (1999) controlled pea root rot disease caused by *Rhizoctoni solani*, *Phytophthora* spp. and *Fusarium solani* with a combined treatment of fungicides (Rizolex-T or Topsin-M) and *Bacillus subtillis* which resulted in significant reduction in the disease incidence. Also, Abd El-Kareem (2002) found that coating pea seeds with *Trichoderma koningii* and *T. viride* was very effective in controlling pea root rot pathogens. Moreover, combining seed coating with chitosan treatment was the most effective treatment for controlling pea root rot disease and increasing growth and yield of pea plant.

The objective of the present study was to improve the efficiency of biological seed treatments such as bio-priming and seed coating with *Trichoderma harzianum* along with utilizing phosphorus fertilization levels in control of root rot disease and improve growth and green pod yield and quality in pea.

Materials and methods

Field experiments were carried out on pea (*Pisum sativum* L.) in an area of newly reclaimed sandy soil that has been known as heavily contaminated with root rot pathogens (El-Mohamedy and Abd–El-Baky 2008). The study was conducted during the winter seasons of 2007/2008 and 2008/2009 at the Experimental Station of the National Research Centre, Noubaria, Behaira Governorate, North Delta of Egypt. The soil had a sandy texture (91% sand), pH of 7.6, EC of 0.18 (Ds/m in saturated soil paste) and the organic matter content of 0.19%. Soil N, P and K contents were 15.00, 9.40, 16.00 mg/100 g soil, respectively.

The experimental plots soil was carefully prepared, in each growing season. Ditches of 20 cm depth and 40 cm width were prepared in the sites of drip irrigation lines. Calcium super phosphate (15.5 % P_2O_5) was applied to provide 25, 50 and 75 Kg P_2O_5 /fed along with organic manure in the ditches and then covered by soil. During the growing season both ammonium sulfate (20.6 % N) at a rate of 60 N Kg/fed. and potassium sulfate (48 % K_2O) at a rate of 50 K_2O Kg/fed were applied in three equal doses as side dressing (30, 60 and 90 days after sowing) by the side of the plants. After land preparation, drip irrigation lines were spread over the ditches. Soil was irrigated continuously three days before sowing. Seeds were sown 50cm apart on the two sides of each ditch which was 75cm in width. Each plot included three ditches, and the plot area was 10.5m^2. Standard agricultural practices commonly recommended by Egyptian Ministry of Agriculture for the area were followed.

Treatments consisted of four levels of phosphorus fertilizer, .i.e. 0, 25, 50 and 75 P_2O_5 unit/fed

as single super phosphate (15.5 % P_2O_5), and four seeds treatments:1) untreated seeds (control); 2) Seed priming [Pea seeds were initially washed with tap water to remove soluble exudates and then primed, as per the method described by Harman and Taylor (1988), in 1% Carboxyl methylcellulose (CMC) in Erlenmeyer flask on a rotary shaker, set at 150 rpm, for 12 hour then air dried at room temperature and kept in polyethylene bag until used]; 3) Seed bio-priming [seeds were primed as described above but with spores of *T. harzianum* ($3x10^6$ spore /ml) added to the CMC during priming process]; 4) Seed coating [Fungal spores of *T. harzianum* were gently scraped from PDA cultures in water and filtered through nylon mesh (38 mm); the spore suspension was adjusted with sterile water to the desired density and seeds were coated by shaking in conidial suspension (4ml per g seeds) in a shaker for 10 min. at 130 rpm. Seeds were air-dried on filter paper for 1 h in a laminar flow hood before planting.

Parameters measured included biological data (preemergence damping-off 15 days after sowing as well as post-emergence root rot infection 40 and 60 days after sowing and the percentage of survival plants in each particular treatment was calculated); vegetative growth characteristics (plant length, leaf number and fresh weight per plant from random samples of five plants harvested at maturity); total green yield and quality (the crop from the whole plot area in each treatments was harvested at maturity and total pod yield calculated; random sample of pods was used to measure the average TSS of the seeds).

The experiment was conducted in a split plots design, with three replicates, with P levels in the main plots and the seed treatments in sub plots. Data were subjected to statistical analysis according to Snedecor and Cochran (1980).

Results and discussion

The aim of this work is to evaluate the effect of different levels of phosphorus fertilizer and seed treatment on the control of root rot and damping off diseases and also to evaluate the effect of these treatment on the pod yield and quality of pea plant. Statistical analysis of the experimental data showed a similar trend in both the seasons; thus a combined analysis for all studied parameters in the two studied seasons was done and data presented are average over two seasons.

Pre-emergence damping-off incidence

There was a significant interaction between phosphorus fertilization level and seed treatments, and a combination of phosphorus application (50 or 75 Kg P_2O_5) and seed treatments had high effectiveness in reducing root rot seedling damping off (Fig. 1). The bio-priming treatment was most efficient in reducing damping off followed by seed coating then priming treatment and the treatment efficacy increased with the elevated levels of phosphorus fertilization. Similar results was observed on pea plants by other investigators (Tu 1992; Persson et al. 1997).

Post emergence root rot disease incidence and revival rate

Post-emergence root rot disease incidence (Fig. 2) was highest in control (0 kg P_2O_5 without seed treatment); root rot reached up to 20.75% 40 days after sowing and another 17.5% after 60 days of sowing. Best disease control was achieved when seed bio-priming was combined with 75 kg P_2O_5/fed treatment. Second best treatment was bio-priming combined with 50Kg P_2O_5 followed by 25 Kg P_2O_5. Seed coating treatments followed the seed bio-priming treatments but its effect reduced with the increase in phosphorus level.

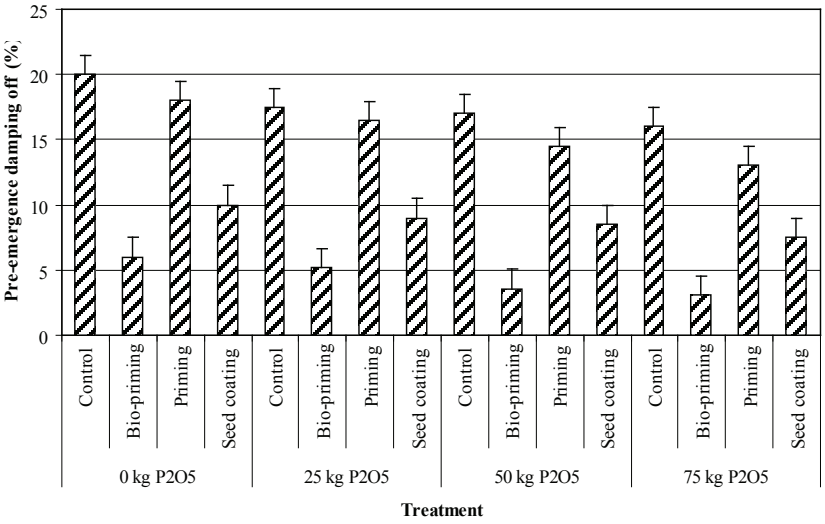

Figure 1. Effect of phosphorus fertilization levels and seed treatments on pre- emergence damping off incidence (%) in pea plants after 15 days of planting. Vertical bars present LSD value at p≥ 5%.

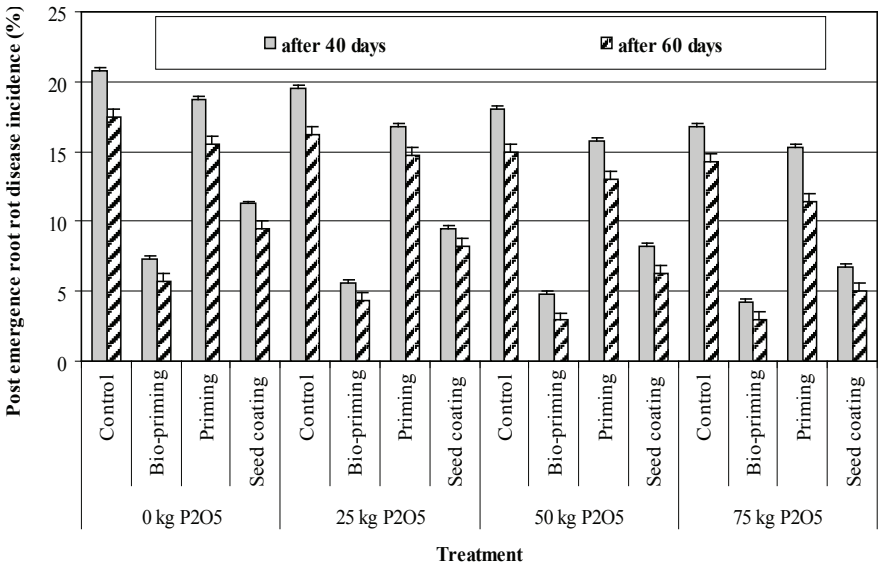

Figure 2. Effect of phosphorus fertilization levels and seed treatments on post emergence root rot disease incidence (%) in pea plants after 40 and 60 days from planting. Vertical bars present LSD value at p≥ 5%.

Plant survival rate

Bio-priming treatment combined with 50 or 75 kg/fed P_2O_5 was very effective in controlling damping off and root rot disease. Hence this treatment increased the plant survival rates from 40% in control treatment to about 90 %. Even with no phosphorus added, bio-priming treatment increased plant survival rate to about 80%. Seed coating treatment came second to bio-priming and was followed by the seed priming treatment. The general efficacy of such treatment increased with increasing phosphorus level.

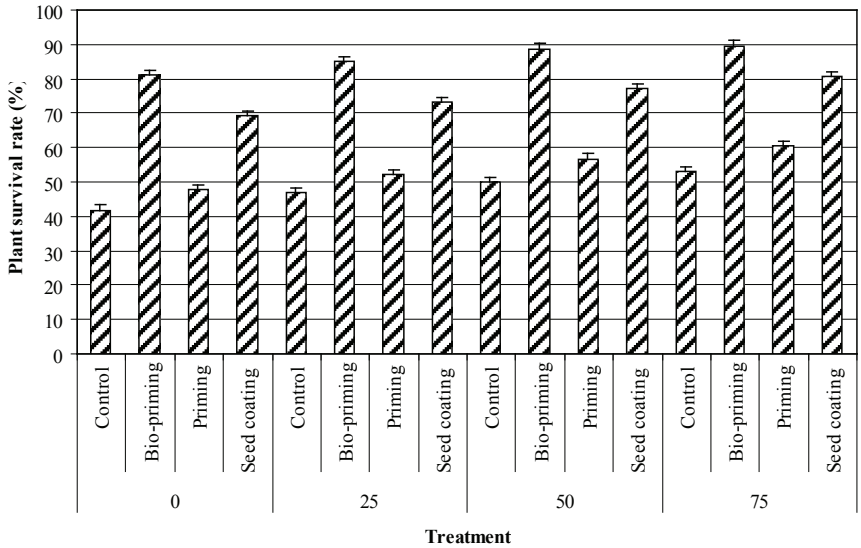

Figure 3. Effect of phosphorus fertilization levels and seed treatments on plant survival rate (%) in pea plants after 60 days of planting. Vertical bars present LSD value at p≥ 5%.

Vegetative growth characteristics

Plant length (Fig. 4) was the highest with seed priming treatment combined with 75 Kg /fed P_2O_5 followed by seed coating with 50 or 25 kg P_2O_5. Shortest plants was obtained with the control. Similar trend was found for leaf number and fresh weight (Fig. 5 and 6) where the highest values were found with bio-priming and 50 Kg /fed P_2O_5, followed by seed coating with 50 Kg /fed P_2O_5 and the lowest values were found with control treatment.

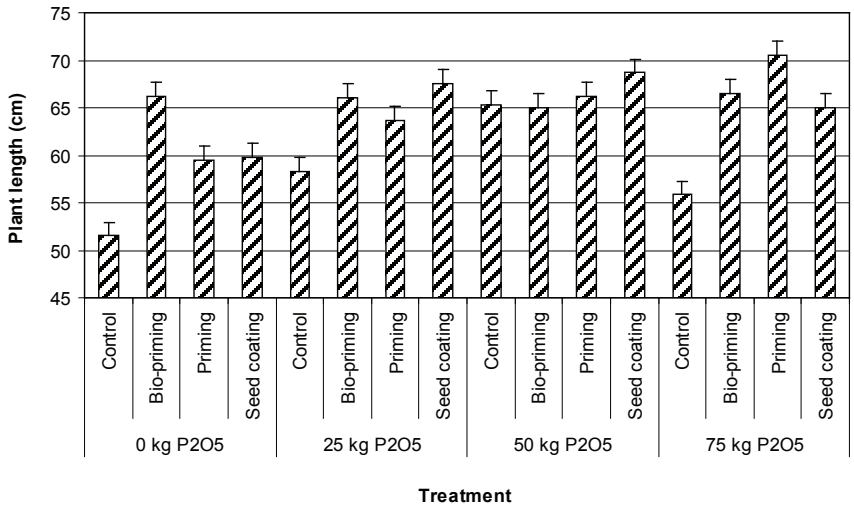

Figure 4. Effect of phosphorus fertilization levels and seed treatments on pea plant length (cm). Vertical bars present LSD value at p≥ 5%.

The general increase in vegetative growth with both increasing phosphorus fertilization levels and bio-priming treatment is a direct result to the ability of *T. harzianum* to control root rot disease in the beginning of the growing season and the increase in root mass caused by the increased phosphorus levels which in general resulted in more vigorous plant. These results are in agreement with the observations of several other researchers such as Parasad et al. (1989); Sharma et al. (1997); Verma et al. (1997) and EL-Mohamedy and Abd–El-Baky (2008).

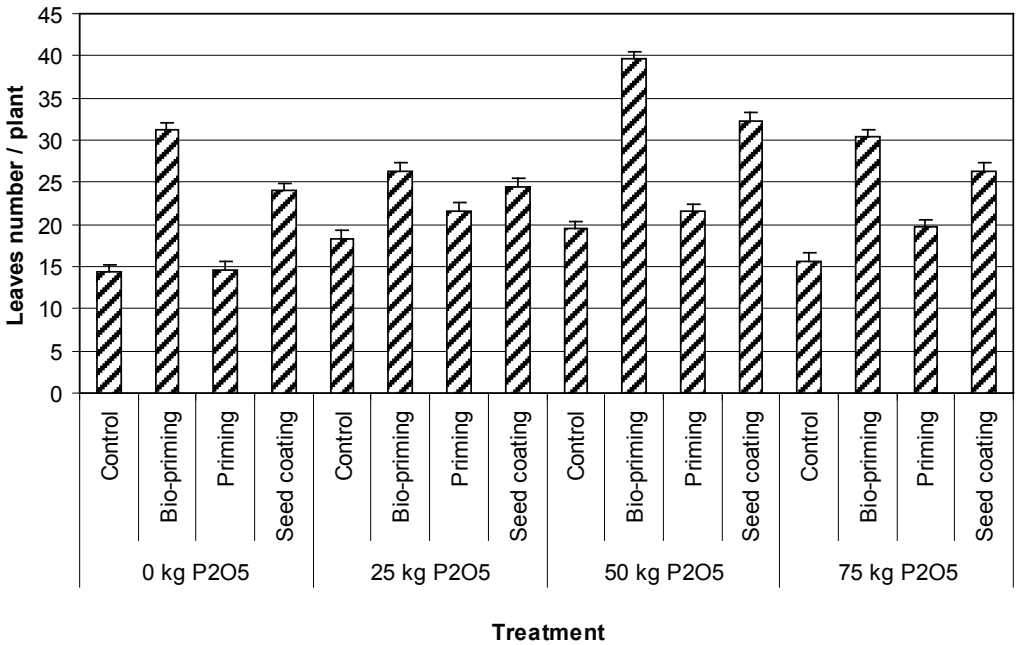

Figure 5. Effect of phosphorus fertilization levels and seed treatments on pea plant leaves number. Vertical bars present LSD value at p≥ 5%.

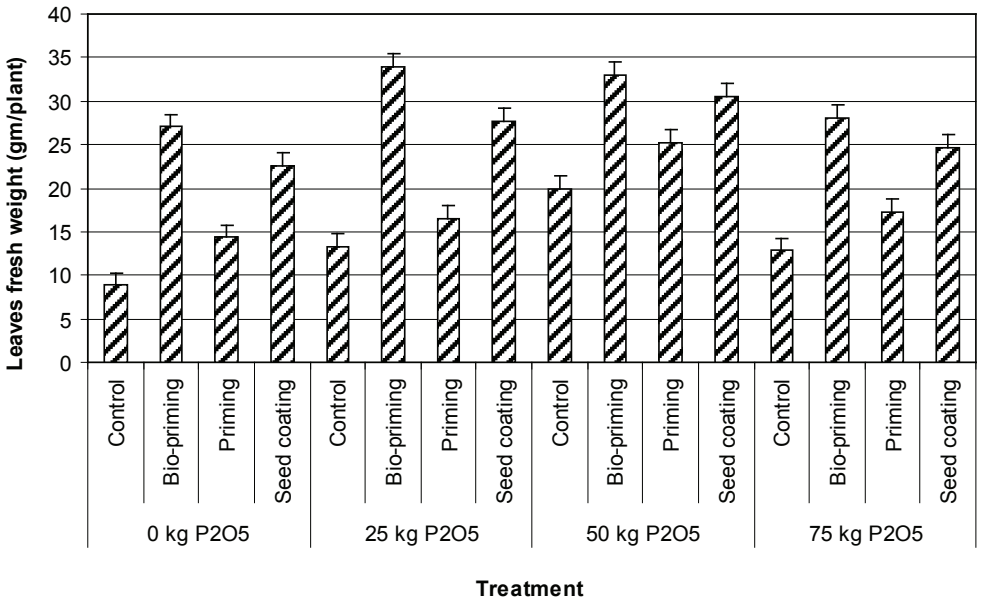

Figure 6. Effect of phosphorus fertilization levels and seed treatments on pea plant leaves fresh weight (gm/plant). Vertical bars present LSD value at p≥ 5%.

Fresh pods yield and quality

The results (Fig. 7) revealed that the highest fresh pods yield was obtained by the combination of 50 Kg P_2O_5 / feddan with bio-priming of seeds. This combination was followed by the treatment combinations of bio-priming with 25 Kg P_2O_5 / feddan and 50 Kg P_2O_5 / feddan . Lower values were obtained under other combinations. The lowest values were obtained under control. Also,

seed TSS values (Fig. 8) were the highest with bio-priming treatment with 50 or 75 Kg P_2O_5 / feddan with no significant differences between them followed by bio-priming with 25 Kg P_2O_5 / feddan. The increase in green pod yield and quality is a direct result of the increased amount of phosphorus levels with all its positive effects on the growth plus the beneficial effect of bio-priming effect on controlling root rot disease. The results are in accordance with Abd El-Kareem (2002), EL-Mohamedy (2004), and EL-Mohamedy and Abd–El-Baky (2008).

It could be concluded from this work that using bio-priming seed treatment with *T. harzianum* in addition to application of 50 Kg P_2O_5/fed was the best combination for controlling damping-off and root rot disease and increasing pea plants growth , yield and fruit quality.

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11. Developing an adaptation strategy to reduce climate change risks on wheat grown in sandy soil in Egypt

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Abstract

A two-year field experiment was conducted at Ali Mobark village in El-Bustan area, El-Behira governorate in Egypt to study the effect of an improved management practice, i.e. chemigation and farmers traditional practice on wheat yield and consumptive use of wheat grown in sandy soil under sprinkler irrigation. The data obtained were used to calibrate CropSyst model. Two climate change scenarios (A2 and B2) obtained from Hadley model were incorporated in the model to assess the effect of climate change on wheat yield. Moreover, the effect of the interaction between the two treatments and two early sowing dates was simulated to develop effective adaptation strategy to reduce climate change risk on wheat yield grown in sandy soil. The results showed that wheat yield increased by of 24% when chemigation was applied, in comparison to farmer practice. Under the two climate change scenarios, wheat grain by 30% under farmer irrigation and by 25% when chemigation was used. As a result, the deterioration in water use efficiency was also lower under chemigation treatment. This finding emphasizes the importance of using improved management practices to reduce the risk of climate change. Sowing wheat one week earlier under chemigation treatment improved wheat yield by an average of 6 and 5% under A2 and B2 scenarios, respectively. Water use efficiency also improved.

Introduction

Human induced global climate change is derived from increases in atmospheric level of carbon dioxide. One of its adverse effects is warmer temperatures and increasing episodes of very hot spells. Therefore, it is expected that climate change will have implications for possible fluctuation on wheat yield (Wrigley 2006). Many studies have documented the effects of climate change on wheat yield in Egypt and concluded that the yield could be reduced by an average of 30% in the Nile Delta and Valley under surface irrigation (Eid et al. 1992, 1993, 1994; Khalil et al. 2009). The damage that climate change could do to wheat productivity is expected to be higher under soils with low fertility. Changes in yields in relation to shifts in climate can become critical for the economy of farmers. An increasing probability of low returns as a consequence of the more frequent occurrence of adverse conditions could prove drastic for farmers experiencing economic stress (Torriani et al. 2007), especially for farmers having marginal soils. El-Bustan area, which is a newly reclaimed land located in the west of the Delta, is an example of that type of soil: sandy with low organic matter and high water infiltration rate. The appropriate irrigation system to be used in this type of soil is drip or sprinkler irrigation.

Wheat yield in El-Bustan area is 10% lower than the yield on the old land in the same governorate (MALR 2007). Under the projected climate change, extra damage is expected to occur to the yield of cultivated crops in this area as a result of deterioration of the soil. Therefore, adaptation

options should be developed and tested to improve the yield under current climate and reduce yield vulnerability to climate change.

Adaptation to climate change has received very little attention compared with mitigation, this may be partly because adaptation seems more complicated than mitigation; emission sources are relatively few, but the array of adaptation is vast, yet to ignore adaptation is both unrealistic and perilous (Parry et al. 1998). Adaptation refers to efforts to reduce system's vulnerabilities to climate. According to IPCC (1996), adaptation is concerned with responses to both the negative and positive effects of climate change. It refers to any adjustments whether passive, reactive, or anticipatory that can respond to anticipated or actual consequences associated with climate change. Thus, it implicitly recognizes that future climate change will occur and must be accommodated in any policy option. A wide range of responses can be implemented by management or policy decisions at the regional or national levels. These adjustments are adaptation strategies (Carter 1996). The effect of using adaptation strategies, such as changing sowing date and/or changing irrigation schedule under surface irrigation was simulated in Egypt for wheat (Khalil et al. 2009), maize (Ouda et al. 2009) and barley (El Afandi et al. 2010) and proved to reduce yield vulnerability to climate change.

On sandy soils and under sprinkler irrigation, chemigation can be used as adaptation option to reduce vulnerability of the growing crops to climate change. Chemigation is defined as application of chemicals (nutrients, herbicides, insecticides and fungicides) via injecting the chemicals into water flow of the irrigation system (Threadgill 1981). The use of chemigation provides more uniform distribution of added chemicals around plants roots (Keeney 1982) and prevents nutrient leaching in sandy soil (Wang and Alva 2000). Furthermore, using chemigation increased water and fertilizer use efficiency compared with the traditional agro-chemical application (Sayed et al. 1999).

The objectives of this research were to: (i) assess the effect of chemigation on wheat yield grown in sandy soil; (ii) use CropSyst model to simulate wheat yield under two climate change scenarios; (iii) use CropSyst model to test the effect of early sowing as an extra adaptation option to relieve the harmful effect of climate change on wheat yield and water use efficiency.

Materials and methods

Field experiment

Field experiments were conducted in Ali Mobark village in El-Bustan, El-Behira governorate in Egypt in the growing seasons of 2007/08 and 2008/09 to study the effect of an improved management practice (i.e. chemigation) and farmers traditional practice (broadcasting fertilizers and spraying pesticides) on yield and consumptive use of wheat grown on sandy soil under sprinkler irrigation. Wheat was planted on 20th November and harvested on 20th of April in the 1st growing season and planted on the 23rd of November and harvested on 6th of April in the second season. The sprinkler system used was a solid set system with spacing of 12X12 meters between laterals and sprinklers. RainBird 30 sprinkler with 1.5 m^3/h discharge at 3 bars nozzle pressure was used. A venturi injector was connected to the sprinkler irrigation system to inject chemicals via irrigation water. Infiltration rate was determined according to Klute (1986) using the double-ring infiltrometer (ASTM 2008). Chemigation treatment included the addition of herbicide (granestar) through irrigation water 20 days after planting at the rate of 19 g/ha for 15 minutes with venturi fertigator. Traditional farmer practice was applying herbicides using regular

manual sprayer. Nitrogen fertilizer was added in the form of ammonium nitrate at the rate of 400 kg/ha. Potassium sulfate was added @ of 100 kg/ha and phosphoric acid was added @ of 25 kg/ha. Evaporation data were collected on a daily basis from a standard Class-A-Pan located near the experimental field. Irrigation amounts were calculated with the following equation (Allen et al. 1998):

$$I = Epan * Kp \qquad [1]$$

where I is the applied irrigation water amount (mm), Epan is the cumulative evaporation amount in the period of irrigation interval (mm), Kp is the pan evaporation coefficient (0.75 according to pan type and weather condition at the experimental site). Consumptive water use was calculated using soil sampling by the following equation (Israelsen and Hansen 1962).

$$CWU = (\Theta_2 - \Theta_1) * Bd * ERZ \qquad [2]$$

where CWU=the amount of consumptive use (mm), Θ_2=soil moisture percentage after irrigation, Θ_1=soil moisture percentage before the following irrigation, Bd=bulk density in g/cm^3, ERZ= effective root zone. The soil of the experimental site was sandy, with an EC of 0.3 to 0.35 dS/m, pH around 9.2. The field capacity was 11.25%, permanent wilting point was 5.45%, bulk density 1.59 g/cm^3 and available water was 9.25 mm in the top 30 cm. The respective values for the 30-60 cm layer were 9.35%, 4.6%, 1.625 g/cm^3 and 8.4 mm.

CropSyst model calibration and validation

CropSyst (Cropping Systems Simulation Model) is a multi-year, multi-crop, daily time step crop growth simulation model, developed with emphasis on a friendly user interface, and with a link to GIS software and a weather generator (Stockle et al. 1994). The model's objective is to serve as an analytical tool to study the effect of cropping systems management on crop productivity and the environment. For this purpose, CropSyst simulates the soil water budget, soil-plant nitrogen budget, crop phenology, crop canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water, and the fate of the pesticides. These are affected by weather, soil characteristics, crop characteristics, and cropping system management options including crop rotation, variety, irrigation, nitrogen fertilization, pesticide application, soil and irrigation water salinity, tillage operations, and residue management. After each growing season, input files required by CropSyst model for El-Bustan location and wheat crop were prepared and used to run the model. A few variety-specific parameters were calibrated within a reasonable range of fluctuation set in CropSyst manual. To test the goodness of fit between the measured and predicted data, percent difference between measured and predicted values of wheat yield in each growing season was calculated, in addition to root mean squared error (Jamieson, et al. 1998) and Willmott index of agreement (Willmott 1981).

Climate change scenarios

In this work, the HadCM3 which is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre for Climate Prediction and Research (United Kingdom) was used (Gordon et al. 2000 and Pope et al. 2000) as it was more sophisticated than earlier versions (Hulme et al. 1998). This model has a spatial resolution of 2.5 x 3.75 (latitude by longitude). HadCM3 provides information about climate change over the entire world during the 21st century and presents information about three times slices: 2020s, 2050s, and 2080s. In order

to provide information on possible changes in the world climate, the climate change models are forced to consider future scenarios. The IPCC (Nakicenvic et al. 2000) has developed emission scenarios known as SRES (Special Report on Emission Scenarios). The four SRES scenarios combined two sets of divergent tendencies: one set varying between strong economic values and strong environmental values, the other set between increasing globalization and increasing regionalization (IPCC-TGCIA 1999). Two climate change scenarios were considered in this study: A2 and B2. These two scenarios (A2 and B2) consider a rise in global annual mean temperature by 3.1 and 2.2° C, respectively, CO_2 concentration 834 and 601 ppmv, respectively, and global mean sea level rise 62 and 52 cm, respectively. As the resolution of the model is too big, using simple interpolation techniques of these percentages have been applied to fit the station site. Data were downloaded in GRIB format from the IPCC Data Distribution Centre web site, and the GRBCONV program source code was found at the following web site: [http://www/dkrz.de/ipcc/ddc/html/HadleyCM3/hadcm3. html]. The GRBCONV program was used to convert the data files from GRIB format to the more conventional ASCII. The download site does not offer the option to subset the data based on an area of interest, so a custom program was used to extract the data for the region of interest. HadCM3 variables were monthly precipitation, solar radiation, and minimum and maximum temperatures. A2 and B2 climate change scenarios were incorporated in CropSyst model to predict wheat yield and consumptive use in 2050s. The effect of climate change on each of the two growing seasons will be discussed separately as if each season could be a representation of the growing season of the year of 2050s.

Effect of early sowing on wheat yield and water use efficiency under climate change

In an attempt to reduce the vulnerability associated with climate change of wheat grown in sandy soil, the effect of two sowing dates, i.e. one week and two weeks earlier was simulated under the two climate change scenarios. Water use efficiency (kg/m^3) values were calculated by the following equation (Vites 1965):

$$\text{WUE} = \text{Grain yield (kg/ha)}/\text{Consumptive use (m}^3\text{/ha)} \qquad [3]$$

Results and discussion

Field experiment

Wheat grain and biological yields were significantly increased ($p<0.05$) when chemigation was used, compared with farmers traditional treatment, although the same irrigation amounts was used for both treatments (Table 1). Under chemigation, grain yield increased over conventional practice by 25.7% and 39.6% in the 1st and 2nd growing seasons, respectively and biological yield increased by 28.7% and 38% in the 1st and 2nd growing seasons, respectively. Results implied that better fertilizer distribution in root zone occurred under chemigation treatments, which, along with the presence of adequate soil moisture, had a positive impact on the plant growth and consequently increased wheat yield.

This emphasizes the importance of using improved management practices, i.e. chemigation, to attain the rationale use of irrigation water, increase wheat final yield and achieve food security.

CropSyst model validation

Under El-Behira agro-climatic conditions, CropSyst model performance was highly acceptable, where RMSE was 0.137 and 0.0262 ton/ha between measured and predicted grain and biological

yield, respectively. WI was 0.9864 and 0.9721 for grain and biological yield, respectively (Table 2). Singh et al. (2008) indicated that CropSyst model is more appropriate than CERES-Wheat in predicting growth and yield of wheat under different N and irrigation application situations. Lobell and Ortiz-Monasterio (2006) stated that CERES-Wheat model was able to predict wheat yield for different irrigation trials quite well with a RMSE of 0.23 ton/ha. In Egypt, Khalil et al. (2009) reported that CropSyst model predicted wheat grain and biological yield in Middle Egypt very well with RMSE equal to 0.0157 and 0.1907 ton/ha for grain and biological yield, respectively. They also stated that WI was 0.9899 for both grain and biological yield.

Table 1. Irrigation amounts and wheat grain and biological yield under two treatments and two growing seasons

Growing Season	Treat-ment	Irrigation amount (m^3/ha)	Grain yield (ton/ha)		Biological yield (ton/ha)	
			Mea-sured	% differ-ence	Measured	% difference
1st season	C1	6953	6.16a	--	14.10a	--
	C2	6953	4.90b	20	10.95b	22
2nd season	C1	6783	5.88a	--	13.50a	--
	C2	6783	4.21b	28	9.78b	28

C1= chemigation treatment, C2= farmers traditional practice.

Table 2. Measured versus predicted wheat grain and biological yield in the two growing seasons

Growing Season	Treatment	Grain yield (ton/ha)		PD%	Biological yield (ton/ha)		PD%
		Measured	Predicted		Measured	Predicted	
1st season	C1	6.16	6.15	0.16	14.10	13.97	0.92
	C2	4.90	4.89	0.20	10.95	10.90	0.46
2nd season	C1	5.88	5.85	0.51	13.50	13.29	1.56
	C2	4.21	4.17	0.95	9.78	9.70	0.82
RMSE		0.0137			0.0262		
WI		0.9864			0.9721		

C1= chemigation treatment, C2= farmers traditional practice, PD%= percent difference between measured and predicted values, RMSE= root mean square error; WI= Willmott index of agreement.

With respect to wheat consumptive use, the model was able to predict it with high degree of accuracy. RMSE was 0.0499 mm and WI was 0.9532 (Table 3). This result is in agreement with Pannkuk et al. (1998), and Wang et al. (2006), and Khalil et al.(2009).

Thus,our results showed that CropSyst model is cable of predicting yield and consumptive use of wheat grown in sandy soil under the Egyptian conditions (Tables 1,2 and 3). One of the benefits of using CropSyst model is it can give an insight to the processes that happened during the growing season of wheat, which was difficult to measure in the field. The good agreement between measured and predicted values of wheat grain and biological yield, as well as consumptive use,

implied that the model worked sufficiently well to warrant the exploration of the effect of climate change scenarios.

Table 3. Measured versus predicted wheat consumptive use (mm) in the two growing seasons

Treatment	First growing season		%PD	Second growing season		%PD
	Measured	Predicted		Measured	Predicted	
C1	514.00	503.94	1.96	495.00	489.31	1.15
C2	477.00	471.69	1.11	468.00	460.74	1.55
RMSE	0.0499					
WI	0.9532					

C1= chemigation treatment, C2= farmers traditional practice, PD%= percent difference between measured and predicted values, RMSE= root mean square error; WI= Willmott index of agreement.

Effect of climate change scenarios

Effect of A2 climate change scenario: Under A2 scenario, which is expected to happen in 2025s, reduction in wheat grain and biological yield under chemigation treatment was improved by 5 and 7%, respectively compared with farmers traditional practice in the 1st growing season (Table 4). Similar trend was also observed in the 2nd growing season.

Table 4. Effect of A2 climate change scenario on wheat grain and biological yield under both seasons

	Grain yield (ton/ha)			Biological yield (ton/ha)		
	Measured	Predicted	PD%	Measured	Predicted	PD%
1st season						
C1	6.15	4.51	27	13.97	10.68	24
C2	4.89	3.26	33	10.90	7.51	31
2nd season						
C1	5.85	4.47	24	13.97	10.59	24
C2	4.17	2.92	30	10.90	6.79	38

C1= chemigation treatment, C2= farmers traditional practice, PD%= percent difference between measured and predicted values.

Effect of B2 climate change scenario: Less deterioration in wheat yield could occur under B2 climate change scenario, which is also expected to happen in 2025s, where grain yield was reduced by 20% in both growing seasons, when chemigation was used compared with 27% reduction under farmer traditional irrigation treatment (Table 5) in the year of 2050s. Gibson and Paulsen (1999) reported that high temperature is a major detrimental factor for wheat development and growth, decreasing yields by 3 to 5% per every 1°C increase above 15°C under controlled conditions.

Table 5. Effect of B2 climate change scenario on wheat grain and biological yield under both seasons

	Grain yield (ton/ha)			Biological yield (ton/ha)		
	Measured	Predicted	PD%	Measured	Predicted	PD%
1st season						
C1	6.15	4.92	20	13.97	11.23	20
C2	4.89	3.55	27	10.90	8.56	21
2nd season						
C1	5.85	4.67	20	13.97	10.93	22
C2	4.17	3.02	28	10.90	7.79	29

C1= chemigation treatment, C2= farmers traditional practice, PD%= percent difference between measured and predicted values.

The result in Tables 4 and 5 showed that under climate change wheat yield was reduced. This result could be attributed to heat and water stresses to which wheat plants would be exposed. High temperature reduced numbers of tillers (Friend 1965) and spikelet initiation and development rates (McMaster 1997). Furthermore, high temperature during anthesis caused pollen sterility (Saini and Aspinall 1982) and reduced number of kernels per head, if it prevailed during early spike development (Kolderup 1979). The duration of grain filling was also reduced under heat stress (Sofield et al. 1977), as well as growth rates with a net effect of lower final kernel weight (Bagga and Rawson 1977; McMaster 1997).

Exposing wheat plants to high moisture stress depressed seasonal consumptive use and grain yield (El-Kalla et al. 1994 and Khater et al. 1997). During vegetative growth, phyllochron decreases in wheat under water stress (McMaster 1997) and leaves become smaller, which could reduce leaf area index (Gardner et al. 1985) and reduce the number of reproductive tillers, in addition to limit their contribution to grain yield (Mosaad et al. 1995). Furthermore, water stress during grain growth could have a sever effect on final yield compared with stress occurring during other stages (Hanson and Nelson 1980). Thus, reduction in grain and biological yield is expected under climate change. However, when chemigation was applied, it reduced the vulnerability of wheat plants and improved their tolerance to the aboitic stresses as a result of increasing water and fertilizer use efficiency and preventing N and K leaching in sandy soil.

Effect of early sowing on yield and water use efficiency under climate change

***Effect under A2 climate change scenario*:** Under farmers traditional practice, sowing one week earlier improved yield by 2 and 6% in both growing seasons and improved water use efficiency, whereas sowing two weeks earlier increased yield losses and reduced water use efficiency (Table 6). Under chemigation, both sowing dates improved wheat yield. This could be attributed to the better growth of wheat plants as a result of better water and fertilizer use efficiency when chemigation was applied. However, sowing wheat one week earlier had better results than sowing two weeks earlier in both growing seasons (Table 6). Furthermore, water use efficiency was also increased when wheat was sown one week earlier in both growing seasons.

Effect under B2 climate change scenario: Similar trend of yield and water use efficiency was obseved under B2 climate change scenario as in A2 scenario (Table 7).

Table 6. Effect of changing sowing date on wheat yield and water use efficiency under A2 scenario in both seasons

	Farmer practice			Chemigation		
	Yield	PD %	WUE	Yield	PD %	WUE
1st growing season Current climate	4.89	--	1.00	6.15	--	1.30
A2	3.26	33	0.62	4.51	27	0.85
ES1	3.37	31	0.66	5.21	15	1.01
ES2	2.91	41	0.61	4.67	24	0.97
2nd growing season Current climate	4.17	--	0.85	5.85	--	1.24
A2	2.92	30	0.58	4.47	24	0.91
ES1	3.15	24	0.60	4.69	20	0.94
ES2	2.83	32	0.58	4.50	23	0.92

A2= climate change scenario, ES1= sowing wheat one week earlier, ES2= sowing wheat two weeks earlier, WUE= water use efficiency (kg/m^3)

Table 7. Effect of changing sowing date on wheat yield under B2 scenario in both seasons

	Farmer practice			Chemigation		
	Yield	PD %	WUE	Yield	PD %	WUE
1st growing season Current climate	4.89	--	1.00	6.15	--	1.30
B2	3.55	27	0.68	4.88	21	0.94
ES1	3.82	22	0.77	5.22	15	1.01
ES2	2.64	46	0.55	4.98	19	0.96
2nd growing season Current climate	4.17	--	0.85	5.85	--	1.24
B2	3.02	28	0.59	4.67	20	0.91
ES1	3.35	20	0.64	4.99	15	0.96
ES2	2.84	32	0.85	4.85	17	0.93

B2= climate change scenario, ES1= sowing wheat one week earlier, ES2= sowing wheat two weeks earlier, WUE= water use efficiency (kg/m^3)

In conclusion, simulation models can provide an alternative, less time-consuming and inexpensive means of determining the optimum management practices required under climate change conditions. Adaptation to climate change could be implemented at the farm level by using management practices that could improve the productivity of the crops.

Conclusion

Rapid changes of climate may seriously inhibit the ability of some crops to survive or to achieve the desired yield in their current production region. Sustainable land and water management

combined with innovative agricultural technologies could reduces the effect of climate change and help poor farmers adapt to its impacts. New knowledge, technology and policy for agriculture have never been more critical, and adaptation and mitigation strategies must urgently be applied to national and regional development programs. Without these measures developing countries will suffer increased food insecurity. This study is the first in Egypt in quantifying the effect of climate change on wheat grown in sandy soil and under sprinkler irrigation and testing an improved management practice to enhance the resilience of farmers for climate change. Plant breeders could also use the results of the application of the simulation models to help them in developing new varieties adapted to climate change. Wheat breeders will need to focus on overcoming heat stress rather than improving drought tolerance as a result of climate change. Moreover, breeding for varieties with higher water use efficiency is also very important goal to be achieved.

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12. The annual organic carbon requirement for sustainable crop production in the Sahel, West Africa

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Abstract

The soil organic matter (SOM) levels in the Sahel are showing severe reduction because of continuous cultivation. Reductions in SOM levels have resulted in decreased soil productivity. Many studies have reported improvement of crop yield through application of organic matter in the Sahel. However, proper evaluation of the effect of this application on sustainable crop production has not been conducted, because these studies were short-term and not long-term trials. Therefore, it is essential to obtain - long term information on the rates of organic matter decomposition and annual carbon input requirement. Although a model simulation approach would be effective for evaluating long-term sustainability, most of the existing SOM dynamic models are configured for the temperate zone. The Rothamsted Carbon Model (Roth-C), one of these SOM models, is convenient and widely acknowledged and has been previously validated for use in Sahelian conditions. This paper aimed to estimate the annual carbon requirement for sustainable crop production in the Sahelian zone. The 10-year soil organic carbon (SOC) values were predicted by Roth-C for 59 treatments (32 from previous trials and 27 from the suggested technology options in the Sahel). The annual carbon requirement was computed to be approximately 0.8 tons of carbon per ha in this region, where the coefficient of determination in the regression was highly statistically significant (0.948). This amount of carbon is equivalent to 1.6 to 2.0 t ha^{-1} of crop residue and 2.0 to 4.0 t ha^{-1} of transferred manure.

Introduction

The soil organic matter (SOM) levels in the West African semi-arid tropics are showing severe reduction because of continuous cultivation. Reductions in SOM levels have resulted in decreased soil productivity. SOM plays an important role in crop productivity, especially in the infertile sandy soil in this region (Bationo and Mokwunye 1991; Bationo and Buerkert 2001; Franzluebbers et al. 1994; De Ridder and Van Keulen 1990). Therefore, it is essential to obtain long-term information on the rates of organic matter decomposition and annual carbon requirement. Many studies have reported a pronounced effect of application of various organic matters on crop yields in the Sahel (Schlecht et al. 2004; Bationo et al. 1998; Hayashi et al. 2009). Moreover, various agricultural management practices were tested in the JIRCAS/ICRISAT/INRAN collaborative project entitled "Improvement of fertility of sandy soils in the Sahelian zone through organic matter management." This project aims to propose technological options that are acceptable and affordable for farmers. Additionally, the project aims to elucidate the

degradation process and kinetics of improving organic matter in soil in the Sahel environment, estimate the nutrient-holding capacity of sandy soils as affected by organic matter application, both on a short- and long-term basis, and identify the synergistic interaction and agronomic significance of combinations of organic and inorganic fertilizers.

The effect of organic matter application on the sustainability of crop production has not been properly evaluated, because previous studies have been short-term. Although a model simulation approach would be effective for evaluating long-term sustainability, most of the existing SOM dynamic models are configured for the temperate zone. Therefore, the Rothamsted Carbon Model (Roth-C) was validated for use in the Sahelian zone to estimate long-term soil organic carbon (SOC) dynamics (Nakamura et al. 2010). Roth-C was used to evaluate various technical options that have been proposed for semi-arid tropics in Niger. This investigation aimed to elucidate the annual carbon requirement for sustainable crop production through Roth-C estimation of suggested technical options in Niger.

Materials and methods

Study sites

Three experiments were conducted to elucidate the effects of various agronomic options on crop yields. Two of these 3 experiments were conducted in the International Crop Research Institute for Semi-Arid Tropics, West and Central Africa (ICRISAT-WCA), located in Sádore, 45 km south of Niamey, the capital of Niger, at an altitude of 240 m above sea level. The climate of Sádore is characterized by a short rainy season from June to September (Subbarao et al. 2000; Sivakumar 1986), with an annual average precipitation of approximately 560 mm. The other study was conducted in the Fakara region located 50 km northeast of Niamey. The soil distributed in the Sádore and Fakara regions is a *Psammentic Paleustalfs*. The authors attempted to estimate the long-term SOC dynamics of these 3 experiments through the model approach.

Experiment 1 focused on the effect of cropping pattern and cropping density of millet (*Pennisetum glaucum* [L.] R. Br.) and cowpea (*Vigna unguiculata* [L.] Walp.) intercropping on millet yield. The details of this experiment were described by Saidou et al. (2010a). They tried to elucidate the effect of cowpea-millet rotation on crop yields and soil fertility using a new cropping design, i.e., 4:4 lines cropping against 1:1 line cropping, and with 3 levels of cowpea planting densities (low, 5882–6275 stands ha^{-1}; medium, 10 588–11 503 stands ha^{-1}; and high, 29 412–32 418 stands ha^{-1}). Initial SOC conditions, crop yields, and annual carbon input are shown in Table 1.

Table 1. Initial SOC and carbon input calculated from dry matter yields of millet and cowpea in Experiment 1.

ID	Crop	System	Design	Cowpea Density	Initial SOC (tC/ha)	Millet Dry Matter (t/ha)			Cowpea Dry Matter (t/ha)			Total Dry Matter (t/ha)	Annual Carbon Input as Plant Material (tC/ha)	Annual Carbon input as FYM* (tC/ha)
						Above[1]	STD	Below[2]	Above[1]	STD	Below[2]			
A1	Millet/Cowpea	Rotation	1:1 Line	Low	5.49	2.38	0.66	0.26	0.45	0.05	0.09	2.83	**0.176**	**0.000**
A2	Millet/Cowpea	Rotation	1:1 Line	Mid	5.59	1.92	0.42	0.21	0.87	0.27	0.17	2.78	**0.192**	**0.000**
A3	Millet/Cowpea	Rotation	1:1 Line	High	5.62	1.29	0.58	0.14	1.60	0.12	0.32	2.88	**0.230**	**0.000**
A4	Millet/Cowpea	Rotation	4:4 Line	Low	5.85	2.00	0.58	0.22	0.82	0.14	0.16	2.82	**0.192**	**0.000**
A5	Millet/Cowpea	Rotation	4:4 Line	Mid	5.67	1.75	0.63	0.19	1.19	0.45	0.24	2.94	**0.215**	**0.000**
A6	Millet/Cowpea	Rotation	4:4 Line	High	6.10	1.75	0.61	0.19	1.51	0.32	0.30	3.26	**0.247**	**0.000**

*FYM: Farm Yard Manure, [1]Above: Above-ground biomass, [2]Below: Below-ground biomass

Experiment 2 was conducted to elucidate the effect of cowpea intercropping combined with manure and/or chemical fertilizer application on pearl millet yield (Saidou et al. 2010b). The initial condition and annual inputs of this experiment are shown in Table 2. This experiment was conducted in a randomized complete block design with 3 replications. As shown in Table 2, the treatments consisted of millet mono-cropping and intercropping of millet and cowpea. Randomized blocks were subjected to different fertilizer applications: no fertilizer (control), chemical fertilizer diammonium phosphate (DAP; 2 g $hill^{-1}$), transported manure (6 t ha^{-1}), and combination of chemical fertilizer and transported manure. The crops were planted at a density of 1.4 m × 1.4 m in mid-June and harvested in October.

Table 2. Initial SOC and carbon input calculated from dry matter yields of millet and cowpea in Experiment 2

ID	Crop	Management		Initial SOC (tC/ha)	Millet Dry Matter (t/ha)			Cowpea Dry Matter (t/ha)			Total Dry Matter (t/ha)	Annual Carbon Input as Plant Material (tC/ha)	Annual Carbon input as FYM* (tC/ha)
					Above[1]	STD	Below[2]	Above[1]	STD	Below[2]			
M1	Millet	Monocrop	Manure + CF**	5.53	3.37	0.89	0.37	0.00	0.00	0.00	3.37	**0.185**	**1.098**
M2	Millet/Cowpea	Intercrop	Manure + CF**	5.72	3.68	1.15	0.41	0.51	0.10	0.10	4.20	**0.254**	**1.098**
M3	Millet	Monocrop	CF**	4.57	1.52	0.19	0.17	0.00	0.00	0.00	1.52	**0.083**	**0.000**
M4	Millet/Cowpea	Intercrop	CF**	4.72	1.55	0.29	0.17	0.34	0.07	0.07	1.89	**0.119**	**0.000**
M5	Millet	Monocrop	None	4.97	1.27	0.32	0.14	0.00	0.00	0.00	1.27	**0.070**	**0.000**
M6	Millet/Cowpea	Intercrop	None	4.93	0.78	0.37	0.09	0.45	0.09	0.09	1.23	**0.088**	**0.000**
M7	Cowpea	Monocrop	None	4.92	0.00	0.00	0.00	0.95	0.19	0.19	0.95	**0.095**	**0.000**
M8	Millet	Monocrop	Manure	5.08	2.47	0.26	0.27	0.00	0.00	0.00	2.47	**0.136**	**1.098**
M9	Millet/Cowpea	Intercrop	Manure	4.98	2.22	0.23	0.24	0.98	0.20	0.20	3.20	**0.220**	**1.098**
M10	Cowpea	Monocrop	Manure	5.46	0.00	0.00	0.00	1.88	0.38	0.38	1.88	**0.188**	**1.098**

*FYM: Farm Yard Manure, **CF: Chemical Fertilizer, [1]Above: Above-ground biomass, [2]Below: Below-ground biomass

Experiment 3 was conducted as a generalization of suggested technical options within Experiments 1 and 2 (H. Omae, JIRCAS 2010 *pers. comm.*). This experiment included the 1:1 and/or 4:4 crop design treatments, selected cowpea varieties, and several different fertilizers such as manure, crop residue, and chemicals. The authors attempted to elucidate the farmer's selection from suggested techniques and to summarize the optimal combination of these techniques for farmers. Manure and crop residues were applied at the rate of 9 t ha^{-1} and 6 t ha^{-1}, respectively. Experiment 3 was conducted in 8 sites of 6 villages in the Fakara region: Tchigo Tegui, Kodey, Yermadey, Bokossay, Katanga, and Maourey Koira Zeno, as replications. The mean initial SOC values and carbon input within 8 replications are shown in Table 3.

Table 3. Initial SOC and carbon input calculated from dry matter yields of millet and cowpea in Experiment 3.

ID	Crop	Variety	Design	Application		Initial SOC (tC/ha)	Millet Dry Matter (t/ha)			Cowpea Dry Matter (t/ha)			Total Dry Matter	Annual Carbon Input as Plant Material (tC/ha)	Annual Carbon input as FYM*** (tC/ha)
				OM*	CF**		Above[1]	STD	Below[2]	Above[1]	STD	Below[2]			
F1	Millet/Cowpea	TN256-87	1:01	no	no	5.76	0.26	-	0.03	0.00	-	0.00	0.26	**0.014**	**0.000**
F2	Millet/Cowpea	TN256-87	1:01	no	NPK	5.76	1.53	0.66	0.17	0.69	0.31	0.14	2.22	**0.153**	**0.000**
F3	Millet/Cowpea	IT99K-213-11-1	1:01	M	no	5.76	1.78	0.84	0.20	1.16	1.06	0.23	2.94	**0.214**	**3.600**
F4	Millet/Cowpea	local	1:01	M	no	5.76	2.11	1.16	0.23	0.91	0.39	0.18	3.01	**0.207**	**3.600**
F5	Millet/Cowpea	local	1:01	M	NPK	5.76	2.86	1.04	0.31	1.22	0.72	0.24	4.08	**0.279**	**3.600**
F6	Millet/Cowpea	local	1:01	no	no	5.76	0.68	0.41	0.07	0.44	0.19	0.09	1.12	**0.081**	**0.000**
F7	Millet/Cowpea	local	1:01	no	NPK	5.76	1.44	0.82	0.16	0.61	0.31	0.12	2.05	**0.141**	**0.000**
F8	Millet/Cowpea	local	1:01	CR	no	5.76	1.08	0.68	0.12	0.63	0.33	0.13	1.70	**2.522**	**0.000**
F9	Millet/Cowpea	local	1:01	CR	NPK	5.76	2.23	0.96	0.25	1.02	0.59	0.20	3.26	**2.625**	**0.000**
F10	Millet/Cowpea	TN256-87	4:04	no	NPK	5.76	1.33	0.57	0.15	0.54	0.21	0.11	1.87	**0.127**	**0.000**
F11	Millet/Hibiscus	Wankoye	1:01	CR	no	5.76	1.15	0.72	0.13	0.59	0.17	1.36	1.74	**3.142**	**0.000**

*OM: Organic Matter, M and CR in the column indicate application of Manure and Crop Residue, respectively. **CF: Chemical Fertilizer, ***FYM: Farm Yard Manure
[1]Above: Above-ground biomass, [2]Below: Below-ground biomass

Soil analysis

Soil samples were air-dried for 1 week, followed by crushing and sieving through a 2-mm sieve. Soil organic carbon content was determined by the Walkley-Black method (Nelson and Sommers 1982). Concentrated H_2SO_4 was added to a mixture of soil and aqueous 0.167 mol L^{-1} $K_2Cr_2O_7$ solution. After a 30-min incubation, residual $K_2Cr_2O_7$ was titrated against 0.025 mol L^{-1} $FeSO_4$. Additionally, carbon contents of crop and crop residue were also determined by the Walkley-Black method.

Model set up

To elucidate SOC dynamics, the Roth-C (version 26.3) (Coleman and Jenkinson 1996) was used. Roth-C is the most frequently used model that has been tested under various climatic and/or agricultural conditions in the world. Furthermore, this model has been validated for use in the Nigerian conditions by Nakamura et al. (2010). It was concluded that Roth-C can simulate organic carbon dynamics under Nigerien conditions independent of various agricultural managements. Thus, it can be used to estimate SOC dynamics in this region.

The detailed model structure was described by Coleman and Jenkinson (1996). This model simulates SOC dynamics with partitioning of SOC for 4 active SOC fractions and inert organic matter (IOM). Active SOCs were partitioned as follows: decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO), and humified organic matter (HUM). In modelling each set of experimental data, we set the initial SOC contents that were measured at the beginning of each experiment and then simulated the changes in SOC with time for each management scenario. These initial SOC contents (Mg C ha^{-1}) were calculated from the analyzed SOC concentration and bulk densities. For this analysis, soil samples were gathered at a depth of 0–15 cm in Experiments 1 and 2, and 0–30 cm in Experiment 3. Simulations were carried out using this depth.

The specified model parameters are the same as Nakamura et al. (2010). Authors calculated the initial allocated amounts of SOC in each of the 5 compartments according to existing studies (Jenkinson et al. 1999, Shirato et al. 2005, Coleman & Jenkinson 1996). This estimated C input was divided equally over 12 months according to Coleman & Jenkinson (1996). Soils were assumed to be covered with vegetation throughout the year before the initiation of the experiments. A DPM:RPM ratio of 1.44, a recommended value for most agricultural crops and grass (Coleman & Jenkinson 1996), was applied. The values of IOM were calculated by the equation outlined by Falloon et al. (1998). For the climatic condition in the research site, monthly mean air temperatures, precipitation, and open pan evaporation were obtained from ICRISAT-WCA during long-term experiments. The rate-modifying factor for soil moisture in Roth-C was a minimum of 0.2 during the dry season and a maximum value of 1.0 during the rainy season (from July to September) in all cases.

Result and discussion

Effect of various management practicess on long-term SOC accumulation

As shown in Figure 1, SOC dynamics in Experiment 1 indicated a notable decrease of SOC among all treatments. Saidou et al. (2010a) reported that the combination of the 4 rows millet: 4 rows cowpea design and crop rotation management provided a significantly high total biomass, millet biomass, cowpea biomass, and millet grain. Additionally, below-ground biomass of millet and cowpea also increased, as calculated in Table 1. In this experiment, the above-ground biomass of

each crop was not returned to the soil. Therefore, the increase in above-ground biomass of crop would not affect SOC accumulation directly. Despite the fact that the below-ground biomass increased, SOC accumulation was not affected because of the high decomposition rate of organic material in the Sahel.

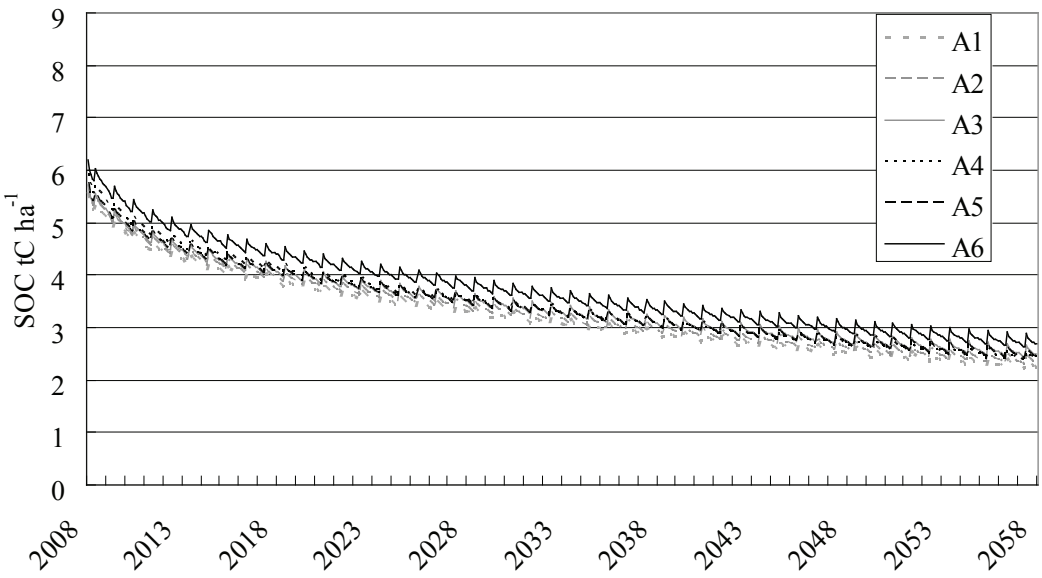

Figure 1. Long-term estimations of SOC dynamics in Experiment 1 treatments.

Additionally, a study conducted by Saidou et al. (2010a) reported the relationships between cowpea density and biomass in different crop designs and showed that the 4 rows millet: 4 rows cowpea system does not alter millet biomass and keeps it stable, whereas cowpea biomass increases with increase in crop density. In contrast, higher crop density increases cowpea biomass but decreases millet biomass in a 1 row millet: 1 row cowpea system. In the model estimates, however, SOC dynamics did not show the clear primacy of the 4:4 system over the 1:1 system. Although this experiment showed an increase in crop yield against traditional management, it also showed that non-SOC application cultivation cannot accumulate SOC in the Sahel.

As shown in Table 2, the clear effects of fertilizer application on crop yield were observed in Experiment 2. The combined application of manure and chemical fertilizer produced the highest yield in both mono- and inter-cropping, that is, 3.37 t ha^{-1} and 4.20 t ha^{-1} as total dry matter, respectively. Manure application also produced a higher yield than that in plots where manure was not applied or chemical fertilizer was applied. SOC dynamics estimation in Experiment 2 is shown in Figure 2. The managements that included manure application indicated a pronounced increase of SOC in long-term estimates. It seemed that the amount of organic carbon applied as manure was enough to maintain SOC, even in the highly decomposing condition of the Sahel. In contrast, SOCs in the chemical fertilizer application and control showed remarkable decline, as well as the results of the estimations in Experiment 1.

In addition, Saidou et al. (2010b) noted an increase in total biomass yield in millet/cowpea inter-cropping compared to mono-cropping due to the input of cowpea biomass. Moreover, the millet yield in the inter-cropping system was not disturbed with cowpea planting density, whereas, SOC dynamics estimation did not show the difference between mono-cropping and inter-cropping (Figure 2).

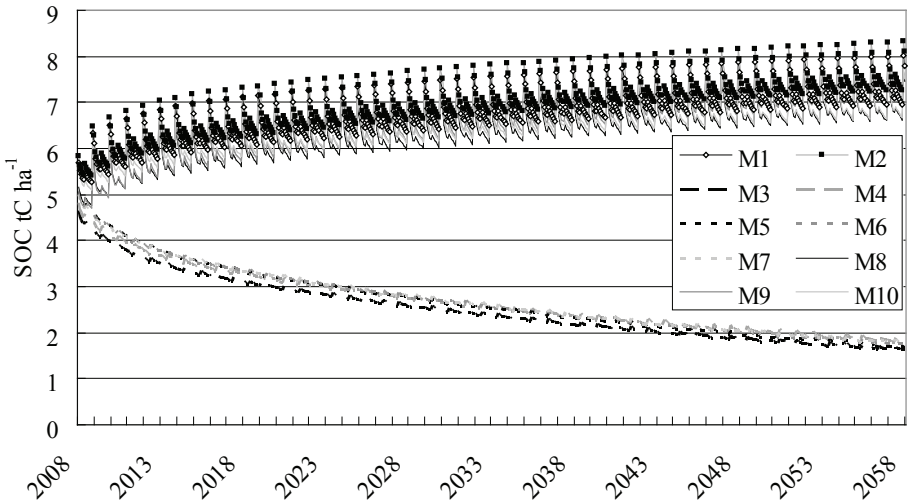

Figure 2. Long-term estimations of SOC dynamics in Experiment 2 treatments.

Experiment 3 was a complex trial performed under the inter-cropping management, consisting of several technical options, including selected cowpea variety, fertilizer application, and cropping design. All options were evaluated under the millet/cowpea inter-cropping system. As discussed above, millet/cowpea inter-cropping is predictably effective.

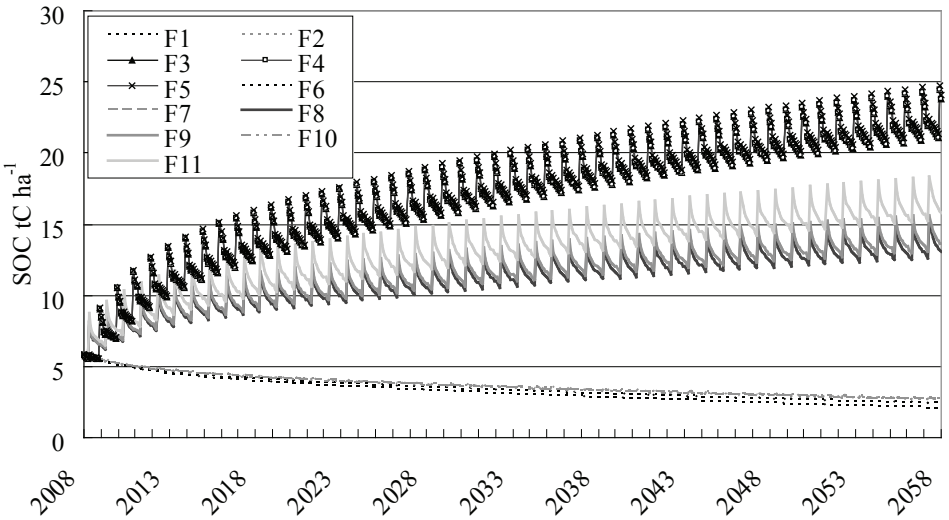

Figure 3. Long-term estimations of SOC dynamics in Experiment 3 treatments.

The predicted SOC in Experiment 3 revealed that organic matter application, and not cropping design and/or cowpea variety, was effective. Manure application (3.6 t C ha^{-1}) showed a pronounced increase of SOC (Figure 3). Moreover, crop residue application also indicated SOC accumulation (Figure 3). The chemical fertilizer application and control declined in long-term SOC dynamics. This fact indicates that these organic matter application rates were sufficient for residual accumulation of organic matters in the Sahel. However, such application rates might be recognized as impractical for farmers due to socio-economical constraints. Therefore, the properly targeted value for the organic matter application rate needs to be calculated. Additionally, it was

notable that all of the suggested technical options without organic matter application increased crop yield compared with F6 as traditional management, while showing a pronounced decline in SOM dynamics.

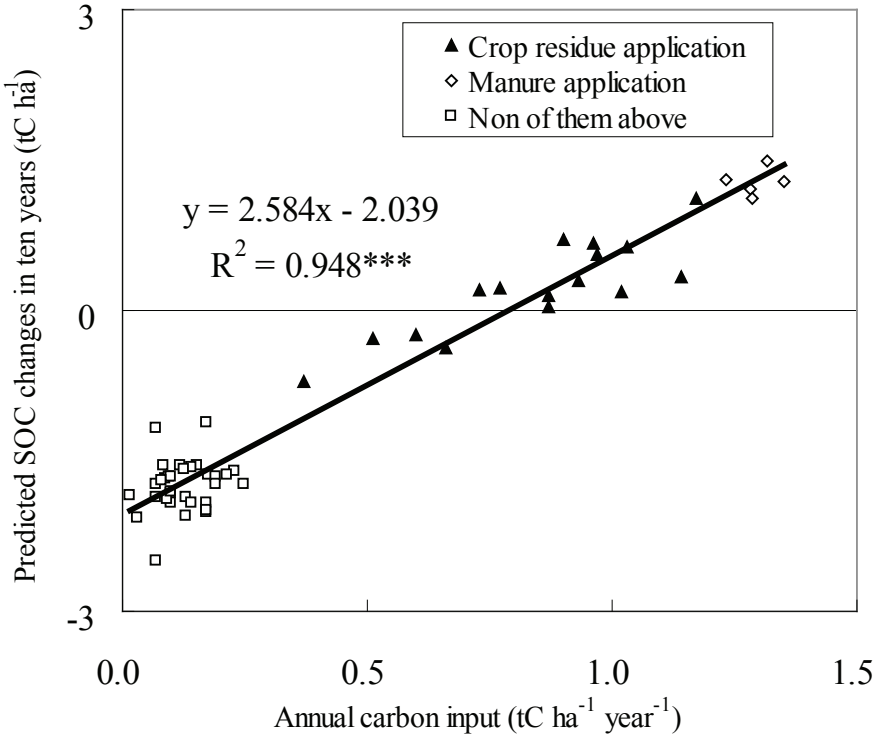

Figure 4. Relationship between annual carbon input and predicted SOC changes in a 10-year period in the Sahel

Annual carbon requirement estimation for sustainable crop production in the Sahel

The annual carbon requirement for maintaining SOC contents in the study area was calculated from simple linear regression analysis between actual annual carbon input and predicted SOC changes after a 10-year cultivation period based on 59 treatments; 27 from technical options tested in Experiments 1, 2, and 3, by the JIRCAS project regarding soil fertility improvement in Niger, and 32 treatments conducted in 2 long-term experiment fields that were used for model validation in Nakamura et al. (2010). In these 2 experiments, the long-term actual SOC change was obtained for 27 and 24 years, respectively. One experiment was conducted to examine the relations between crop yields and long-term fertilizer application, including the application of no fertilizer, crop residue, chemical fertilizer, and a crop residue and chemical combination. The other experiment focussed on elucidating the long-term effect of ridging, rotation, and crop residue applications on millet yield. The detailed information of these 2 experiments have been described in studies by Geiger et al. (1992) and Subbarao et al. (2000), respectively. The initial SOC, mean value of annual inputted carbon, and predicted carbon changes in 10 years are presented in Table 4.

The computed annual carbon requirement was about 0.8 t C ha^{-1} in this region (Figure 4). The determination coefficient in this regression equation was 0.948, which was statistically significance ($p < 0.01$). Annual input of 0.8 t C ha^{-1} can be converted to approximately 1.6–2.0t ha^{-1} as crop residues, and 2.0–4.0 t ha^{-1} as transferred manure. The manure applications

indicated a higher accumulation rate compared with crop residue application. The rate of crop residue application was often dependent on the biomass yield in the field, whereas the manure application rate was not limited by yield.

Table 4. Initial SOC and carbon input calculated from dry matter yields of millet and cowpea in 2 long-term experiments conducted in ICRISAT-WCA

Treatment	Without crop residue application			Crop residue application		
	Initial SOC	Annual Carbon input	Predicted carbon balance in ten years	Initial SOC	Annual Carbon input	Predicted carbon balance in ten years
Site Combination effect of crop residue and chemical fertilizer from 1983						
Control	3.44	0.07	-1.17	3.81	0.51	-0.28
Chemical Fertilizer	3.84	0.17	-1.12	4.05	1.17	1.12
Site2 Long-term experiment of millet/cowpea intercropping, rotation, ridge management (from 1986, Crop residue was applied from 1989)						
Traditional Practice with Improved Variety	5.69	0.03	-2.07	3.94	0.37	-0.70
Intercropping / Ridge / No Rotation	6.32	0.10	-1.66	4.55	1.03	0.64
Intercropping / Ridge / Rotation 1	5.96	0.17	-1.91	4.99	0.87	0.03
Intercropping / Ridge / Rotation 2	6.14	0.13	-2.05	4.96	0.66	-0.38
Intercropping / Flat / No Rotation	5.33	0.07	-1.86	4.06	0.96	0.68
Intercropping / Flat / Rotation 1	5.65	0.13	-1.87	4.07	0.77	0.22
Intercropping / Flat / Rotation 2	5.38	0.10	-1.83	4.20	0.60	-0.24
Sole / Ridge / No Rotation	5.65	0.10	-1.93	4.47	0.97	0.56
Sole / Ridge / Rotation 1	6.28	0.17	-2.01	5.61	1.02	0.18
Sole / Ridge / Rotation 2	5.83	0.14	-1.92	5.11	0.93	0.30
Sole / Flat / No Rotation	5.47	0.09	-1.88	3.54	0.90	0.72
Sole / Flat / Rotation 1	6.23	0.17	-2.00	4.84	0.87	0.16
Sole / Flat / Rotation 2	5.38	0.10	-1.82	3.85	0.73	0.20
Traditional Practice with Local Variety	7.03	0.07	-2.50	6.10	1.14	0.33

*Rotation 1: Millet cultivation in even years
**Rotation 2: Miller cultivation in odd years

Even when the crop residue was applied, there were several cases where the applied carbon was less than the required amount. This appeared to be due to the low yield of plant biomass.

Conclusion

The annual carbon requirement for sustainable crop production in the Sahel was estimated to be approximately 0.8 t C ha^{-1} through Roth-C prediction using several experiments that were conducted in Niger. The suggested technical options were effective for improving crop production; however, SOC declined without application of organic matter. For sustainable crop production, organic matter should be applied under consciously to target the estimated carbon requirement. This estimated carbon requirement value, however, does not ensure good crop yields.

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13. Role of conservation agriculture in the control of carbon emission and enhancement of crop yield and water productivity under dry farming systems

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Abstract

The key problem of agricultural production in arid and semi-arid environments is the steady decline in water availability and soil fertility, which are closely related to duration of soil use. Implementing agricultural practices that reduce soil degradation has the potential to increase agricultural sustainability and soil conservation. Conservation agriculture (CA) system is considered as one of the most important adaptive approaches to mitigate the vulnerability of the agro-ecosystems to climate change, where it can reduces the harmful impacts resulting from drought and minimizes the rate of soil erosion by water. CA system has a higher adaptability to drought resulting from climate change. An experiment was conducted to determine the effect of three tillage systems on crop yield in a winter wheat-vetch rotation during three growing seasons in Syria. The highest grain yield was obtained with no tillage and treatment compared with double disk and conventional tillage. Heads density and head length increased significantly with minimum tillage, but tillage practices had no significant influence on thousand kernel weight

Introduction

The Mediterranean region encompasses a wide variety of agricultural systems where water is probably one of the main keys to productivity. Yield of dry land Mediterranean crops is usually low and widely variable due to high seasonal variability of rainfall, with 85% of annual rainfall occurring during the months of October to April. This variation in rain causes 75% of the variation in wheat yield (Kun 1988). Cereal grain response to conservation tillage practices has been variable (Rao and Dao 1996). Higher yields are usually attributed to increased water retention or utilization by the crop, especially in arid and semi-arid regions, while lower yields are attributed to greater disease, weed infestations, and N immobilization (McMaster et al. 2002).

It has been found that when soil moisture limited plant growth, grain yield was always equal or greater in conservation tillage than in mouldboard ploughing, and positively correlated with earlier/greater seedling emergence and autumn growth (López-Bellido et al. 1996). Some authors found that conservation tillage might diminish yield through decreased N availability (Rao and Dao 1996). However, residue retention by conservation tillage such as shallow or reduced tillage practices can, over the long term, improve soil structure and nutrient cycling. Soil erosion is a perpetual concern in many semi-arid regions with conventional tillage-based systems. Tillage is responsible for most soil degradation in the Mediterranean basin (López-Bellido et al. 1996).

No-tillage (NT) accompanied with suitable crop rotation causes an increase in the microbial biomass carbon (MBC) compared to conventional tillage (CT). This could be attributed to several

factors. Plant residues lower soil temperature, and increase water content, soil aggregation and C content compared to CT systems, whereas removal of crop residues exposes soil surface to direct sun light, increasing the rate of water loss by evaporation. The accumulation of crop residues at the soil surface provides substrates for soil microorganisms, which accounts for higher MBC at the surface under NT. Soil microorganisms mediate mineralization of soil organic matter (SOM) and nutrients. The microbial biomass is a small but important reservoir of nutrients (C, N, P and S) and substantial transformation of these nutrients occur in the biomass (Dick 1992).

Soil aggregation and aggregate dynamics are important in facilitating water infiltration, providing adequate habitat and protection for soil organisms, supplying oxygen to roots, and preventing soil erosion (Denef et al. 2001; Franzluebbers 2002a b). Erodibility of soils is directly related to aggregate stability. The continued existence of large pores in the soil that favor high infiltration rates and aeration depends on their stability. Soil aggregation is also one of the principle processes responsible for carbon sequestration in soils (Lal et al. 1997) and structural degradation provokes soil organic matter loss (Six et al. 1999). Soil management systems that leave more plant residues on the soil surface generally allow improvements in soil aggregation and aggregate stability (Carpenedo and Mielniczuk 1990).

Restoration of soil organic carbon (SOC) in arable lands represents a potential sink for atmospheric CO_2 (Lal and Kimbel 1997). Strategies for SOC restoration by adoption of recommended management practices include conversion from conventional tillage to no-till, increasing cropping intensity by eliminating summer fallows, using highly diverse rotations, introducing forage legumes and grass mixtures in the rotation cycle increasing crop production and C input into the soil (Hao et al. 2002).

Several experiments have demonstrated that different tillage systems applied to clayey soils help retain varying amounts of water in dry areas (Goss et al. 1978). Plants need relatively deep soil. The roots of wheat for instance, are known to reach depth of more than 1m, although the greatest root density is found in the first 0.6m (Wulfsohn et al. 1996). In intensive tillage systems that does not make use of subsoiling ploughs, a pan develops below the worked horizon, which alters both the hydrological and mechanical proprieties of the soil profile. This limits the depth of the root system. For this reason, the water content in this ploughing layer is of particular importance when growing cereals, as most root development will occur above this depth.

Farmers in the east and northeast region of Syria grow wheat which is rotated with legumes, such as vetch, lentil, and chickpea. Conventional tillage with mouldboard ploughing is commonly used in this region, but conservation tillage (minimum and no-tillage) has not yet been introduced. Crop response to tillage systems is diverse due to the complex interactions between tillage-induced soil edaphic characters, crop requirements, and weather conditions. Experiments were therefore conducted to study the response of winter wheat to different tillage system in north eastern Syria.

Materials and methods

An experiment was conducted to determine the effects of three tillage systems on crop yield components and yield of winter wheat grown in rotation with vetch over 3 years growing seasons on a clay–loam soil.. The 10-yr average precipitation, temperature and relative humidity values for the experimental site were 510 mm, 17 °C, and 75% respectively. The tillage treatments consisted of no tillage (NT), double disc tillage (MT): two passes of disking; and conventional

tillage (CT): mouldboard ploughing followed by two passes of tandem disk. All disk operations were performed to a depth of 8-10 cm. All the tillage treatments were fixed and repeated on the same plot. W heat was drilled @ of 200 kg ha^{-1} on 15 November, while vetch was drilled at a rate of 120 kg ha^{-1} on 13 November.. Fertilizer applications were based on the recommended regional guidelines. Only a small amount of residues was left on the soil surface. In both tillage systems, crop residues were incorporated into the topsoil following the traditional practice in the area (in July or August). The crop residues remaining on the soil surface covered less than 30% of the soil surface.

Results and discussion

The wheat grain yield was significantly higher in the shallow tillage treatment compared to the double disk and conventional tillage treatments. The grain yield increased as tillage decreased (Fig. 1). The lower grain yield with CT compared to the other two treatments might have been partly due to the greater water loss, or reduced root development.

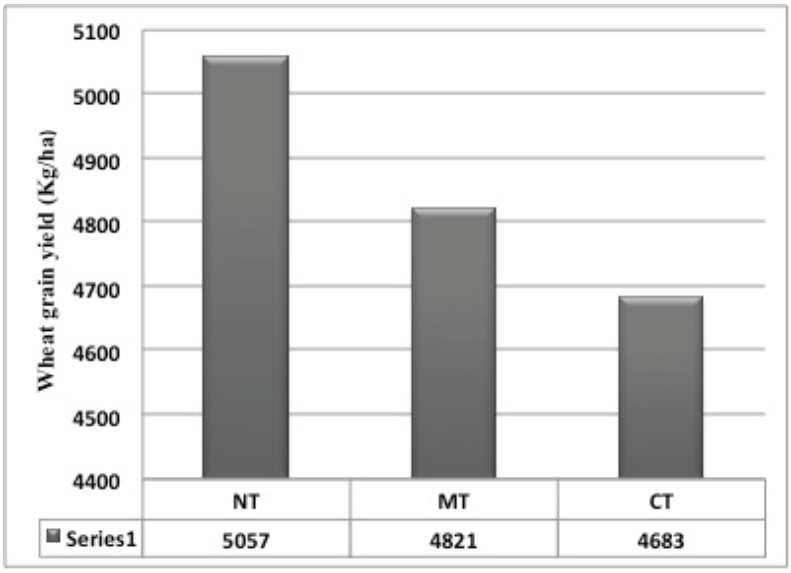

Figure 1. Effect of different tillage systems on wheat grain yield.

Bradford and Peterson (2002) attributed the increase in wheat yield to improved physical, and moisture conditions while Campbell and Janzen (1995) related increased yields of wheat under NT to a reduction in soil moisture loss and increase of organic carbon in the surface horizons.

The increase in yield was attributable to the improvement in head density (Fig. 2) and kernels per head (Fig. 3). Head density was higher in the no tillage treatment than in the other treatments. This large number of heads might be attributed to better seedling establishment, increased tiller production, and higher tiller survival. But tillage system did not significantly affect 1000-kernel weight.

There was also effect of tillage on the precipitation use efficiency of wheat (Fig. 4). No tillage treatment gave a significantly higher precipitation use efficiency (PUE) than CT, as averaged across years, because of better water usage in the preanthesis period, when plants usually suffer from terminal drought and heat stresses under semi-arid conditions.

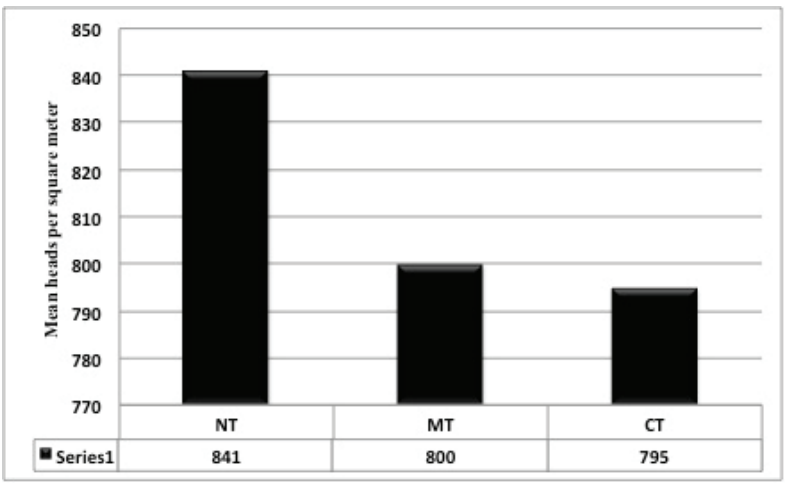

Figure 2. Effect of different tillage systems on heads per square meter.

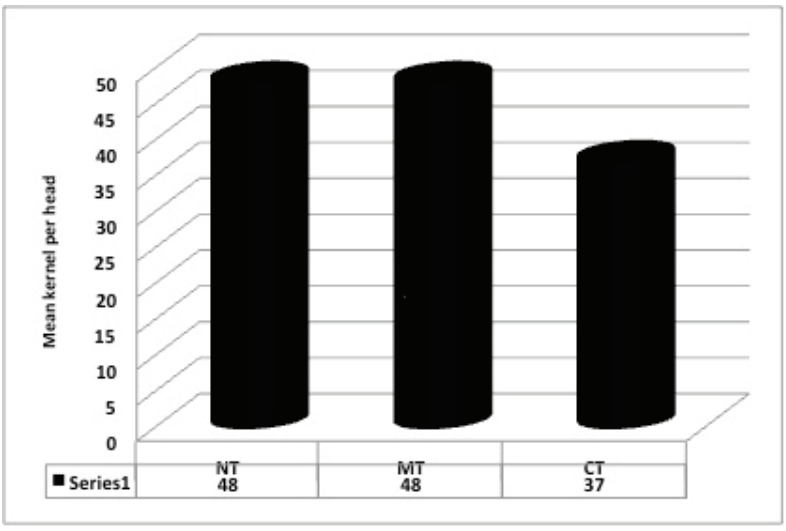

Figure 3. Effect of different tillage systems on kernels per head.

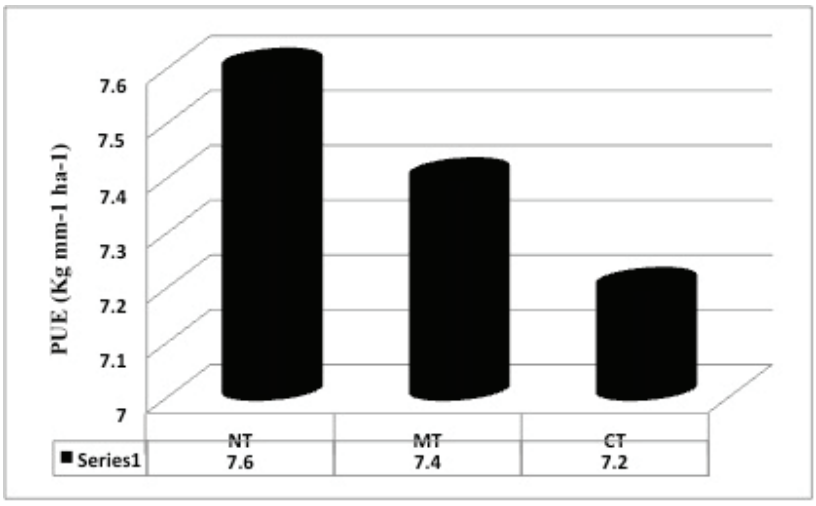

Figure 4. Effect of different tillage systems on precipitation use efficiency (PUE).

Conclusion

Conservation tillage (no tillage and minimum tillage) for growing winter wheat in the Mediterranean rainfed environment in the north eastern Syria resulted in increased wheat yield because of improved yield attributes over the conventional tillage practiced by the farmers in the region. No tillage was slightly better than minimum tillage. The precipitation use efficiency was also improved by no tillage. Thus, minimum tillage could be recommended for use in this region.

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14. Olive mill wastewater spray to improve structural stability and reduce wind erosion in the southern Tunisian arid zones

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Abstract

Use of waste water in agriculture is widespread and its impact on the environmental and human health has been widely investigated. In Tunisia, the olive oil extraction process, both by the traditional (or the press system) and the three-phase decanter system produces a large quantity of Olive Mill Wastewaters (OWM) or "margine". The quantities of the OMW that accumulate from one year to the next constitute a real environmental problem. On the other hand, in the Tunisian arid zones, where the soils are sandy and very poor in organic and mineral matters, wind erosion process is very active leading to dune building. To face these situations, many simple and efficient practices for combating desertification have been tested since many years in the Tunisian arid zones. The mulching of the olive mill wastewaters is one of these techniques. Olive mill wastewaters sprays of 50 m^3/ha, 100 m^3/ha and 200 m^3/ha were compared with no spray of OMW, in an experiment started in 1995 in Chammakh –Zarzis, Tunisia. There was an increase in the organic matter content in the soil in proportion to the dose of OMW, from 0.06% to 1.27%, after 10 years of OMW mulching and there was an improvement of the soil structural stability or "the mean weight diameter" where the aggregation of more than 2 mm increased by 34 % with the highest dose of OMW. The wind tunnel tests on the soil treated with different doses of OMW showed that the threshold friction velocity was raised from 8.5 m/s to 12 m/s for 50 m^3/ha and 200 m^3/ha OMW doses, respectively, indicating the benefit of the spray in controlling soil erosion by wind.

Introduction

In many countries where the olive oil is produced (Spain, Italia, Greece, Tunisia, Marroc, Syria, etc), the olive oil extraction process produces large quantities of solid and liquid waste. The liquid waste fraction is called the "margine" or the Olive Mill Wastewater (OMW). In Tunisia 700, 000 tonnes of OMW is produced yearly. Indeed, the traditional system of oil extraction produces 400 litres of OMW for 1 tonne of olives and the three-phase system of extraction produces 1000 litres per 1 tonne of olives (Bonari and Ceccarini 1990). Therefore, the quantities of OMW accumulating each year and dumped in open reservoirs and lakes, constitute a real environmental problem in Tunisia. The OMW increases saltiness and very complex organic load (sugar, proteins, lipids and phenolic compounds) which are very toxic.

On the other hand, soil degradation especially with regard to deterioration of the soil physical properties is a common feature in southern Tunisia. It results in surface crust formation and reduction of vegetative cover leading to water and wind erosion. To find a remedy for these soils changes, mulching of Olive Mill Wastewater as an organic amendment seems be a simple and possible method to improve the organic matter content of soil particularly in arid environment.

The objective of this study was to evaluate the impact of 10 years of successive OMW sprays on the surface properties of sandy soils in olive orchards in Chammakh-Zarzis in southern Tunisia. In this work three parameters were studied: the change in the organic matter content of the soil, the structural stability of the soil, and the threshold friction velocity after 10 years of Olive Mill Wastewater sprays.

Material and method

The Chammakh-Zarzis olive orchard is situated in southern Tunisia in an environment with an arid Mediterranean climate with a mean annual rainfall of 180 mm, as long term average for the period of 1923-2004. The soil is moderately deep with a sandy texture and poor in organic matter (Taamallah 2007).

The OMW was pumped from a pit cistern in a tank and brought by tractor to the field (Photo 1). Then it was sprayed homogeneously on the sandy soil surface, previously tilled to a 10-15 cm depth (Photo 2). Since 1995 until 2006 'margine' was sprayed during December-January period at a yearly rates of 0 (control), 50, 100, and 200 m^3ha^{-1} . The four one hectare parcels were selected, each containing 16 olive trees between 60 and 70 years old, planted at intervals of 25 meter. The parcels were separated by 2 non-treated olive tree rows (50 m distance).

Photo 1. OMW spray from tank and tractor

Photo 2. OMW treated parcel

Results and discussion

Organic matter content

The organic matter content was determined by Walkley and Black method in soil samples taken in 2006 from each parcel (i.e., after 10 years of yearly OMW application). The organic matter content increased with increasing rate of OMW application, the respective values being 0.06, 0.41, 0.71 and 1.27 % under control, 50, 100 and 200 $m^3.ha^{-1}$ treatments.
Similar results were obtained by Cabrera et al. (1996) who showed that after three successive years of OMW application organic matter content went up considerably.

Aggregate formation and stability

Disturbed surface samples were taken and brought to the laboratory. Previously air dried samples were sieved and the dry aggregate distribution determined. It was only at rates of 200 $m^3.ha^{-1}$ treatment that differences in aggregate formation could be found, as at lower rates of applications (50 and 100 $m^3.ha^{-1}$) only 10 % of the aggregates had diameters larger than 2 mm, while at the 200 $m^3.ha^{-1}$ rate 35 % of the aggregates had diameters larger than 2 mm.

The same samples were then subjected to a under water sieving test and allowed to break down. When aggregates are submerged in water and gently sieved (wet sieving), their status changes compared to their initial status (dry aggregates). Hence, the difference in mean diameter of the aggregates before (dry sieving) and after wet sieving can be used to compute the instability index (IS). The difference of the areas under the curves of dry and wet aggregate distribution describes this stability. Generally, the inverse of IS, the stability index (SI) is taken as a measure for the stability of the soil aggregates. The plot of the aggregate size distribution after dry and wet sieving showed that 200 $m^3.ha^{-1}$ rate of OMW application resulted in marked improvement in the aggregate stability as compared to the lower application rates. The 200 $m^3.ha^{-1}$ application rate resulted in 25 % of aggregates with diameters larger than 2 mm, while at lower application rates this value was only 5% (Figure 1). These results are in concordance with Mellouli (1996) who concluded that it is possible to improve the stability of an unstable soil (loamy soil). Indeed, in presence of water, the soil could be structured but iis stability is dependent on its clay and silt contents, both of which are considered to permit cohesion (Hartmann et De Boodt, 1974). The same results were obtained by Gabriels at al. (1975) on the sandy soil treated by compost. This technique of mulching with OMW could improve the soil stability and reduce the evaporation.

Threshold friction velocity for initiating particle movement

Bulk samples of the upper sandy soil layers were shipped to the Department of Soil Management of Ghent University, Belgium to be tested in the wind tunnel of the International Center for Eremology (ICE). The wind tunnel of ICE is described in detail by Gabriels et al. (1997) and Cornelis et al. (2004). The boundary layer was set at about 0.60 m using a combination of spires and roughness elements (Cornelis 2002). The samples were placed in 0.95 x 0.40 x 0.02 m trays and put at a distance of 6.00 m downwind from the entrance of the wind tunnel working section. To ensure wind tunnel profile equilibrium with the roughness of the sample surface, the test section was covered with commercially available emery paper with the same roughness length as the surface of the sample, as determined experimentally from measured wind velocity profiles (Cornelis et al. 2004)

Wind at different reference velocities u_{ref} (recorded at a height of 1.00 m at the entrance ofthe test area) were introduced in the test area and wind velocities u were monitored at a 1-Hz frequency with 13 mm diameter vane probes mounted at heights of 0.05, 0.l0 , 0.15, 0.20, 0.30, 0.40, 0.50, 0.60 and 0.70m. The shear velocity u_* of the sand surface could be calculated from the wind profile and the roughness length z_0 and the Von Karman constant k = 0.4:

$$u_z = \frac{u_*}{k} \mathrm{h} \frac{z}{z_0}$$

The initiation of particle movement was determined by continuously recording particle transport with a 'saltiphone'. The saltiphone, described by (Spaan and van den Abeele1991), is an acoustic sensor that records the number of saltating particles that bounce against a microphone at a frequency of 0.1 Hz. To determine the threshold friction velocity u_{*t} for initiating particle movement, the u_{ref} was increased until first particles were recorded with the saltiphone (Cornelis and Gabriels 2004). The threshold friction velocity values were 8.5, 8.65, 10.25 and 12.15 for 0, 50, 100 and 200 $m^3.ha^{-1}$ OMW treatments, respectively.

These results showed that the threshold velocity was raised with increasing doses of OMW spray. The same results are obtained by (Mellouli 1996; (Ben rouina and Taamallah1999) and (Abichou 2003). They showed that OMW with it is power to create mulch formation can reduce water and wind erosion.

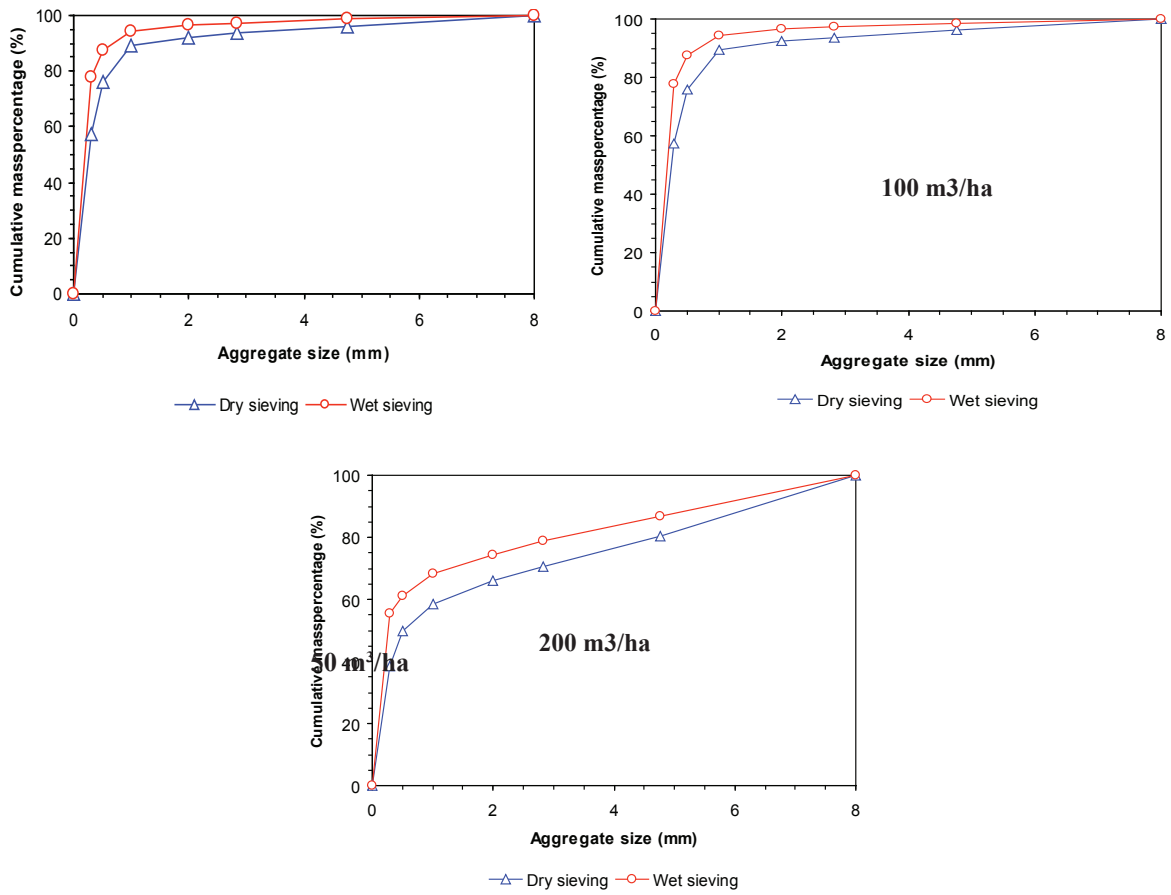

Figure 1. Mulching effect of OMW on structural stability.

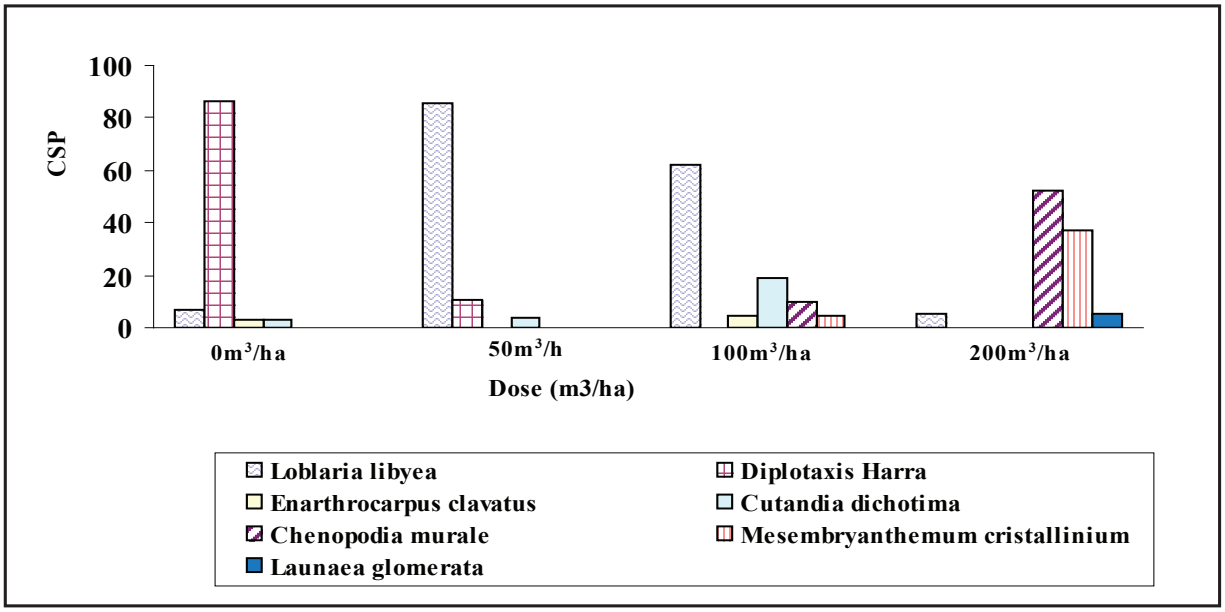

Figure 2. Natural floristic composition.

Natural floristic composition for soil roughness improvement

The mulching effect of OMW on the vegetation cover and natural floristic composition was investigated when a visual difference was observed in the yearly species coming up on the sites treated with different rates of OMW. Indeed, some species such as *Chenopodia murale* and *Mesembryanthemum cristallinum* which had never been found in the test site in the past were observed in the plots treated with OMW. Their Specific Contribution (CSP) was 53% and 37%, respectively, to the total plants present in the plot treated with 200 m^3ha^{-1} OMW (Figure 2). This could be explained by the ecological and biological features of these two species which tolerate a large quantity of nitrates and salts in soils as was the case in the plot treated with 200 $m3.ha^{-1}$. *Diplotaxis harra* was relatively abundant (18 individual/m^2) in the control plot (CSP= 11%), but was absent in the plot treated with 200 m^3ha^{-1}. The latter could be attributed to the inhibition seed germination by the high dose of OMW. Indeed, the acidic pH and the presence of phenolic composed seems be very toxic to some sensitive species.

Thus the mulching of OMW in the abandon and pastoral areas can be beneficial to control the less palatable annual species development. In most cases, the fallow lands are dominated by *Diplotaxis harra* which is a of poor economic value (pastoral, medicinal or other). OMW mulching could decrease the competition of this species to the other more useful species for pastoral and industrial purposes (e.g., *Mesumbryanthemum cristallinium* is used for soap manufacture).

Conclusion

Mulching with OMW ("margine") on poor sandy soil could be an interesting practice for increasing the organic matter content, formation of aggregates and improving the soil structure stability. This has been demonstrated by the results of the field study carried out since 1995 in an olive plantation in Chammakh-Zarzis, South Tunisia. Mulching of OMW also affected the natural floristic composition besides creating vegetative cover that improves the resistance of soil surface to erosion. Hence, OMW can be an effective way to control wind erosion in southern Tunisian arid zones.

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15. Potential of protected agriculture to enhance water and food security in the Arabian Peninsula

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Abstract

Food security is a major issue in the Arabian Peninsula (AP) countries especially the six Arab States of the Gulf Cooperation Council (GCC). Harsh environment, high temperature and water scarcity are the major boundaries for enhancing food production in the region. The present conventional farming has low water and land productivity which makes it technically and economically incompetent to confront the food deficit and water scarcity. Groundwater is being rapidly depleted and agriculture is mostly dependent on desalinized water, which is expensive and its economic utilization requires more efficient production systems. Protected Agriculture (PA) provides a valuable option. Collaborative research of ICARDA and the national agricultural research systems (NARS) in the AP region has confirmed the high potential of PA for improving the food and water security. For example, tomato yield in open field in Qatarwas 4 to 6 kg/m2 compared to 17 kg/m2 in cooled GH during 2007. Using soilless production techniques (hydroponics) improved the water productivity even further. For tomato it was respectively 7 and 48 kg/m3 in soil and hydroponics system under PA in November to April growing period. Cost-benefit analysis confirmed that PA is more profitable compared to the traditional production in open field. Although the initial capital investment is higher, better yield and water saving would cover the costs within 3 to 4 seasons.

Introduction

Food security is a major issue in the Arabian Peninsula (AP) countries especially the six Arab States of the Gulf Cooperation Council (GCC). Almost 90% of the food consumed is imported. The situation is worst in Yemen where 32.1 percent of the population is food insecure and 57.9 percent of all children are malnourished (Olivier Ecker 2010). During 2007 and 2009, when the food prices reached a crises high, exacerbated by the by the global financial crises and economic recession, the number of people suffering from hunger and undernourishment reached a peak in 2009 of more than 1 billion (FAO 2011a). As a result, the world witnessed an increase in export restrictions by trading partners and caused an alarm for the Arabian Peninsula countries, particularly the six GCC countries, as they are the major food importers in the world. The local supply at the same time decreased because of the low productivity of farming systems and severe water scarcity. Meanwhile, regional demand for food has been rising because of population increase which is expected to become double in 2030 from that in 2000 (Woertz et al. 2010).

International food prices showed an up-ward trend (Figure 1) during a six-year period between 2005 and 2010(FAO 2011 b). The food price index rose steadily until 2008, when it peaked. Although the graph showed a slight decrease in 2009, it exhibited an-upward trend during 2010, which is expected to continue in 2011.

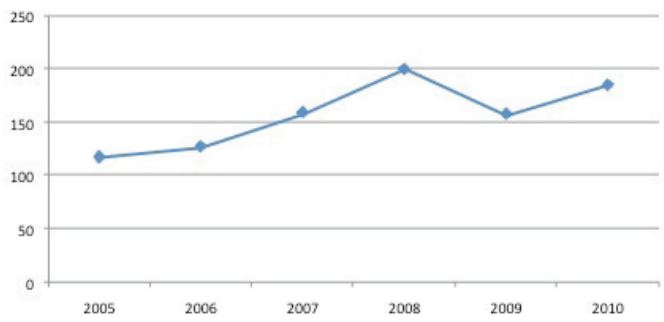

Figure 1. FAO Food Price Index from 2005 to 2010 (2002-2004=100).

During last 20-30 years, all the GCC countries have aimed to achieve a greater level of food self-sufficiency by improving their agricultural production. Therefore, they encouraged expansion of areas under irrigated agriculture by providing economic incentives and subsidies (Bazza 2005). However, the water resources in the region are very limited and agriculture has to depend mainly on the water resources from expensive desalination process.

Harsh environment, high temperature and increasing water scarcity are the major limiting factors for enhancing food production in the region. The conventional farming practices have low water and land productivity, making them technically and economically unfit to confront the food deficit and water scarcity. Large-scale crop production is limited to cereals (primarily wheat), vegetables, potatoes, and fruit crops, most notably dates (Kotilaine 2010).

Arabian Peninsula soils are generally poor because of high content of lime, gypsum, or salts because of the aridity of the climate (Pauw 2002). Arid conditions act as a natural constraint for expansive agriculture. Only 1.7% of the total land area is arable (Kotilaine 2010).

The whole cultivated area in AP is irrigated, mainly with groundwater as winter rainfall is limited. As for the countries with more substantial agricultural sectors, their agricultural production is constrained by severe biotic and abiotic stresses that include heat and salinity, as well as a lack of improved cultivars, cultural practices, and trained labor. Yemen and Saudi Arabia have by far the largest agricultural labor force (FAO 2008). Thus, AP is facing a great challenge in developing more sustainable land use and efficient water usage, while preserving its environment and heritage, with the current rate of population growth. The issues of water management, productivity, sustainability, and environment are closely interconnected. If current inefficient practice continues, there will be rapid depletion of water resources, extinction of native species and associated knowledge and rapid environmental destruction (ICARDA 2007).

To meet these challenges, there is need for developing the agricultural production system that has high productivity per unit of water and land while ensuring that the crops are protected from the extremes of heat and fragile environment is protected. Protected agriculture provides an option.

Protected agriculture

Protected agriculture (PA), where crops are grown under protective housing (plastic houses or greenhouses), is an intensive and dynamic form of crop production. In PA the environment and, therefore, timing of the production can be controlled and yields can be substantially improved. PA and its associated production techniques can significantly improve productivity per unit of area and land for the production of high value crops. Furthermore, PA would significantly reduce

the amount of water and chemicals used in producing high value fresh produce compared with open field production (Moustafa 2008).

ICARDA's research has showed that using protected agriculture with its associated modern techniques such as soilless culture (hydroponics) and Integrated Production and Protection Management (IPPM) program could substantially increase water productivity with the use of no or minimum amount of agro-chemicals in the Arabian Peninsula. Using such techniques would considerably save water and land that could be used for other field crops and food production activities.

Why soilless culture?

ICARDA has developed and introduced in Arabian Peninsula a number of soilless production systems, particularly to avoid the problems of diseases caused by soil organisms and nematodes, unsuitable soil reaction, salt accumulation due to irrigation, unfavorable soil compaction, poor drainage, degradation due to erosion, etc. (Moustafa 2010). Moreover, the conventional growing system using soil, wastes a lot of fresh water due to run off and deep percolation. In arid countries, rapid evaporation from the soil surface may also lead to salinity problems. Soilless culture (hydroponics) would avoid these constrains and would permit successful production of high quality products. Hydroponics offer opportunities to provide optimal conditions for plant growth and therefore, higher yields can be obtained compared to conventional soil-based agriculture (Moustafa et al. 2007). Soilless techniques also offer a way of improving water-use efficiency and obtaining better water and fertilizer management in crop production.

There are two main types of soilless cultivation systems (Moustafa et al. 2005):

1. Open systems, where plants are grown in containers or channels filled with an inert medium. Water and nutrients are supplied through drip irrigation and the surplus nutrients and water is allowed to run off as waste. The substrate must be inert and have a high water-holding/ release capacity. Maintenance of appropriate water and nutrient levels within the substrate is essential to prevent plant stress and waste.
2. Closed systems, where plants are grown in containers or bare roots placed in pipes or channels lined with polyethylene. A film of nutrient solution circulates around the roots and comes back to a catchment tank. This provides good contact between the solution and air, sufficient to maintain the oxygen level required by the roots without additional aeration of the solution.

The advantages of soilless culture over conventional soil systems include (Moustafa et al. 2005):

- Better control of water and nutrients;
- Very efficient use of water by reclaiming and reusing;
- Shorter cropping , allowing more crops within the season;
- Top quality crops grown on the land that has poor and contaminated soil;
- Increased production per unit area, water and energy.
- Reduction in labor requirement by more than 50%;
- Increased job satisfaction among workers;
- Elimination of the costly operations such as soil sterilization, cultivation, and weed control.

Productivity of soilless production system in the Arabian Peninsula

Productivity per unit of water and land for selected vegetables and fruit crops in Arabian Peninsula grown in hydroponics and conventional soil bed systems were studied by ICARDA under a project funded by Qatar National Food Security Program. The materials used in this study were based on ICARDA's previous research and experiment results in the region, as well as, the data generated during the course of studies on different hydroponics production system in collaboration with Al Sulaiteen Agricultural & Industrial Complex (SAIC).

Tomato production in hydroponics is highly successful all over the world. Figure 2 shows the comparison of tomato production grown in hydroponics system in Oman and coventional soil under cooled GH in Qatar and UAE. Water productivity of the hydroponics system was 38kg/m^3 in Oman while in soil it was 17kg/m^2 and 13kg/m^2 in UAE and Qatar respectively. Under cooled GH conditions water required to produce 1kg tomatoes was 110 liters. With this amount of water 2.3 kg tomatoes could be produced in the hydroponic system. Productivity per unit of land of tomato under hydroponic was also more than that of cooled greenhouses in Qatar or UAE.

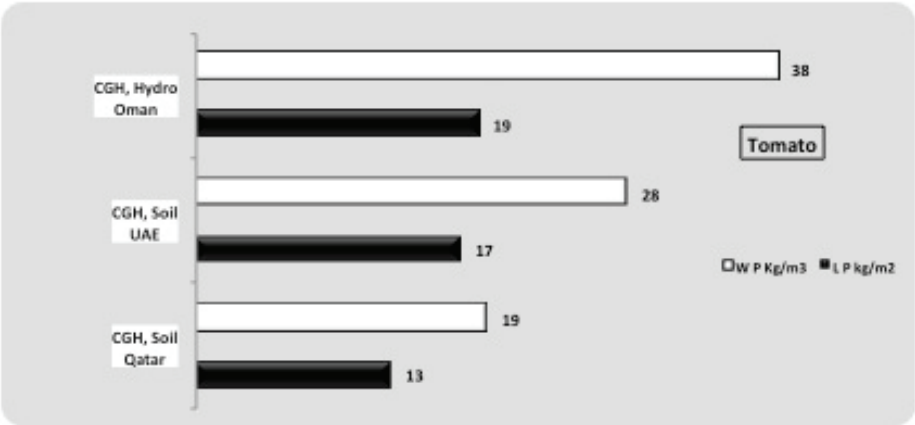

Figure 2. Land and water productivity (LP and WP) of tomato grown in hydroponics (Hydro) and soil culture system (Soil) in cooled greenhouse (CGH).

Cucumber is successfully grown in hydroponics in all the countries in the region. Productivity per unit of land and water for cucumber grown under cooled GH in hydroponics and soil is illustrated in Figure 3. The GH areas and structure were the same and both were under SAIC management. The production shown is from a single crop during the period from Sep to end Nov 2009. Land productivity under hydroponics was doubled compared to traditional cooled greenhouse. Similarly the productivity per unit of water for cucumber under hydroponic system was 5 times higher than that of the soil system.

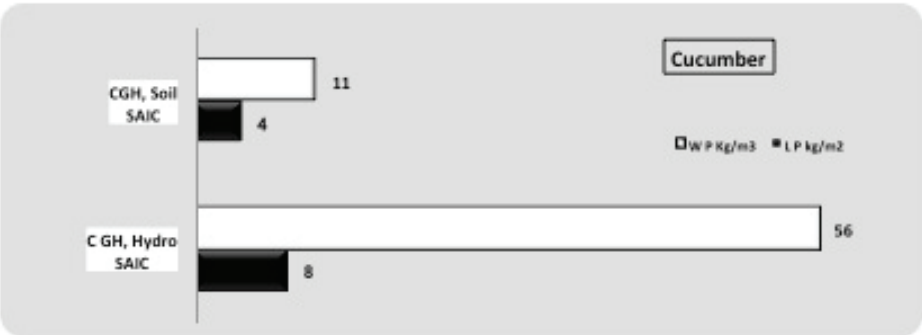

Figure 3. Land and water productivity (LP and WP) of cucumber grown in hydroponics (Hydro) and conventional soil based production system (Soil) in cooled greenhouse.

Lettuce is one of the most successful crops to grow in the high density hydroponics systems due to its limited plant height and short cropping period of 45 days. Hydroponics systems for lettuce are constructed in open filed, greenhouse and even industrial buildings using artificial lights. In this study, lettuce production in open filed was compared with the conventional soil production system. The system is successfully operated since early 2008 by Mirak farm in UAE. Data for convetional soill based production system was collected from Arab Qatari Agricultural Production Company (AQAPC). Land productivity of lettuce in hydroponics was three times higher than that of the soil culture. Similarly, productivity per unit of water in the hydroponics system was about 13 times higher than that with soil.

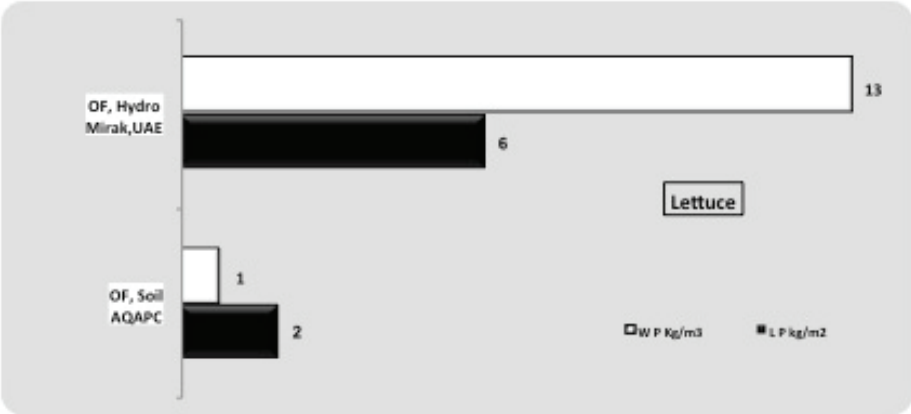

Figure 4. Land and water productivity (LP and WP) of lettuce grown in hydroponics (Hydro) and conventional soil based production system (Soil) in open field (OF).

Green beans were successfully produced in hydroponics system in open field in Mirak, UAE. The production was 2 kg/m^2 from a single crop produced in 2 months (Nov and Dec). Records of SAIC represent production of 2 crops within 4 months (Oct – Jan) in soil under cooled GH condition (Figure 5). The average water productivity under cooled house was ca. 5 kg/m^3 per crop while in the open field hydroponics it was almost three times as much. Hydroponics system under cooled GH will have added advantages of year-round production.

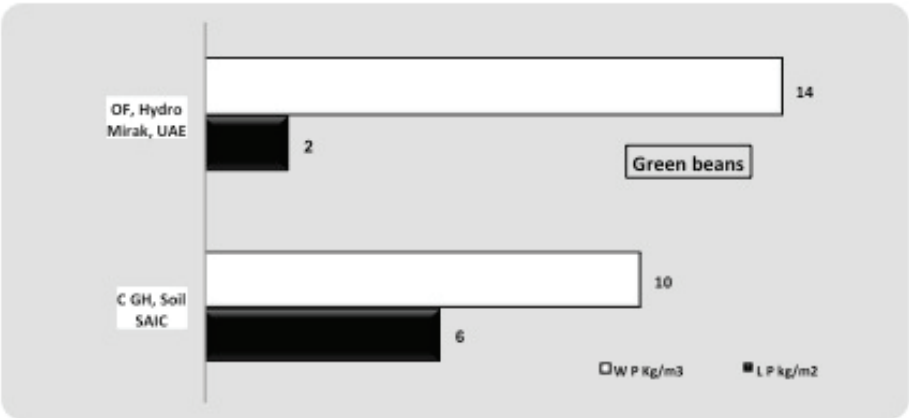

Figure 5. Land and water productivity (LP and WP) of green beans grown in open field (OF) in hydroponics (Hydro) and in conventional soil based production system (Soil) in cooled greenhouse.

Strawberry: Production experience of strawberry under hydroponic system in Kuwait, Oman & UAE is encouraging. Production of strawberry in vertical hydroponics system was introduced

by ICARDA to the region and adopted in a number of countries including Qatar, Bahrain, Oman, Kuwait, and Saudi Arabia (Oraifan & Moustafa 2003). Land productivity was highest under cooled GH with hydroponics (Figure 6). Strawberry production per unit of area in open field hydroponics was 1.5 times that in soil in cooled GH. Water productivity was far greater in the hydroponics in cooled green house than the open field hydroponics and soil GH. To produce 1 ton of strawberries in soil under cooled GH about 507.6m^3 of water was required. The same amount of water would produce 7.9 tons and 3.9 tons of strawberries in cooled GH hydroponics and open filed hydroponics systems, respectively.

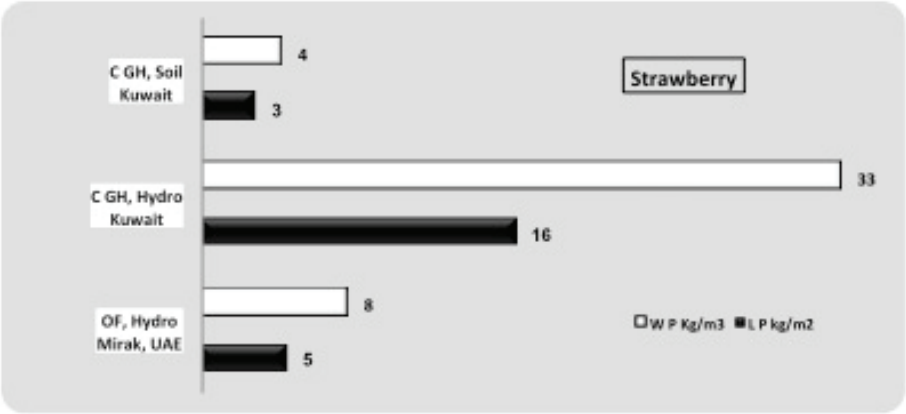

Figure 6. Land and water productivity (LP and WP) of strawberry grown in open field (OF) in hydroponics (Hydro) in Mirak, UAE and in cooled greenhouse in hydroponics and in conventional soil based production system (Soil) in Kuwait.

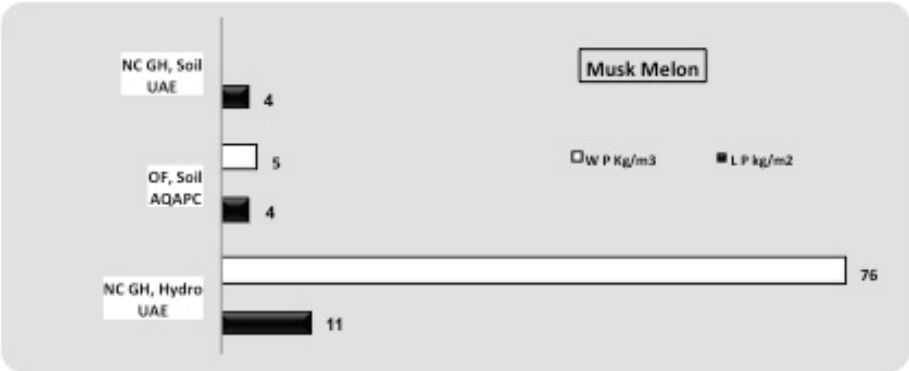

Figure 7. Land and water productivity (LP and WP) of muskmelon grown in hydroponic (Hydro) and soil culture (Soil) in non cooled (NC) greenhouse in UAE and in open field (OF).

Muskmelon is also a successful crop to grow in hydroponics both under GH and in open filed. Productivity per unit of land under hydroponics was 2.7 times that of open field soil-based production. Production of 1 ton muskmelon in open field required 200 m^3 of water. With the same amount of water, hydroponics produced nearly 15 tons produce. Thus, water productivity in non cooled GH hydroponics was 15.2 times that in the soil culture in open field (Figure 7).

Conclusion

For Arabian Peninsula countries food security has become a major issue since 2008, when export restrictions on food were increased significantly by trading partners. At the same time, the

conventional agricultural production systems in the Arabian Peninsula are not able to provide enough food for the rising population of these countries due to low land and water productivity. Major production constraints are the harsh environment, sever water scarcity and lack of arable land. Soilless production techniques under protected agriculture show great potential for improving productivity per unit of water and land in the Arabian Peninsula.

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16. Productivity and water use efficiency of five grasses in United Arab Emirates

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Abstract

Freshwater in the Arabian Peninsula (AP), is scarce and the consumption is high, which has put negative pressure on land resources, agricultural production and public health. A joint research effort between the National Agriculture Research Systems (NARS) of the AP countries and the International Center for Agricultural Research in the Dry Areas (ICARDA) is focusing on identifying new forages that use less water. Collection missions for indigenous plant species were carried out in six AP countries, where seeds of potential forages were collected. In the present paper forage productivity, seed production and water use efficiency (WUE) was determined for two seasons in the United Arab Emirates of: buffel grass (Cenchrus ciliaris L.) also called "labeid", dakhna (Coelachyrum piercei Benth.) Bor, da'ay (Lasiurus scindicus Henr.) and tuman (Panicum turgidum Forssk.) and one exotic species: Rhodes grass (Chloris gayana Kunth). Three irrigation levels were used: W1 (1858-6758 m3 ha-1), W2 (929-3379 m3 ha-1) and W3 (464-1689 m3 ha-1). Buffel grass was the highest producer of dry matter (DM) under all irrigation treatments. The average yield of buffel grass was 14.6 and 15.1 t ha-1 in the two seasons, which was significantly higher than other grasses, while dakhna was the lowest yielder. Buffel grass had the highest WUE values in the two seasons (0.7 and 0.8 kg DM m-3), which were significantly higher than of other grasses. Buffel grass showed the highest increase in WUE in both seasons when irrigation was reduced from W1 to W3. The results suggest that native desert grasses such as buffel grass could replace Rhodes in the cropping system of the Arabian Peninsula in order to save irrigation water. More research is needed in the area of seed production

Introduction

Rangeland degradation in the Arabian Peninsula (AP) has resulted in severe feed shortage over the years and obliged the farmers to grow Rhodes grass and alfalfa. Both forages are produced under high level of irrigation estimated at 48 000 m^3/ha per year (Peacock et al. 2003). Pumping of ground water for irrigation has resulted in lowering of water table in many countries of AP, increased salinity and in severe cases abandonment of farms (Sharaf 2001; Al-Senafy and Abraham 2004; Peacock et al. 2003). In all countries of the Arabian Peninsula, freshwater is scarce and the consumption is high, which has put negative pressure on land resources, agricultural production and public health. For example in United Arab Emirates, M. C. Brook (personal communication) indicated that the current annual water consumption in Abu Dhabi Emirate is 26 times greater than the annual renewable water resources, which has led to heavy reliance on ground water, and water from desalination and sewage treatment plants. Agriculture consumes the majority of water (76%), mostly for forage production and afforestation.

A joint research effort between the National Agriculture Research Systems (NARS) of the AP countries and the International Center for Agricultural Research in the Dry Areas (ICARDA)

is focusing on identifying new forages that use less water in the production process. Under this joint effort, collection missions for indigenous plant species were carried out in 6 AP countries (Bahrain, Oman, Qatar, Saudi Arabia, United Arab Emirates and Yemen), where seeds of potential forages were collected (Osman 2005). Most of these species are being evaluated for their forage and seed production, feed quality and water use efficiency in the respective countries. The present paper reports the performance of four indigenous and one exotic forage grass under the conditions of the United Arab Emirates

Field experiment

The field experiment was conducted at Dhaid Research Station of the Ministry of Environment and Water; United Arab Emirates (25º 16′ N, 55º 55′ E, elevation 135 m). The climate is arid with wide variation in total annual rainfall (35-308 mm in the period 1994-05), falling mostly in winter (January-March). The climatic data for Dhaid over the above period indicate that the monthly average minimum temperature ranges between 11º and 14ºC in January and 26º and 31ºC in July, and the maximum temperature between 23º and 26ºC in January and 42º and 45ºC in July. The minimum relative humidity (RH) ranges between 30 and 58% in January and 20 and 36% in July, and the maximum RH between 78 and 98% in January and 50 and 86% in July. Total rainfall in the years of the study (2002, 2003 and 2004) was 46, 44 and 55 mm, respectively. Soils are coarse, dominated by sand which exceeds 90% in the subsoil at the 30-60 cm depth while the top soil is close to sandy loam with silt around 13%. Soil reaction is alkaline (pH 8.4-9.4) and permeability is high. Soil salinity (EC_e) ranges between 1.9 and 2.5 dS/m. Soil nutrient contents vary between 0.9 to 6.4 mg/kg for N, <1 to 8 mg/kg for P and 15 to 60 mg/kg for K.

The grasses tested were four native species: buffel (also called lebid) grass (*Cenchrus ciliaris* L.); dakhna (*Coelachyrum piercei* Benth.) Bor; da'ay (*Lasiurus scindicus* Henr.); tuman (*Panicum turgidum* Forssk.) together with one exotic species: Rhodes grass (*Chloris gayana* Kunth). The native grasses were originally collected from inside the fence of Sharjah Natural History Museum, 30 km from Sharjah city on the main road to Dhaid. The seeds used for the study were multiplied at Dhaid Research Station. Three levels of irrigation (high-W_1, medium-W_2 and low-W_3) were assigned as main plots (2.5 m x 16.5 m), with the five grasses as sub-plots (2.5 m x 2.5 m) within each main plot. Boarders between sub-plots, main plots and experimental blocks were 1, 2 and 3 m, respectively. The experiment was replicated three times.

All grasses were seeded in jiffy pots and transplanted in April 2002 at 3 seedlings in alternating holes 50 cm apart along drip lines which were 50 cm apart. Drip irrigation was applied daily and measured in minutes day^{-1} (Table 1) during summer (May, June, July, August), winter (November, December, January, February) and spring and fall (March, April, September, October). The irrigation system was tested for uniformity before crop establishment by collecting the water discharged from 5 nozzles taken at random in each main plot. All nozzles were then monitored against clogging throughout the study. The irrigation system was fitted with pump (1.5hp), 2-filters and operated by automatic controller. The amounts of water delivered by the system were calculated from equation 1:

$$Y_{Wn}=(C_m D N T_m)\,(6P)^{-1} \qquad (1)$$

where Y is the amount of water in $m^3\ ha^{-1}$, W is the irrigation treatment and n is 1, 2 or 3. C is the number of days for each harvest, D is the nozzle discharge rate in L h^{-1}(4), N is the number of nozzles per experimental plot (33), T is the irrigation period in minutes based on irrigation

treatment and month of the year, m is the month of the year and P is the plot size (6.25 m^2). Equation (1) was abbreviated to equation (2):

$$Y_{Wn}=3.52\ (CT)_m \qquad (2)$$

The sub-plot treatments were also monitored for soil moisture at 0-30 cm and 30-60 cm depth, using Time Domain Reflectometry (TDR). All grasses were cut down to 5 cm height in May 2002, marking the beginning of the study, and every 5 to 8 weeks (depending on season) thereafter. Grasses were harvested when approximately 10% of the tillers carried flower heads. Forage yield was assessed using sampling areas (1 m x 1 m) permanently located in the center of each plot. The rest of the plot was cut to the same height (5 cm) and discarded after each harvest.

Compound fertilizer supplying 25 kg N ha^{-1} was applied to the plots after each harvest which meant that various amounts of P and K were also applied (depending on fertilizer used). Fertilizers containing the following NPK were used during the study depending on their availability in the Research Station (20-20-20; 28-14-14; 24-12-12; 15-30-15). Forage from the sampling areas of the plots were oven dried (70ºC) and weighed. Ten forage harvests were taken during 2002/03 and 2003/04 seasons. After the last forage harvest in May 2004, all plots were cut to 5 cm height, fertilized and monitored for seed production under the same irrigation treatments till May 2005. Observations on seed production included flower head count on weekly basis for 9 weeks during May-July 2004, September-November 2004 and March-May 2005. Each period, the plots were monitored daily for flower heads leaving untouched flower heads on the sampling areas while cutting and discarding the rest from the plot. Seed production was assessed in September 2004, January 2005 and June 2005 after the periods of flower counts. Seed sample consisted of plants and sweeping the ground of the sampling area. Samples were sun-dried and manually threshed with subsequent counting of seeds.

Table 1. Drip irrigation periods in minutes day-1 at different months of the year for treatment W1 (1858-6758) m^3 ha^{-1} $year^{-1}$, W2 (929-3379) m^3 ha^{-1} $year^{-1}$ and W3 (464-1689 m^3 ha^{-1} $year^{-1}$)

Months			
Irrigation treatments	November, December, January, February	May, June, July, August	March, April, September, October
W1	16	48	32
W2	8	24	16
W3	4	12	8

Results

Water application

Total irrigation water applied during the two years ranged between 1858 and 6758 m^3 ha^{-1} under treatment W1 depending on the month of the year. The values for treatment W2 ranged between 929 and 3379 and for W3 464 and 1689 m^3 ha^{-1}. Total water application reflects the crop

water requirements during the year with June-July having the highest water requirements while November-December the lowest. Crop age (C) too, was influenced temporally by month of the year. In winter (November-December) the crop took longer time (42 to 47 days) to be ready for harvest compared with 32 to 36 days in other months of the year. These differences were also reflected in water application between seasons for the same forage cut (Table 2). In the 6th cut the crop was harvested in 47-days in the first season and 42-days in the second, while in the 9th cut it was harvested in 32-days in the first season and 37-days in the second. Water application was the same during the 2nd and 4th cut for both seasons under the same level of irrigation due to forage being harvested at the same age (36-days).

Table 2. Total dry matter production (t ha^{-1}) of five grasses as affected by 3 levels of irrigation (W1-W3) during two seasons*

Grasses	W1		W2		W3		Grass mean	
	Season1	Season2	Season1	Season2	Season1	Season2	Season1	Season2
Buffel grass	20.3	19.0	14.8	16.5	8.8	9.8	14.6	15.1
Rhodes grass	19.3	19.1	11.1	12.2	5.2	8.1	11.9	13.1
Tuman	15.6	9.1	14.4	7.8	6.0	5.5	12.0	7.4
Da'ay	14.3	10.2	10.0	6.1	4.1	4.8	9.4	7.0
Dakhna	13.4	5.2	8.9	4.1	4.0	3.3	8.8	4.2
Mean	16.6	12.5	11.8	9.3	5.6	6.3		

** Data represent ten cuts in the first season and nine cuts in the second season*

	Season 1	*Season 2*
s.e. of mean of grass species	*0.74*	*0.70*
s.e. of mean of irrigation treatment	*0.57*	*0.54*
s.e. Grasses mean within Irrigation level	*1.27*	*1.22*

Dry matter production

Total dry matter production (cumulative of ten cuts in the first season and nine in the second) indicated that buffel grass was significantly higher in yield than all other grasses during the two seasons (Table 2). The distribution of DM production on monthly basis differed with the grass species. Buffel and Rhodes grasses were generally high DM producers all year round. Buffel was the highest producers of all grasses in 7 out of 10 sampling dates in the first season and in 5 out of 9 in the second season. Tuman and da'ay were high producers in May through October but the yield dropped gradually during the relatively cool time of year (December-March). Dakhna was generally the lowest DM producer of all grasses most of the months in the year especially in the second season.

Water use efficiency

Buffel (lebid) grass had significantly greater water use efficiency (WUE) than the other grass species with average values 0.7 and 0.8 kg DM m^{-3} in year 1 and 2, respectively (Table 3). As the amount of irrigation dropped from treatment W1 to W3, the grasses showed increased WUE values but the magnitude was different among the species. While Rhodes grass showed no change in WUE in the first season because of irrigation treatment, and an increase of 0.4 kg DM m^{-3} (69%) in the second season between treatment W3 and W1, all other grasses except dakhna showed greater WUE values. The increases for buffel grass were 0.4 kg DM m^{-3} (74%) and 0.6 kg DM m^{-3} (106%) in the 2 seasons. Similarly for da'ay and tuman the increase ranged between 0.1 kg DM m^{-3} (17%) and 0.2 kg DM m^{-3} (53%) in the first season and between 0.2 kg DM m^{-3} (86%) and 0.4 kg DM m^{-3} (140%) in the second season.

Table 3. Water use efficiency (kg DM m^{-3} of water) in five grasses as affected by 3 levels of irrigation (W_1-W_3) during two seasons*

Grasses	W1		W2		W3		Grass mean	
	Season1	Season2	Season1	Season2	Season1	Season2	Season1	Season2
Buffel grass	0.50	0.52	0.74	0.90	0.87	1.07	0.70	0.83
Rhodes grass	0.48	0.52	0.55	0.67	0.52	0.88	0.52	0.69
Tuman	0.39	0.25	0.71	0.43	0.60	0.60	0.57	0.42
Da'ay	0.35	0.28	0.50	0.33	0.41	0.52	0.42	0.38
Dakhna	0.33	0.14	0.44	0.22	0.40	0.36	0.39	0.24
Mean	0.41	0.34	0.59	0.51	0.56	0.69		

** Data represent mean for ten cuts in Season 1 and nine cuts in Season 2.*

	Season 1	*Season 2*
s.e. of grass species mean	*0.040*	*0.040*
s.e. of mean of irrigation treatment	*0.031*	*0.031*
s.e. of mean of grass species within treatment	*0.069*	*0.069*

Seed production

Flower heads appeared earlier on indigenous species than Rhodes grass and increased faster throughout the year with the maximum numbers recorded in March-May. Rhodes grass was the lowest in flower heads of all grasses throughout the year, while tuman was the highest followed by buffel grass during September-November and March-May periods. Tuman on the other hand was the highest of all grasses in seed production (seeds m^{-1}) in January and June harvests (Table 4). The difference in seed production was not significant over rhodes grass in Sep 2004 or buffel grass in June 2005. Da'ay and dakhna were poor seed producers both in September and January and improved somewhat in June harvest (Table 4).

Table 4. Number of seeds m^{-2} at different times of the year (average of three irrigation levels) in five grasses during 2004 and 2005 at Dhaid, UAE

Grasses	Time of the year					
	Sep 2004		Jan 2005		June 2005	
	Swept seed number	**Total seed number**	**Swept seed number**	**Total seed number**	**Swept seed number**	**Total seed number**
Buffel grass	7	40	54	289	407	577
Rhodes grass	0	378	0	985	0	39
Tuman	326	350	2584	2632	721	806
Da'ay	4	49	5	53	4	122
Dakhna	0	29	0	71	0	202
s.e.	*64.8*	*103.6*	*443.6*	*455.0*	*162.0*	*176.2*

Discussion

In this study buffel grass was the highest DM producer throughout the year. This is in agreement with previous results suggesting that irrigated buffel grass is well adapted to frequent defoliation (Osman 1979; Osman and Abu Diek 1982). Ability to withstand frequent defoliation is believed to be related to carbohydrate reserves in the root system of perennial grasses. Humphreys (1967) indicated that buffel grass produces more leaf and tiller growth than Rhodes grass following defoliation due to the higher accumulation of carbohydrates in stem bases and roots of the former species. Dakhna in this study did not tolerate the frequent cutting imposed and was the lowest DM producer especially in the second season. The highest mean DM of all grasses was under high irrigation (W1), which was 16.6 and 12.5 t ha^{-1} in season 1 and season 2, respectively. Yield dropped respectively by 29% and 66% under R2 and R3, in season 1 and 26% and 50% in season 2. The magnitude of reduction in dry matter was much less in the indigenous species compared with Rhodes grass (9.4 to 11.5 kg DM ha^{-1} in season 1 and 1.9 to 9.2 kg DM ha^{-1} in season 2 for indigenous grasses compared with 14.1 and 11.0 kg DM ha^{-1}for Rhodes grass in the two seasons).

Buffel grass was the highest in water use efficiency of all grasses in the summer through winter (June-December), a feature extremely important in the dry areas particularly in the Arabian Peninsula due to water shortages. Hamblin and Tennant (1987) attributed drought tolerance in cereals to rooting depth. The root system in buffel grass constitutes a relatively high proportion of the total dry weight (Humphreys and Robinson 1966; Burt1968). Buffel grass showed the highest increase in WUE when irrigation was reduced from W1 to W3. Singh and Singh (1997) reported increased water use efficiency of *Lasiurus scindicus* from 9 kg DM/ha/mm to 21 kg, as rainfall decreased from 326 mm to 144 mm in Jodhpur, India.

Indigenous grasses produced more flower heads than Rhodes grass throughout the year but it seems a lot of these flowers were either shed or did not produce seeds. Yadav and Singh (1997) reported that seed shedding and lack of uniformity of seed maturity were the major problems

faced when producing seeds of sub-tropical grasses such as *Lasiurus scindicus* and *Cenchrus ciliaris*. In the present study most seeds were obtained after sweeping the ground. Seed sizes of the indigenous grasses were different as indicated by the seed count per gram of seeds. Dakhna had the highest number of seeds per gram (2076) followed by buffel (1056), tuman (200) and da'ay (152). It must be noted that these sizes represent a handling problem during harvest and sowing. For example we estimated a seed rate of 60 g $ha^{-1}$for dakhna, 120 g ha^{-1} for buffel, 200 g ha^{-1} for tuman and 270 g ha^{-1} for da'ay but it is rather impossible to obtain uniform distributions of these quantities during manual sowings of the forage crops. It is expected therefore that farmers would use husk seeds (seed enclosed in glumes and bristles) rather than pure seeds in the near future. It is important therefore to identify husk seeds which contain the maximum number of seeds. Table 4 suggests that the maximum number of seed is contained in January harvest for tuman and rhodes grass while June harvest is the best for buffel, da'ay and dakhna.

The study suggest that grass seed production is possible under the dry conditions of the Arabian Peninsula, however more research is needed to identify proper machinery for sowing, pellet making and harvesting. Moreover much effort is needed to make the seed production an attractive investment for private farmers. Without sufficient seeds in the market the new forages with valuable traits, such as buffel grass, will not find their way to farmer's fields.

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17. Approaches and efforts on mitigating aeolian desertification in northern China

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Abstract

Desertification is damaging the drylands that cover approximately 41% of the land surface of the world and are home to more than 38% that of the current total global population. Some efforts have been made to combat desertification worldwide. This paper reviews some typical field experiments and regional case studies of combating aeolian desertification in the agro-pastoral ecotone of northern China. Basing on the research results, this paper concludes that (1) the rehabilitation of arid human-environmental (H-E) ecosystems is a slow and long-term process; (2) the external input in the arid H-E ecosystem is necessary for combating desertification; and (3) the regional differences and complexity within the arid H-E ecosystem have to be taking into account to develop and implement strategies that can control desertification.

1. Introduction

As one of the most important social, economic and environmental problems in today's world, land degradation/desertification occurs everywhere, but is most damaging in the drylands that cover approximately 41 % of the land surface of the world (hyper-arid areas included) and are home to more than 38% of the total global population of 6.5 billion (MEA 2005; Reynolds et al. 2007; UNCCD 2008). According to the Millennium Ecosystem Assessment (2005), 10-20% of drylands is already degraded (medium certainty) and over 250 million people are already directly affected by land degradation in the developing world, an estimate likely to expand substantially in the face of climate change and population growth (Reynolds et al. 2007; UNCCD 2008). Therefore, the control and rehabilitation of desertified land is crucial to meet the need of the growing human population for food, feed, biomass energy, fiber and timber (Daily 1995), as also to meet the need of keeping the stability of dryland ecosystem in the face of global climate change.

For past 20 years, some efforts have been made to combat desertification with worldwide scope. The United Nations has periodically focused on desertification and drylands, notably adopting the Convention to Combat Desertification (CCD) in 1992 (UNCCD 1994) and designating 2006 as the International Year of the Desert and Desertification. The immediate goals of UNCCD (1994) are (i) prevention and/or reduction of land degradation; (ii) rehabilitation of partly degraded lands; and (iii) reclamation of desertified land. However, recent advances in preventing and reversing desertification, are embedded more in the integrative and systematic theory approaches and multi causal factors analysis (Geist and Lambin 2004; MEA 2005). For example, through the study of coupled human-environmental (H-E) systems, Reynolds et al. (2007) presented a new synthetic framework, the Drylands Development Paradigm (DDP), which consists of five principles and supported by a growing, and well-documented, set of tools for policy and

management action to help navigating the inherent complexity of desertification and dryland development, and identifying and synthesizing those factors important to research, management, and policy communities.

Similar to other countries, desertification plagues almost all arid, semi-arid and sub humid areas of the northern China and has become a challenge that more 200 million people in more than 1.6 million km^2 area are facing (Zhu and Wang 1993; Zhu and Chen 1994; Wang et al. 2008a). The direct and indirect economic loss by the desertification was estimated to be more than 54 billion Chinese Yuan (USD $6.75 billions) per year in northern China (http://www.cpirc.org.cn/rkkx/2003_3.htm 2003).

There are mainly three different kinds of desertification processes in China (Zhu and Wang 1993). The first is the land degradation which results from wind erosion (which is called aeolian desertification); the second is water and soil loss resulting from water erosion; and the third is salinazation caused by unsustainable irrigation and management practices. Of the three processes, aeolian desertification is dominant and it accounted for 46% of the total desertified area in early 1990s (Zhu and Chen 1994) and more than 84% of the total desertified area in early 2000s (SFAC 2005; Wang et al. 2008a).

Aeolian desertification has developed mainly in the agro-pastoral ecotone, nomadic zones, and inland river basins and oasis in northern China in the past 50 years. The total aeolian desertified areas in northern China was 0.137 million km^2 in 1955, increased to 0.176 million km^2 in 1975 and 0.334 million km^2 in 1987, and reached 0.386 million km^2 in 2000 (Wang et al. 2004a). On average, the desertified land increased at a rate of 1,560 $km^2\ yr^{-1}$ from 1955 to 1975, and 2,100 $km^2.yr^{-1}$ from 1976 to 1987, and 3,600 $km^2.yr^{-1}$ from 1988 to 2000 (Wang et al. 2004b). Although aeolian desertification in northern China still remains a major environmental problem, impeding local development, there are also some projects and community-based initiatives which have successfully addressed these problems. For example, in past 20 years, some reversal of desertified lands has occurred in some regions of agro-pastoral zone, due to several sustainable and effective measures adopted there (Xue et al. 2005).

Desertification is caused by a combination of factors that change over time and vary by location. The prevention and reversal of desertification should therefore also be diverse in different situations of time and space. This paper reviews the issues on local aeolian desertification and some efforts that link dryland ecosystem management with human livelihoods in northern China and aims to provide the regional-scale case studies that might support the theoretic approaches of desertification prevention and reversal on global scale.

2. Aeolian desertification description in agro-pastoral ecotone of northern China

2.1. Sites

The agro-pastoral ecotone of northern China is the transition zone from cropping to grazing, which is interlaced spatially with pasture and cropland, and overlaps temporally with agriculture and pastoral uses. In different historical periods, the scope of the agro-pastoral ecotone shifted constantly due to climate change and successive changes in the control over the region by Han and nomadic minority nationality (Zhu and Chen 1994). The Great Wall, stretching along the 400 rainfall isohyets in northern China, marks the boundary between semi arid zone and sub humid

zone, loess soil and aeolian soil, Han and nomadic minority nationality in history, sedentary agriculture and nomadic pasture, which was ever the north boundary of the agro-pastoral ecotone before AD18 (Zhao et al. 2003). At present, the agro-pastoral ecotone is mainly distributed to the north of the Great wall, between 200 mm and 450 mm isohyets of northern China, and consists of (1) the Horqin region located in southeastern Inner Mongolia and western Jilin and Liaoning Provinces, including 13 counties of Inner Mongolia (Balinzuo, Balinyou, Aluhorqin; Wongniute, Aohan, Tongliao, Zhalute, Keyouzhong, Kailu, Kulun, Naiman, Kezuozhong, Kezuohou), two counties of Jilin Province (Tongyu and Shuangliao), and two counties of Liaoning Province (Zhangwu and Kangping); (2) the regions in southern Inner Mongolia and northern Hebei Province (SIM & NH), including 12 counties of Inner Mongolia (Huade, Shangdu, Chayouhou, Chayouzhong, Siziwang, Damao, Wuchuan, Taibushi, Duolun, Zhenglan, Zhengxiangbai, Xianghuang), and six counties of Hebei Province (Kangbao, Kuyuan, Shangyi, Zhangbei, Fengning, Weichang); and (3) the Ordos region located among southwestern Inner Mongolian, northern Shanxi Province and eastern Ningxia Province, including eight counties of Inner Mongolia (Dalate, Zhunger, Dongsheng, Yijinhuoluo, Hangjin, Etuoke, Etuokeqian, Wushen), and 7 counties of Shanxi Province (Shenmu, Fugu, Yulin, Hengshan, Jingbian, Dingbian, Jiaxian), and one county of Ningxia Province (Yanchi) (Fig. 1). Almost all of these regions were nomadic pastures 200 years ago.

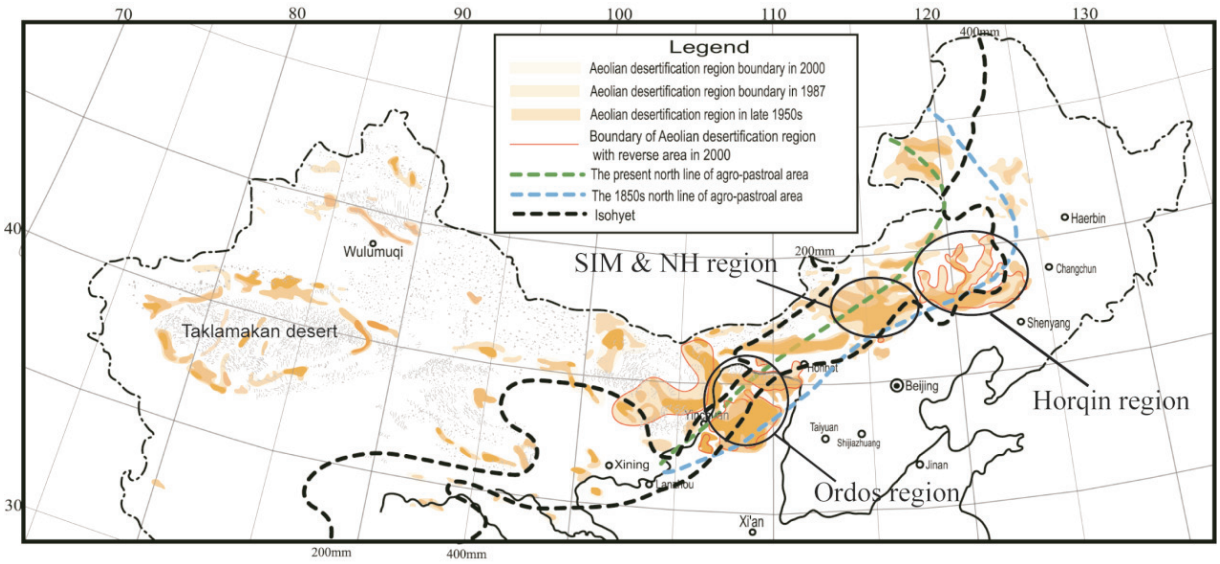

Figure 1. The location of study area and distribution of aeolian desertified land in north China.

2.2. Physical features and climate change

In agro-pastoral ecotone of northern China, 80% of rainfall is concentrated in summer; annual rainfall varying from 150-200 mm in the west to 400-450 mm in the east (Fig. 2 and Table 1). Strong winds with velocities above the threshold blown sand ($\geq$5 m s^{-1}) and drought always occur simultaneously in dry spring and winter (Table 1). Most of the soil consists of Quaternary loose sandy deposits from ancient river courses (Fig. 3), which is very prone to wind erosion, once the original vegetation is removed. The natural vegetation gradually transitions from typical temperate grassy steppe on the eastern parts of study area into temperate desert steppe with drought-tolerant vegetation in the west.

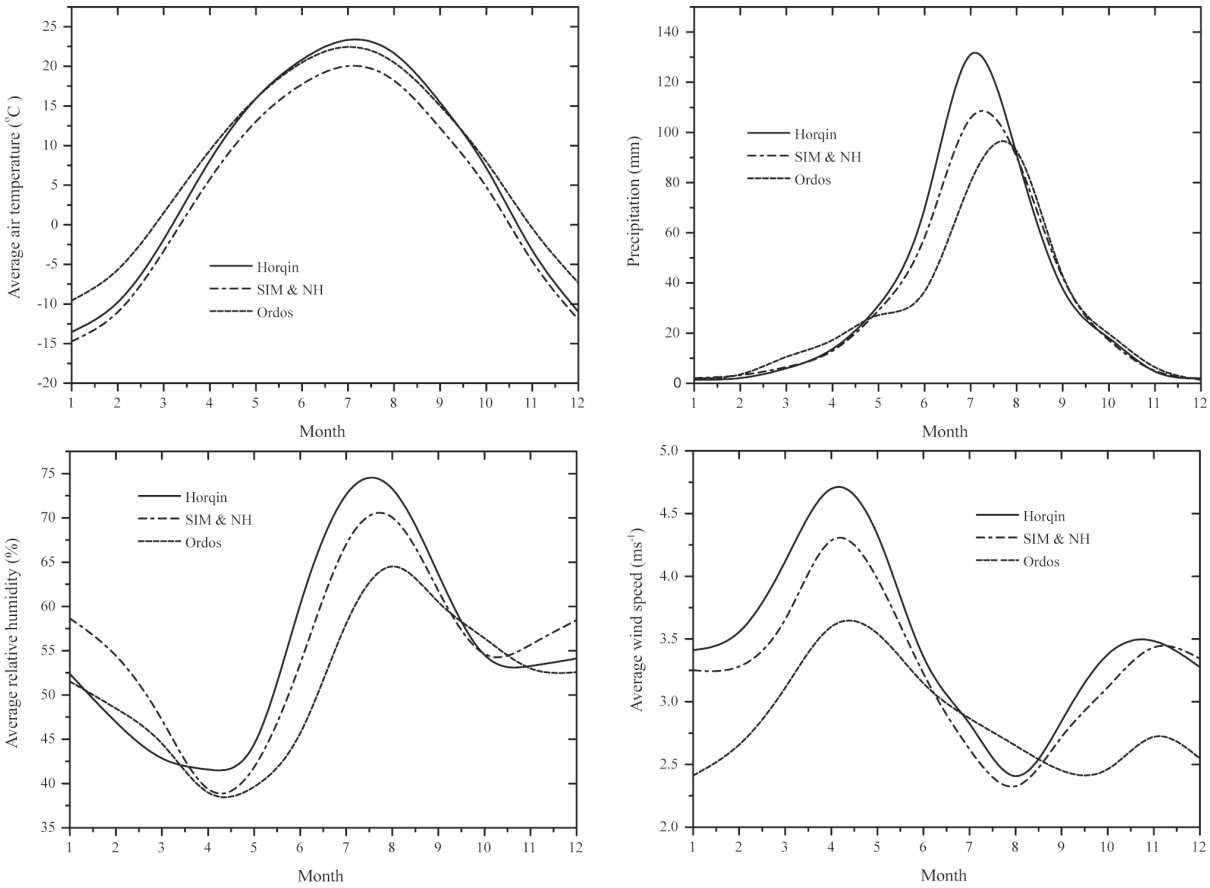

Figure 2. Climate features basing on data recorded by 21 local meteorological stations in Tongliao, Shuangliao, Kailu, Tongyu, Balinzuo, Zhalute, Wongniute, Zhangwu of Horqin region, Fengning, Weichang, Damao, Siziwang, Huade, Duolun, Zhangbei of SIM & NH region and Etuoke, Yijinhuoluo, Yulin, Yanchi, Dingbian, Hengshan of Ordos region (record period: as shown in Table 1).

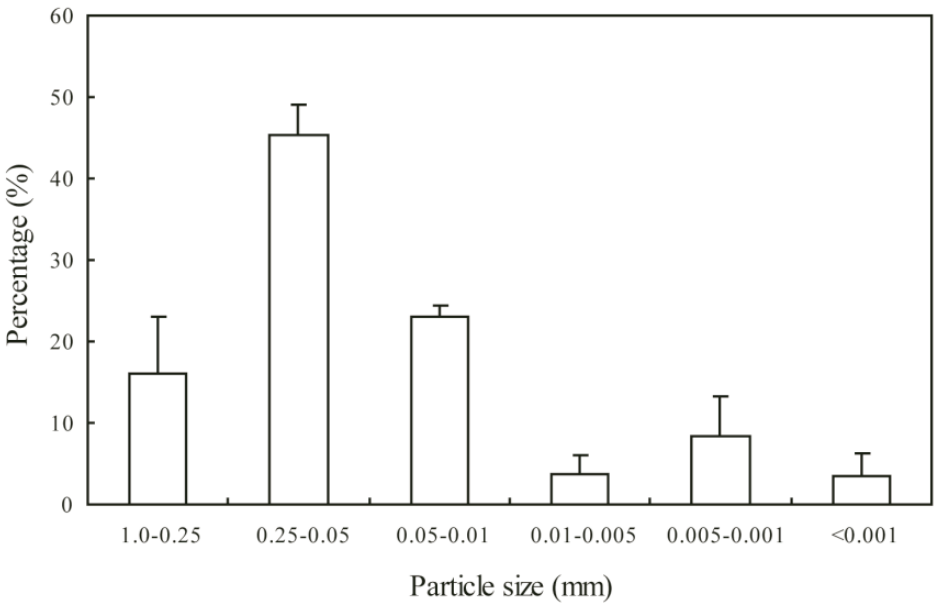

Figure 3. The average distribution of 0-20 cm depth soil particle size in study area (data source: Zhu & Liu 1980).

Table 1. Climate characters in some counties of the study area

Regions	Counties	Record Period	Annual Average Temperature (℃)	Annual precipitation (mm/yr)	Annual Average Relative Humidity (%)	Annual Average Wind Speed (m/s)	Annual Average Strong Wind Frequency (times) *	Strong Wind Frequency Ratio of Spring to Full Year (%)*	Humidity Index (P/E) △
Horqin	Balinzuo	1953-2005	5.2	383.3	51.76	2.8	148.7	36.4	
	Wongniute	1957-2000	6.2	371.3	47.94	3.0			0.15
	Tongliao	1951-2005	6.4	385.6	55.87	3.8	145.8	37.8	0.21
	Zhalute	1952-2005	6.4	383.7	49.77	3.0	96.6	39.1	
	Kailu	1953-2000	7.5	340.7	53.51	4.1			
	Tongyu	1955-2000	5.4	403.1	57.22	4.0			
	Shuangliao	1953-2000	5.9	471.5	62.90	3.5			
	Zhangwu	1953-2000	7.3	512.7	60.28	3.7	156.8	39.7	
SIM & NH	Huade	1953-2005	2.5	327.8	56.56	4.4	196.1	31.9	
	Siziwang	1959-2000	3.3	313.2	53.18	3.8			0.12
	Damao	1953-2005	4.0	257.8	49.03	3.9	179.2	30.0	
	Duolun	1953-2005	2.1	385.8	61.43	3.5	198.1	33.3	0.24
	Zhangbei	1989-2000	4.4	403.1	56.72	3.4			
	Fengning	1956-2000	6.6	477.9	54.08	2.1			
	Weichang	1951-2000	5.0	449.4	55.99	1.8			
Ordos	Yijinhuoluo	1959-1994	6.3	339.0	50.76	3.3			
	Etuoke	1955-2005	6.9	266.6	47.15	3.0	137.0	33.5	0.12
	Yulin	1951-2000	8.2	394.1	56.43	2.1	70.9	43.6	0.23
	Hengshan	1954-2000	8.7	371.6	51.95	2.4			
	Dingbian	1960-2000	8.2	318.5	51.67	3.1			
	Yanchi	1954-2005	8.1	291.9	50.11	2.7	98.8	35.0	0.15

* Strong wind means wind with a velocity of ≧8 m/s， data record period: 1971-2008; △ P/E means the ration of annual average precipitation to annual average evaporation, data are from Zhu and Liu (1980)

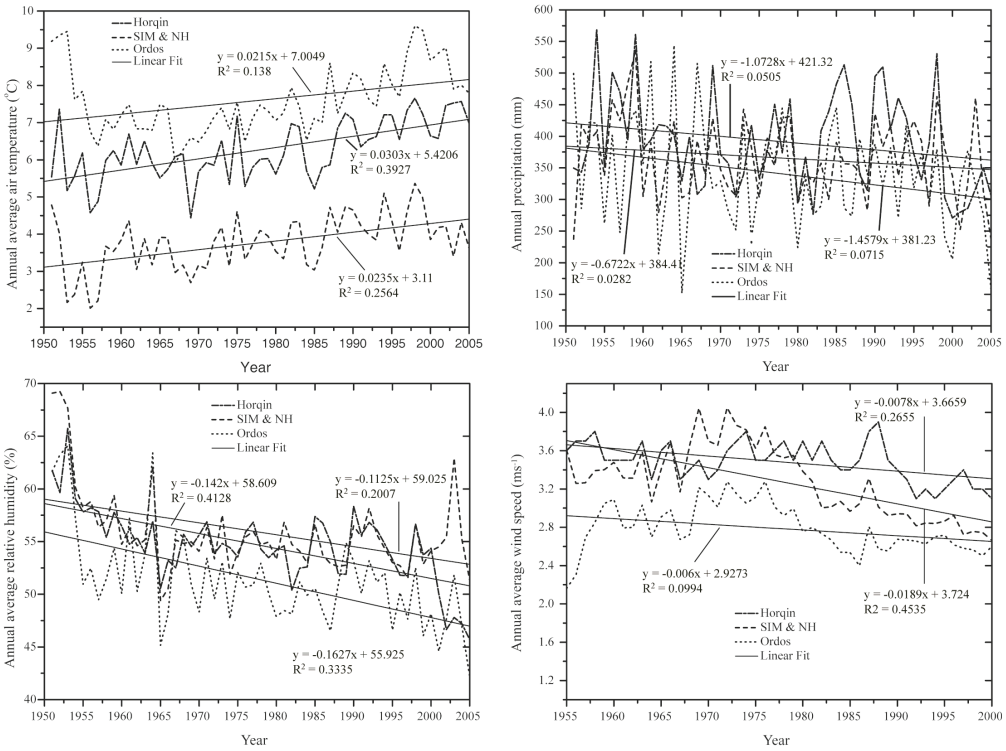

Figure 4. Climate changes basing on average values from meteorological data recorded in Aluhorqin (1959-1998), Kailu (1953-2000), Shuangliao (1953-2000), Wongniute (1957-2000), Zhangwu (1953-2000), Tongyu (1955-2000), Balinzuo (1953-2005), Balinyou (1959-1998), Aohan (1957-1998), Tongliao (1951-2000), Zhalute (1952-2005), Naiman, (1961-2005), Fengning (1956-2000), Weichang (1951-1995), Zhangbei (1989-2000), Siziwang (1959-2000), Damao (1954-2005), Duolun (1953-2005), Huade (1953-2005), Dongsheng (1957-2000), Yijinhuoluo (1959-1992), Etuoke (1955-2005), Dalate 1957-1980), Zhunger (1959-1980), Hangjin (1959-1980), Wushen (1959-1980), Yulin (1951-2000), Hengshan (1954-2000), Jingbian (1966-2000), Dingbian (1960-2000), Yanchi (1954-2005).

Meteorological data recorded by 31 local meteorological stations reveal that there are same climate trends of warming and increased aridity in the three regions of the study area in the past half century (Fig. 4). From 1950 to 2005, air temperature had a linear increase of 0.8°C; precipitation showed a decrease of 30 mm; and atmospheric average relative humidity decreased by about 4%. Average wind speeds in study area also showed a mild trend of weakening from 1955 to 2000.

2.3. Human activity

The inhabitants of the agro-pastoral ecotone 200 years ago had been pastoral minority people and grazing had been dominant, because strong winds, drought, and loose soil surface were not conductive to sedentary cultivation. In the early Qing Dynasty, the steppes in the study area were the royal rangelands kept in good condition due to the policy of 'forbidding farming', although scattered conversion to farmland also existed at that time (Zhu and Chen 1994). However, farmland landscapes gradually became dominant in the study area after several large scale conversion events (Table 2). In Inner Mongolia alone, farmland increased from 50,200 km^2 in 1952 to 82,000 km^2 in 1998 (http://old.fon.org.cn/index.php?id=3189). In the Ordos region, the converted area was 1,150 km^2 from 1915 to 1928, and reached 13,330 km^2 in 1949 (Yang and Ta 2002). In the six counties of north Hebei Province, farmland increased from 3,700 km^2 in 1948 to 7,300 km^2 in the late 1980s and natural pasture area decreased from 8,700 km^2 to 2,700 km^2 in late 1980s (Han and Han 2003; Sheng et al. 2003). Due to the fragile environment mentioned above, farmland had to be abandoned after several years of cultivation. For example, the accumulated converted area was 700 km^2, but the reserved farmland only was 300 km^2 after the three conversion events of 1955-1956, 1958-1962, and 1970-1973 in Yijinhuoluo county located in the Ordos region (Jia et al. 2003).

As a consequence, conversion extended the farmland northwestwards and pushed north the boundary of the historical agro-pastoral ecotones at an average of 180-220 km into typical steppe or desert steppe after several conversion events (Wang et al. 2008b).

2.4. Aeolian desertification processes

The human-induced changes in the land-use patterns destroyed vegetation and created favorable conditions for erosion of loose sandy soil under spring strong wind and drought in the study area. Especially, spring plowing in sandy steppe allowed the fine soil particles and soil organic matter to be eroded by strong wind (Fig. 5), which resulted in the formation and exacerbating of aeolian desertified farmland with rough surface and infertile soil (Table 3). During the conversion of the mid-1970s to the 1980s, farmlands encountering wind erosion in the study area increased at a rate of 387.2 $km^2\ yr^{-1}$ (Zhu and Chen 1994).

Conversion not only induced the formation of aeolian desertified farmlands but caused overstocking of the remaining pasture due to the gradually diminished grassland area and increased livestock number. The overstocking of pasture usually reached over 50% in the study area (Zhu and Chen 1994). With a humidity index (the ratio of actual precipitation and actual evaporation) of 0.20-0.50, an area of 0.04 km^2 of temperate steppe, with some predominate species of *Gramineae,* is necessary to graze one mature sheep unit. In the early 1950s in the study area each mature sheep unit had only 0.03 km^2 of grassland, which decreased in the late 1970s to 0.01 km^2 (Zhu and Chen 1994). Such livestock pressure resulted in quantitative and qualitative degradation of steppe (Table 4).

Table 2. Several large scale conversion events in the study area

Regions	Dates	Counties	Sponsors	Motivation	Consequences	Citation
Horqin	1750-1876	Kulun, Kezuohou, Tongliao	Qing Dynasty government	Increase national income	North boundary of agr-pastoral ecotone moved northward for 390 km in west part and 244 km in east part of this region since since 1700s	Zhao et al., 2003
	1877-1911	Kezuozhong, Keyouzhong, Zhalute	Qing Dynasty government	Resolved the huge international war debt		
	1912-1925	Aluhorqin, Balinzuo, Balinyou	Minguo government	Increase national income		
	1931-1945	Wongniute, Aohan, Naiman	Private companies	Increase private income		
	1949-1952	Whole region	Chinese central government	Resolved the problem of food		
	1958-1960	Whole region	Chinese central government	Implemented the policy of increasing the product of land		
	1966-1976	Whole region	Chinese central government	Implemented the policy of converting pasture into agriculture		
	1982-2000	Whole region	Chinese central government	Implemented the policy of the household contract responsibility		
SIM & NH	1877-1911	Kangbao, Kuyuan, Shangyi, Zhangbei, Fengning, Weichang	Qing Dynasty government	Increase national income	Farmland percentage increased from 5% of 1700s to above 60% of 1980s in this region	Zhu and Chen, 1994
	1912-1925	Huade, Shangdu, Chayouhou, Chayouzhong, Siziwang, Damao, Wuchuan, Taibushi,	Private companies and catholic churches	Increase private income		
	1937-1945	Duolun, Zhenglan, Zhengxiangbai, Xianghuang	the Japanese government	Provided food provision for the Japanese army in China		
	1953-1956	Whole region	Chinese central government	Implemented State policies of the cooperative transformation of agriculture		
	1958-1960	Whole region	Chinese central government	Implemented the policy of increasing the product of land		
	1966-1976	Whole region	Chinese central government	Implemented the policy of converting pasture into agriculture		
Ordos	1902-1911	Dalate, Hangjin	Qing dynasty government	Reslove military requires	Conversion rate from grassland to farmland increased 0.85% in late 1900s to 11.11% in 1949, and the total conversion area was 133 0000 ha	Song and Zhang, 2007
	1912-1922	Yijinhuoluo, Wushen, Etuoke	Minguo government	Increase national income		
	1953-1956	Whole region	Chinese Central government	Implemented State policies of the cooperative transformation of agriculture		
	1958-1960	Whole region	Chinese central government	Implemented the policy of increasing the product of land		
	1966-1976	Whole region	Chinese central government	Implemented the policy of converting pasture into agriculture		

The particles eroded by wind can be transported and accumulated far downwind. The fine particles and clay easily ascend into the air currents and form the dust storms in downwind areas. Although there is not yet conclusive evidence, the study area is considered to be one of the sources of dust origin for the Beijing area, which now has frequent dust storms. Furthermore, sand particles move downwind along the land surface and form sand patches or active dunes

when they encounter barriers. After long periods of wind erosion, only coarse gravel without productivity or some aeolian landforms such as Yardangs or gravel lands remain. The aeolian desertified land area in the study area has increased at an annual mean rate of 2103.2 km^2 from 1970s to 1980s and reached a total of 121,900 km^2 in 1987, 40.5% of the total aeolian desertified land area of Northern China (Zhu and Chen 1994). These changes in typical counties can be seen in Table 5.

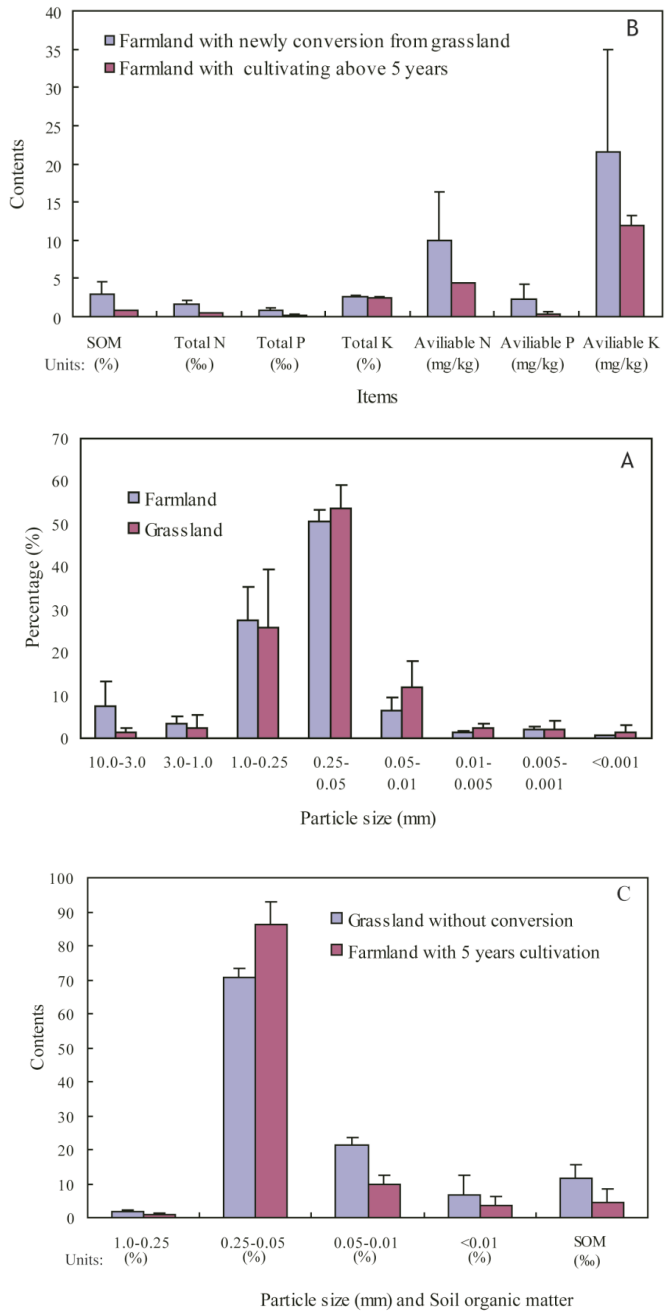

Figure 5. The changes in the soil particle size distribution in 0-20 cm depth after conversion from grasslands to farmlands (A) and soil nutrition changes (B) in SIM & NH region (Zhu & Chen 1994); the changes of soil particle size distribution and soil organic matter after 5 years cultivating in grassland in Ordos region (C) (Zhu & Liu, 1980).

Table 3. Soil particle size distribution and soil organic carbon and total N content in different types of aeolian desertified farmlands in Horqin region (NADF: non desertified; LADF: lightly desertified; MADF: moderately desertified; SADF: severely desertified; VSADF: very severely desertified farmland; SOC: soil organic carbon; Values are means±SD. Values with the same letters are not significantly different at P < 0.05; Data source: Zhao et al. 2003)

Farmland type	Soil particle size (mm) distribution (%)							SOC ($g\ kg^{-1}$)	Totol N ($g\ kg^{-1}$)	C/N
	2-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.002	<0.002			
NADF	0.6±0.5	6.6±2.8b	20.3±8.8b	41.4±7.1b	12.2±1.1a	12.2±1.6a	7.0±1.7a	6.48±0.64a	0.85±0.15a	7.77±0.93
LADF	0.6±0.6	7.0±3.7b	22.8±9.7b	42.6±10.8b	11.4±2.9a	9.6±1.8b	5.9±2.1a	5.68±1.02ab	0.72±0.14b	7.91±0.38
MADF	0.6±0.5	6.2±3.3b	17.1±4.8b	52.9±7.7a	10.3±1.2a	8.1±1.6b	5.1±2.9ab	5.04±0.81b	0.64±0.12b	7.92±0.85
SADF	0.5±0.2	8.7±3.3b	22.5±3.5b	53.6±6.9a	6.3±1.5b	5.5±1.6c	3.0±1.1bc	3.92±1.32c	0.47±0.12c	8.12±0.96
VSADF	0.4±0.3	18.3±6.1a	33.9±2.3a	33.9±7.3b	3.1±1.9c	2.1±1.5d	2.1±1.0c	2.31±0.66d	0.31±0.08d	7.3±1.13

Table 4. Changes in ecological system factors after 5 years of different grazing treatments in Horqin Region

Items	Treat-ments	1992	1993	1994	1995	1996
Vegetation coverage (%)	NG	70.0±5.0	80.3±10.6	89.0±14.9	78.7±24.1	84.3±6.0
	LG	26.7±2.9	62.3±5.0	75.0±8.9	59.3±6.0	81.0±3.6
	MG	36.7±30.6	64.3±30.4	46.3±25.1	48.0±22.0	47.7±15.1
	OG	29.0±12.8	34.7±4.7	28.7±44.5	24.0±35.6	10.1±17.3
Vegetation height (cm)	NG	33.2±8.0	24.9±6.2	33.7±5.8	20.4±4.1	33.1±14.1
	LG	10.6±3.6	13.7±3.1	26.3±7.7	17.1±7.6	18.7±3.2
	MG	7.2±1.7	13.0±4.1	10.8±4.2	5.3±10.2	16.6±11.2
	OG	5.9±3.3	4.0±0.7	3.0±0.6	1.5±1.0	1.0±0.6
Aboveg-round biomass ($g\ m^{-2}$)	NG	266±62	347±271	335±108	220±58	242±44
	LG	70±40	117±33	158±19	192±47	218±52
	MG	98±75	113±97	86±87	57±20	67±40
	OG	38±16	27±10	24±37	24±37	3±6
Net prima-ry produc-tivity ($g.\ m^{-2}$)	NG	266.1	347±272	335±108	220±58	242±44
	LG	198.9	242±39	280±91	263±102	246±102
	MG	246	212±118	213±114	127±41	152±96
	OG	204.6	187±24	112±100	155±149	120±206

NG means no grazing with 0 sheep/ha, LG means light grazing with 2 sheep/ha, MG means moderate grazing with 4 sheep/ha, OG means overgrazing with 6 sheep/ha; Within columns, average values ± SD; Data source: Zhao et al. (2003).

3. Experiments on combating aeolian desertification

Pioneering efforts at combating aeolian desertification, including stabilization of dunes with straw checkerboards and shrubs; preventing farmlands from wind erosion by planting wind shelter forests; and protecting grassland by enclosures, were first carried out at the Shapotou Desert Research & Experiment Station and the Naiman Desertification Research Station, of the Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences. The experimental results and experience gained at the two sites provide good examples of combating aeolian desertification for other regions of the study area.

3.1. Stabilizing and rehabilitation of mobile dunes using the straw checkerboard method

The straw checkerboard method is one effective way to stabilize mobile sand dunes in arid and semi-arid regions (Fig. 6). This method was first used at the Shapotou Station about 50 years ago to protect 40 km of the Baotou–Lanzhou railway from the shifting sands of the Tengger Desert. Physical and ecological experiments at Shapotou have resulted in the development of a

procedure for establishing an artificial ecosystem on mobile dunes (Zhu et al. 1988a). The process transforms areas with shifting sands and less than 5% vegetation cover to areas of fixed dunes with 30–50% cover. Initially, a sand barrier is established with woven willow branches or bamboo, reducing aeolian deposition. Behind the sand barrier, straw checkerboards are built with wheat or rice straw. Usually 1 m^2 in area, straw checkerboards at a height of 0.15-0.2 m above the ground increase aerodynamic roughness of the sand surface by 400–600 times (Table 6), thereby decreasing wind velocity by 20-40% at a height of 0.5 m and by 10% at a height above the surface (Zou et al. 1981; Shapotou Desert Research Station 1986; Liu 1987). The quantity of sand transported over a straw checkerboard is only 1% of that over uncovered mobile sand dunes (Zhu et al. 1992).

After straw checkerboards were built, artificial vegetation was selected and planted inside the checkerboards to trap the atmosphere dust and keep the stability of sand surface. Some native shrub species with properties of tolerating drought, wind erosion and sand covering, such as *Artemisia ordosica*, *Caragana korshinskii* and *Hedysarum scoparaium,* were first raised in nursery beds, and then transplanted at the center of straw checkerboard sections and grown without irrigation. The straw remained intact for 4-5 years, allowing planted xerophytic shrubs to become well established. Stabilization enables the formation of a cryptogamic crust, composed of a succession of algae, lichens and mosses. Research shows that local cryptogamic crust containing mosses can resist erosion forces from wind at speeds as high as 25 ms^{-1}(Shapotou Desert Research and Experiment Station, CAS 1991; Mitchell et al.1998). In addition, cryptogamic crust also can fix atmospheric nitrogen, making it available to developing vascular plants and providing a niche for soil invertebrates.

After the use of straw checkerboards and planting of indigenous shrubs for a period of 50 years, a stabilized ecosystem with 4 species of algae and 5 species of moss on mobile dunes in Shapotou got established. In the topsoil, fine particles, total N, P, K and organic matter increased significantly with increasing age of the checkerboards (Fig. 7). The number of herbaceous species increased up to 30 years and then leveled off to 12–14 species, whereas the number of shrub species decreased from the 10 initial sand-binding species to only 3 species. Shrub cover decreased from a highest average of about 33% to the current 9%, whereas cover and biomass of herbaceous species increased throughout succession from 1956 to 2006 (Fig. 8).

Table. 5. Changes of aeolian desertified land area in study area past 30 years

Regions	Counties	Aeolian desertification area (km^2)		
		1975	1987	2000
Horqin	Balinzuo	1113.81	1176.44	1255.94
	Balinyou	6131.67	5340.37	5205.17
	Zhalute	5062.36	9051.96	3905.76
	Wongniute	6531.40	5665.89	5029.89
	Aohan	1649.31	1546.90	771.70
	Aluhorqin	5613.58	8322.36	7010.26
	Naiman	5657.12	5409.63	4505.83
	Kezuozhong	3616.87	5479.60	5570.50
	Kezuohou	8400.06	9631.91	9056.81
	Kailu	1527.02	2693.93	1535.63
	Tongliao	1397.87	1489.78	624.68
	Keyouzhong	2024.49	2872.35	3631.05
	Kulun	2658.57	2327.08	2094.18
SIM & NH	Zhangbei	531.78	1037.33	834.53
	Shangyi	147.14	725.38	545.78
	Kuyuan	254.37	329.44	119.71
	Kangbao	828.34	1347.37	1071.38
	Fengning	342.24	575.91	435.07
	Weichang	418.99	760.68	614.01
	Huade	1117.31	1733.80	1122.6
	Shangdu	1887.50	2634.00	1668.9
	Chayouhou	765.00	1160.00	1025.1
	Chayouzhong	565.00	1880.00	798.95
	Siziwang	6537.50	10305.00	9408.15
	Damao	2337.50	5553.00	/
	Wuchuan	160.00	1035.00	/
	Xianghuang	1354.33	1466.53	1295.21
	Zhengbai	383.21	918.43	3236.83*
	Zhenglan	521.13	885.52	7413.76*
	Taipushi	602.33	1629.73	854.62
	Duolun	1067.87	1978.53	1717.70
Ordos	Yijinhuoluo	4241.40	4451.73	/
	Wushen	10163.43	9560.66	10779.38
	Etuokeqian	6321.06	6305.44	11426.34*
	Etuoke	4720.73	4165.12	13103.17*
	Hangjin	76.74	87.01	/
	Fugu	125.02	97.92	/
	Shenmu	3772.94	3345.77	3395.18
	Yulin	5502.22	4937.75	4360.00
	Hengshan	1596.54	1292.35	782.50
	Jingbian	2217.46	1815.50	1227.00
	Dingbian	2093.52	1729.80	2295.00
	Yanchi	1368.90	1845.50	3494.65

Monitored areas in 2000 are larger than that in 1975 and 1987. Data sources: Zhu and Chen (1994); Zhao et al. (2003); Wang et al. (2004b); Xue et al. (2005)

The development of soil and cryptogamic crusts on the surface of stabilized dunes enhanced the colonization and establishment of herbaceous plants due to increasing water availability, clay and silt content and soil nutrients (Xiao et al. 2003; Li et al. 2003; 2007; Zhao et al. 2004a; Duan et al. 2004).

Table 6. Protection evaluation of straw checkerboards

Surface type	V_2 (m/s)	Z_0 (cm)	V_* (cm/s)	V_z / V_2			Q ($g.cm^{-1}.min^{-1}$)
				Z=1m	Z=0.5m	Z=0.3m	
Shifting sand	12.6	0.007	19.6	0.92	0.86	0.82	13.9
Gravel plain	8.3	0.41	32.4	0.88	0.78	0.7	0.398
New straw checkerboards 1×1m²	7.9	1.517	41	0.86	0.72	0.62	0.007
Old straw checkerboards 1×1m²	8	1.886	43	0.84	0.7	0.6	0.102
Old straw checkerboards 2×2m²	8.1	2.398	45.3	0.84	0.68	0.58	0.609

V_2 means wind velocity at the height of 2 m; Z_0 means aerodynamic roughness length, which reflects the surface friction imposed on the boundary-layer winds; V means shear wind velocity; Vz means wind velocity at the height of Z m; Q means sand transportation amount.*

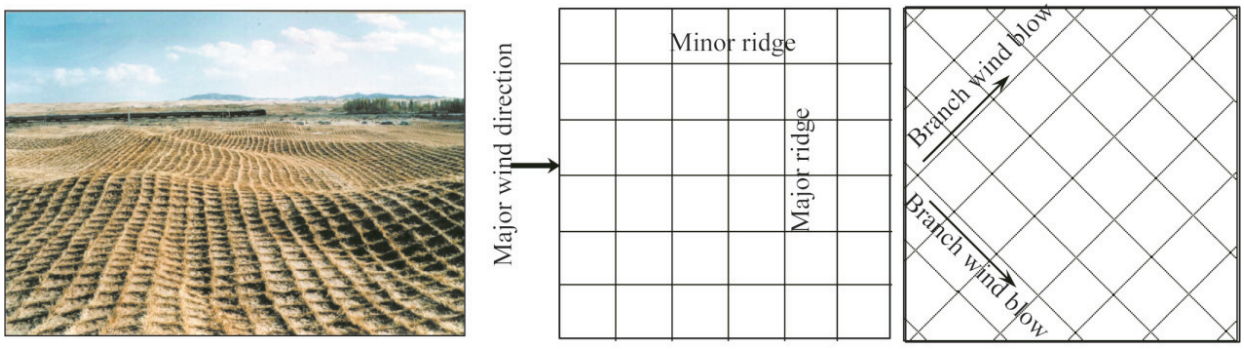

Figure 6. The straw checkerboard near the railway in Shapotou (left) and two kinds of arrangements (right).

Straw checkerboards were also used in the semiarid Horqin region to protect the road, railway and steppe. Local observations showed that the use of straw checkerboards can change microclimate by lowering the albedo, air and soil temperature, increasing the air humidity to aid germination of the seeds, nursing and recovering vegetation, and fixing sand dunes (Li et al. 2002; Hao et al. 2005a).

Similar to those planted in Shapotou, local artificial sand binding shrubs such as *Caragana microphylla* Lam. and *Artemisia halodendron* Turcz. ex Bess, with tolerance of drought and wind erosion, were widely used in re-vegetation programs to control desertification in the Horqin region with 400 mm yearly precipitation. Research showed that soil fine fractions, water holding

capacity, organic C and total N significantly increased in the 0-5 cm topsoil, and species diversity increased with increasing plantation age, after about 20 years of stabilizing shifting sand dunes using straw checkerboards and establishing shrub plantings (Su and Zhao 2003; Su et al. 2005a; Zhang et al. 2004). The thickness, hardness, water content, fine fraction and nutrient contents of biological soil crusts gradually increased along the dune stabilization gradient, and organic matter concentrations and other nutrients in the 0-5 cm topsoil layer under biological soil crusts were significantly higher compared to unconsolidated (control) soil (Guo et al. 2008; Table 7). These results suggest that shrubs created significant 'islands of fertility' and had an important role in maintaining or augmenting herbaceous species richness in shifting sand dunes, and could improve soil properties and facilitate vegetation recovery for controlling desertification processes (Zhao et al. 2007).

Also in the Horqin region, Shirato et al. (2005) compared the effects of ecosystem restoration between straw checkerboards (Sc) and planting *Artemisia halodendron* (Ar) and concluded that Sc was slightly more effective than Ar, presumably because Ar inhibited the invasion of other plant species, whereas Sc allowed invasion of various species.

3.2. Protecting farmlands using wind shelter forest grids

Afforestation projects in the study area have been widely initiated to restore degraded ecosystems and control wind erosion since the 1960s. Afforestation projects mainly include sand binding forest belts with shrubs in sand dunes, sand blocking forest belts with trees or mixed tree-shrub forests in the outer margin of a sand dune field, and wind shelter forest grids with trees or mixed tree-shrubs in farmland. In this paper, the experiment of wind shelter forest grids is presented.

In the study area, wind shelter forest grids consisting of belts of shrubs and trees were developed to prevent arid farmland from the wind erosion. The forest belts range in width depending on the height and species of forests and usually range from 50 m in west part to 500 m in east part of study area (Fig. 9); the selection of trees and shrubs also differs in different parts of the study area. In eastern areas with good irrigation, trees such as *Populus* and *Salix* are usually selected as the main part of the belts. In western areas without irrigation, trees, shrubs and grasses such as *Pinus sylvestris*, *Ulmus propinqua*, *Caragana microphylla*, *Amorpha fruticosa*, *Astragalus adsurgen*s, and *Agropyron cristatum* are planted to constitute the sub forest belts (Hu et al. 2001; Wang et al. 2003; Hao et al. 2005b).

A wind shelter forest can reduce the wind velocity and change the wind direction. The reduction of wind velocity depends on the density of the wind shelter forest and increases proportionately as density increases from 0% and 80% (Fig.10). The protected distance is in proportion to the height of the forest (Fig. 10). Usually, the space between two adjacent wind shelter forest belts depends on the height of trees or shrubs. Therefore the establishment of a wind shelter forest can effectively prevent the farmland lying in the forest grids from wind erosion and enhance the crop production. Also, the effectiveness of wind velocity reduction decreases with the upward distance above the wind shelter forest.

Shirato et al. (2004) surveyed the change of soil properties following 19 years of afforestation of Poplar in Naiman, Horqin regions. Research results show that soil physical and chemical properties inside forest belt and grassland protected by forest belts evidently were superior to that outside the forest belt without protection (Fig. 11). Similar result has also been found in middle and west parts of the study area (Wang et al. 2003). Additionally, the forest belt can affect the local micrometeorological environment. Researches in arid Ningxia Province show that the

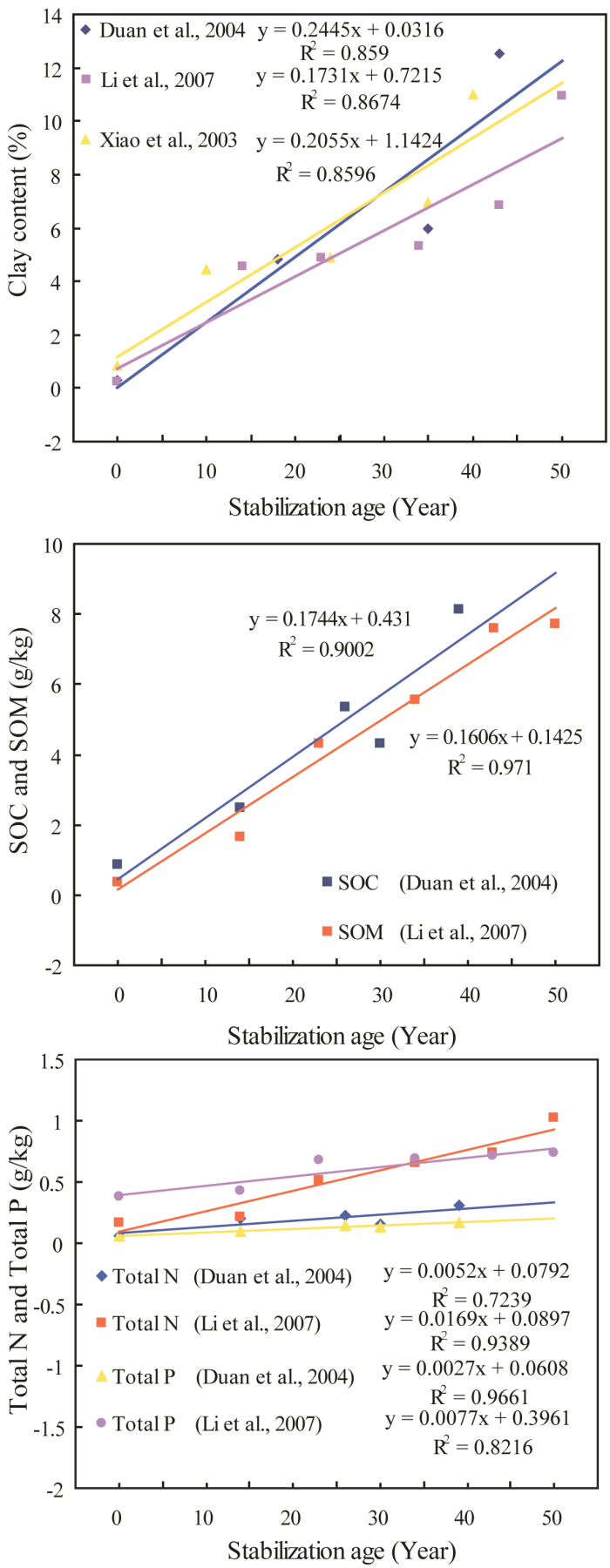

Figure 7. Changes in the topsoil (0–5 cm) properties with sand stabilization age in Shapotou.

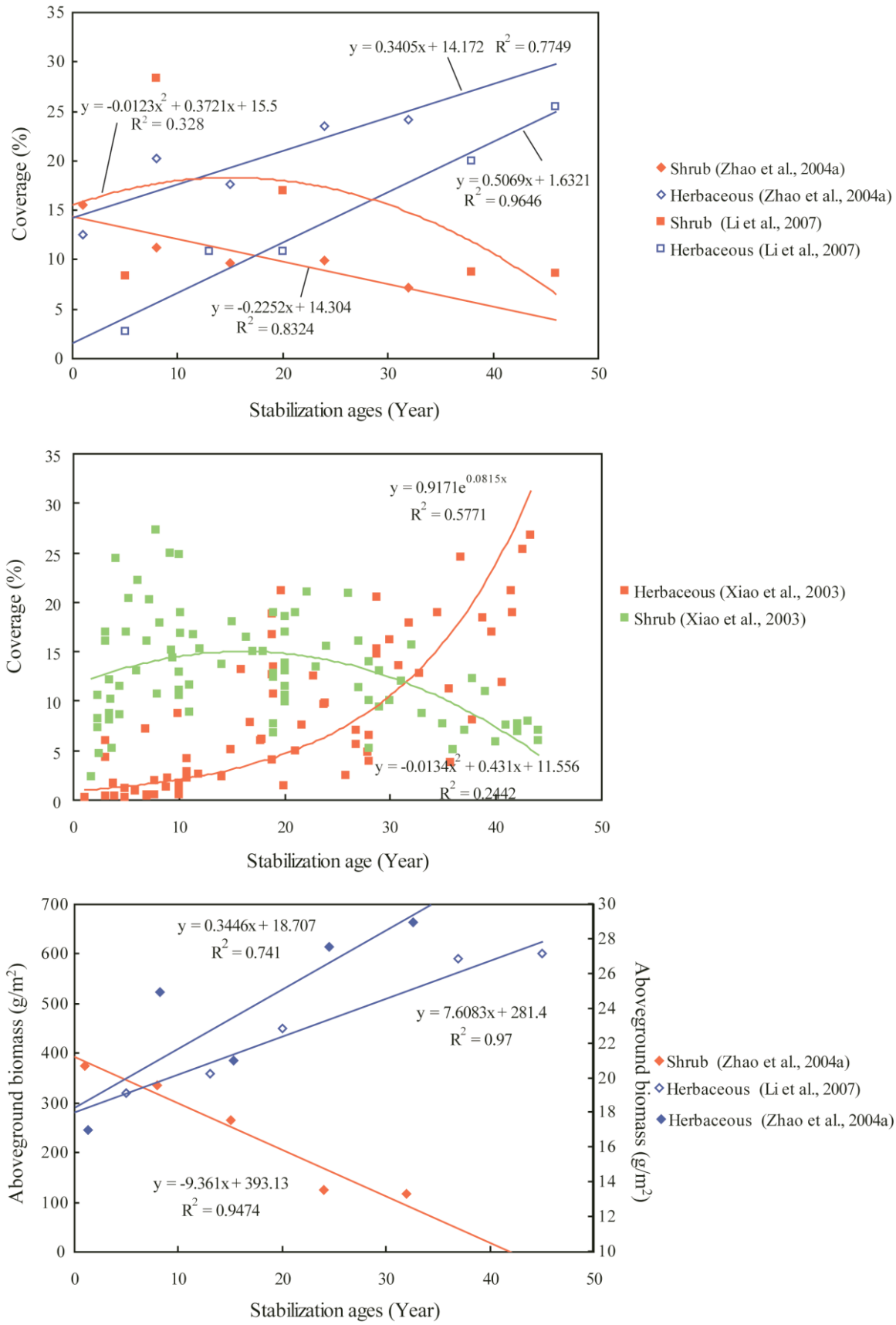

Figure 8. Changes in the coverage and aboveground biomass with sand stabilization age in Shapotou.

average temperature of soil surface was 24.5℃ (SD±7.87) inside the shelter forest, and 39.6℃ (SD±6.20) outside of it, and the shelter forest could reduce air temperature by 14-40%, increase air moisture by 25% and increase soil moisture (0-10cm depth) by 30% (Zha et al. 2004).

Although, there still exist some problems in selection of trees and shrubs for the wind shelter forest grids program, there have been some great successes. Some trees such as poplar are high water-consuming vegetation and cannot exist for long time in semi-arid regions. Some data from fields in the west and middle regions of the study area show that poplar usually dies from the lowering of groundwater table after about 20 years. Therefore, the drought-tolerant shrubs gradually substituted for the poplar in the wind shelter forest in some regions of the study area.

Table 7. Changes of biological soil crust properties with the sand dune stabilization age

Crust type	No crust	Physical crust	Algae crust	Moss crust	*F*	*p*
Dune type	MD	SMD	SFD	FD		
Crust cover (%)	–	14.6±3.2a	28.9±4.4b	52.8±5.4c	62.82	<0.001
Crust thickness (cm)	–	0.57±0.12a	0.68±0.18a	1.79±0.34b	25.24	<0.05
Crust hardness (kg cm^{-2})	–	1.10±0.32a	1.28±0.35a	1.68±0.55a	1.50	0.29
Crust water content (%)	–	0.47±0.13a	0.66±0.19a	1.76±0.25b	24.69	<0.05
Particle size distribution (%)						
2–0.25 mm	–	18.66±3.04a	17.20±2.72a	12.57±2.14b	4.29	0.07
0.25–0.1 mm	–	70.33±5.83a	62.29±3.92a	24.61±2.90b	92.76	<0.001
0.1–0.05 mm	–	6.36±1.05a	9.28±1.11a	26.12±3.12b	84.83	<0.001
< 0.05 mm	–	5.00±0.96a	11.47±1.53b	37.10±3.94c	138.07	<0.001
SOM (g kg^{-1})	–	6.64±1.96a	9.31±1.56a	31.91±2.71b	127.15	<0.001
TN (g kg^{-1})	–	0.48 ± 0.18a	0.67±0.16ab	1.33±0.58b	4.54	0.06
TP (g kg^{-1})	–	0.13 ± 0.06a	0.16±0.04a	0.23±0.13 a	3.08	0.12
AN (mg kg^{-1})	–	23.19±2.42 a	38.96±3.47b	88.59±4.58c	269.68	<0.001
AP (mg kg^{-1})	–	4.16 ± 0.41a	4.42±0.64a	8.65±1.74b	27.03	<0.05
CaCO3 (g kg^{-1})	–	0.24 ± 0.03a	0.28±0.04a	0.44±0.04b	24.59	<0.05
EC (μs cm^{-1})	–	47.33 ± 4.02a	75.24±4.49b	111.15±5.61c	135.89	<0.001
pH (H_2O)	–	7.37 ± 0.54a	7.44 ± 0.43a	7.59 ± 0.58a	0.14	0.87

Value represents the mean ± SE. Values with different letters in a row are significantly different at p 0.05; MD- mobile dune, SMD- semi-mobile dune, SFD- semi-fixed dune, FD- fixed dune, SOM - soil organic matter, TN - total nitrogen, TP- total phosphorus, AN- available nitrogen, AP- available phosphorus, EC- electrical conductivity. (Data source: Guo et al. 2008)

3.3. Protecting grassland using enclosure of grazing land

Overgrazing is one of the main factors causing aeolian desertification. Therefore, grazing control using enclosure and rotational grazing has been considered to be effective for combating desertification by local governments and scientists in the study area. A grazing experiment was

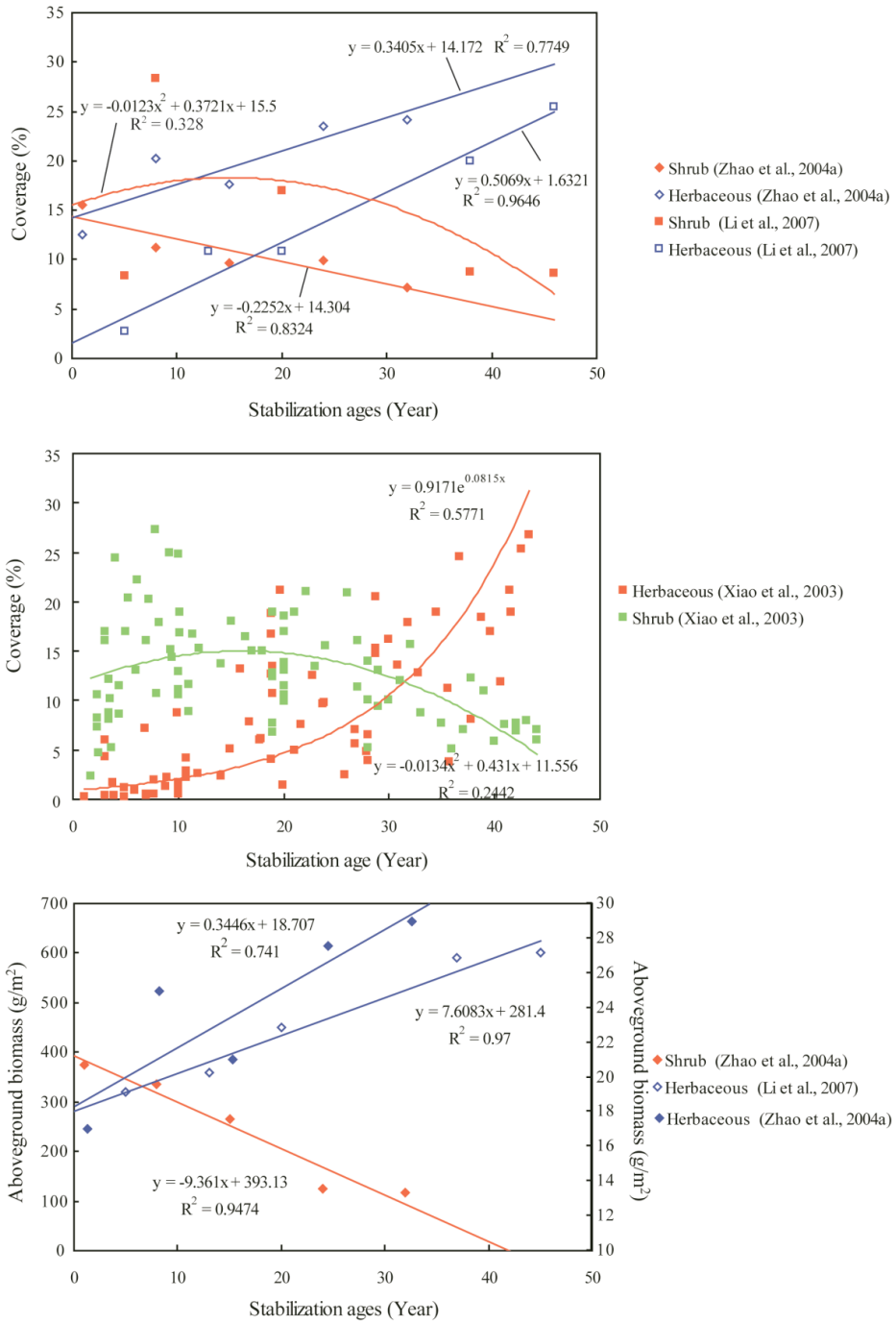

Figure 9. Wind shelter forest of farmland in Shangdu County of SIM & NH region (A) and schematic diagram of wind shelter forest in Naiman of Horqin region (cited from Hao et al. 2005b) (B)

conducted since 1992 at Naiman Station. The grassland had been grazed by sheep for many years before the experiment at an intensity of 4.5 sheep ha-1. The experiment consisted of 4 grazing treatments: no grazing (NG., 0 sheep ha^{-1}), light grazing (LG, 2 sheep. ha^{-1}), moderate grazing (MG, 4 sheep. ha^{-1}) and overgrazing (OG, 6 sheep. ha^{-1}). After 5 years, observations indicated that NG and LG treatments had higher species diversity as well as higher biomass production than MG and OG treatments (Table 4 and Fig. 12). Vegetation recovery in the un-grazed grassland plots was favorable and resulted in the improvement of physiochemical and biological properties of the surface soil (0-7.5 cm), largely by protection from wind erosion

and increased litter input (Zhao et al. 1998; 2004b; Su et al. 2004). At the same sites, Su et al. (2005b) analyzed the ecosystem change in the sites that had been enclosed for 10 years, 5 years and non-enclosed with continuous grazing. The results showed that vegetation coverage, litter accumulation, total biomass, and total C storage of plant components increased with increased enclosure time, but the change of soil properties with the increased enclosure time was not evident. The results suggest that soil restoration on degraded sandy grassland is a slow process, although the vegetation can recover rapidly after removal of livestock disturbance (Su et al. 2005b). Seasonal enclosure experiments also were conducted at the Naiman station. The results showed that seasonal enclosure was sufficient to restore and maintain grassland vegetation in the study area.

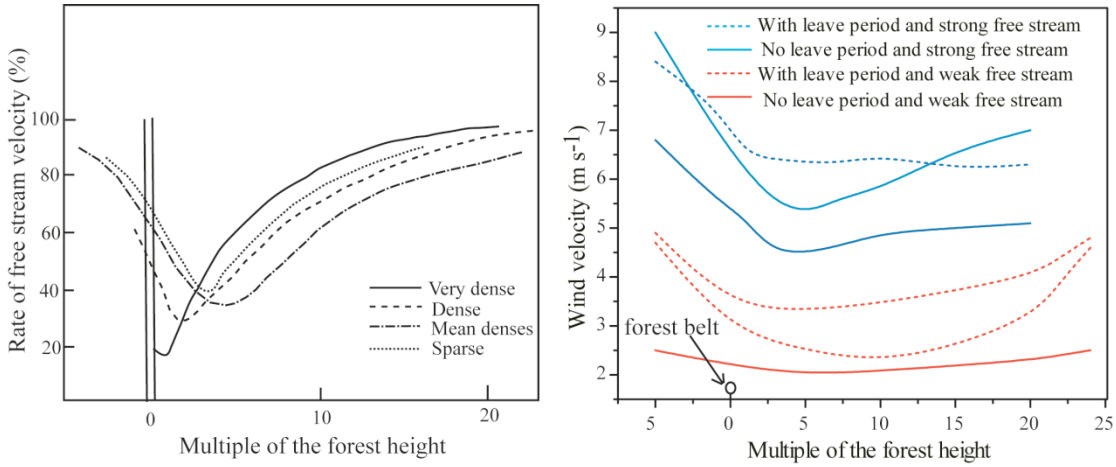

Figure 10. Relation between the effect of the wind velocity reduction and the various ranks of the denseness in the windbreak forest (height 1.4 m) (Naegeli, 1946) (left) and the effect of wind shelter forest in Shangdu county, SIM & NH region (right) (Xiao et al. 1983; Niu et al. 2001)

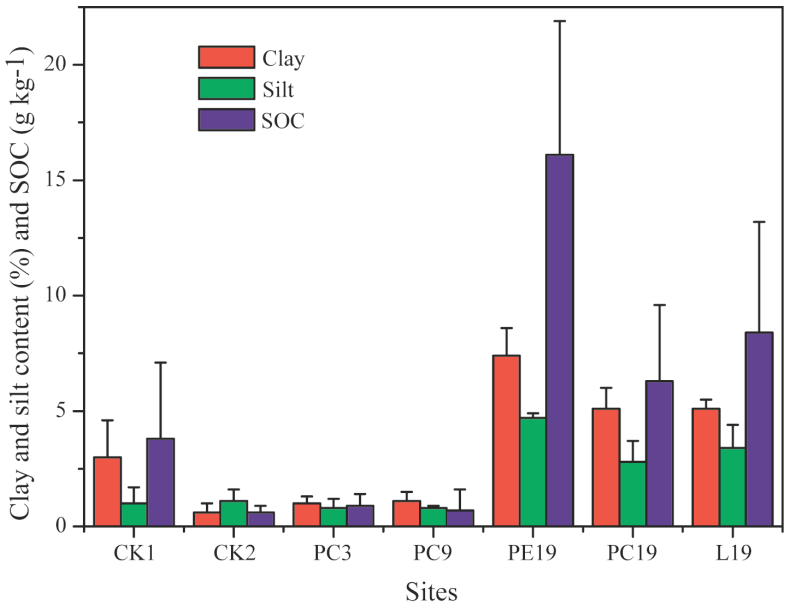

Figure 11. Contents of fine particles and soil organic carbon in the surface 5 cm layer at 7 different sites with poplar grown for different years; PC3, PC9 and PC19 means the center of wind shelter forest with 3, 9 and 19 years of poplar. CK1 and CK2 means windward sand dunes outside wind shelter forest with 1 and 2; PE19 means the windward edge of wind shelter forest with 19 years of poplar; L19 means leeward edge of wind shelter forest with 9 years of poplar (Yasuhito Shirato et al. 2004).

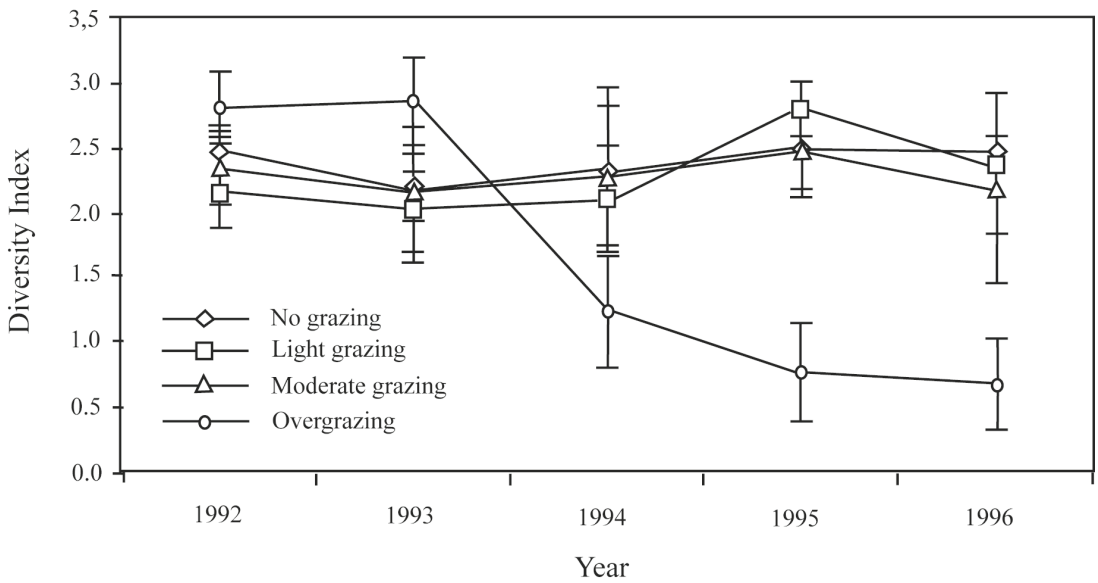

Figure 12. Plant species diversity index in sandy grassland of Naiman in Horqin from 1992 to 1996 as affected by different levels of grazing. Bars represent ± SD (cited from Zhao et al. 2004).

Thus, seasonal enclosure and light grazing with 2-3 sheep or sheep equivalents per hectare is suggested to recover overgrazed grassland and maintain plant species diversity in the study area (Zhao et al. 1998; 2004b; Kazuhiro et al. 1998). When shrub or tree vegetation is needed for reasons such as fixing sands or preventing sand dune remobilization, complete enclosure is recommended (Kazuhiro et al. 1998).

4. Nation level efforts for combating aeolian desertification

In addition to the regional efforts for combating aeolian desertification some efforts have also been made to conduct experiments with nationwide scope.

The Central Government of China initiated tree plantation campaigns in the late 1970s to solve the land degradation problem. In 1978 the government initiated the 'Three-North Shelterbelt Development Program' to form an environmental screen 700 km wide across northern China. The aim was to plant more than 35 million ha of trees between 1978 and 2050 and create one of the world's largest environmental projects. In 1992 the government reported that 9.1 million ha of planting had been completed in the first 11 years, protecting 11 million ha of cropland, reclaiming 8.73 million ha of desert and implementing 7.3 million ha of wind erosion control in the Yellow River catchments (Ministry of Forestry 1992).

While the program was being implemented, the aeolian desertified land area rapidly increased as mentioned in the introductory section (Wang et al. 2004b). This proved that the 'tree planting' policy was not fully successful. The failure mainly resulted from the low survival rates of trees (often below 10 percent) because of poor selection of species, careless planting and inadequate follow-up. For example, poplar selected as the primary species in this program was not suitable for arid- and semi-arid regions with rainfall of less than 200 mm. As a high water consumer, poplar has a deep rooting system and can suck deep groundwater but with low water use efficiency. As a consequence, this species can alter groundwater dynamics in the area where it first survives and then dies as the ground water table becomes very low. This also induces the degradation of native grasses and shrubs because of the lack of underground water.

Although the 'Three-North Shelterbelt Development Program' has not been perfect for all of the regions of study area, it has been helpful in the restoration of some aeolian desertified lands in the southern parts of the study area with better rainfall conditions. By the establishment of wind shelter forests for wind-eroded farmland, more than 1/2 of farmlands in the south have been restored in the last 20 years. From Table 5 it is clear that the rehabilitation in the study area began in the late 1980s. The aeolian desertified area in the study area was 121,900 km^2 in 1987, 109,900 km^2 in 2000 and occupied 36.5% and 28.5% of total aeolian desertified area of Northern China separately (Zhu and Chen 1994; Xue et al. 2005).

5. Local level case of combating aeolian desertification

After the 'Three-North Shelterbelt Program' policy, China developed the 'Grain for Green' policy in 1999. The government changed its policy so that regions may have more flexibility to choose the method that should be adopted, i.e., decide which crops, grasses, shrubs and trees they may grow according to the local situation. A typical case is presented in this paper to help understand the policies and problems of combating desertification in the study area.

Located in the west part of the Horqin region, Balinyou County, with a total land area of 9909.97 km^2 and an average rainfall of 344.4 mm. yr^{-1}, had 6131.67 km^2 of aeolian desertified land in 1975, 5340.37 km^2 in 1987, 5205.17 km^2 in 2000 (Table 5), and 3499.28 km^2 in 2005 (unpublished data obtained through the use of remote sensor monitoring by Key Lab of Desert and Desertification, Cold and Arid Regions Environmental and Engineering Research Institute, CAS). The local government owes the rapid reversal of desertification after 2000 to the establishment and implementation of the local ecology recovery model, which consists of 'Forbidding Grazing (FG)', 'Restoring Desertifified Land (RD)', and 'Ecological Emigration (EE)' from desertified land.

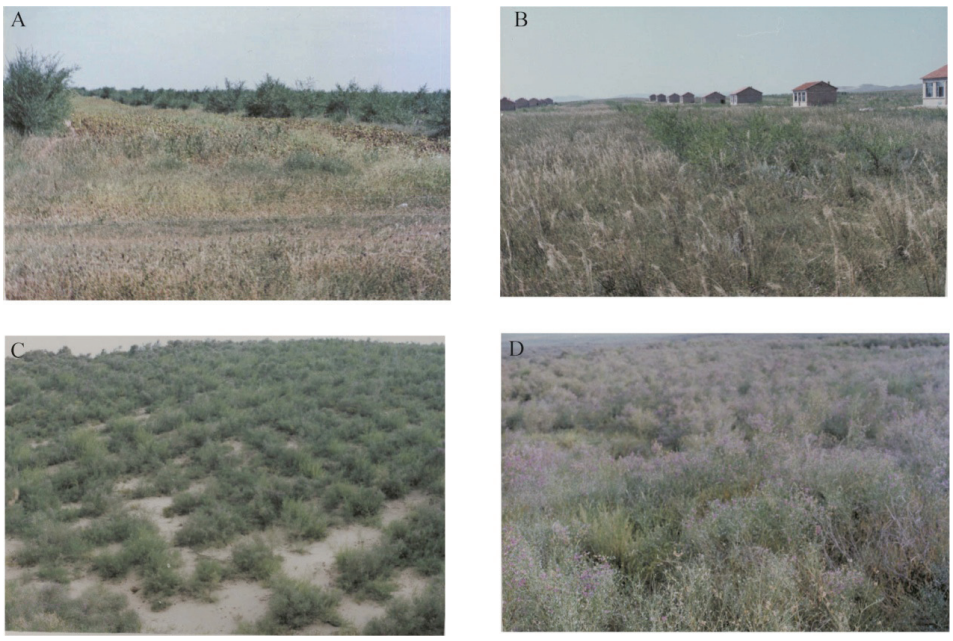

Figure 13. Mixed tree-shrub-grass in enclosure pasture of Balinyou Banner (A); the new migration sites in Balinyou Banner (B); the middle stage Hedysarum laeve Maxim checkerboards of binding sand dunes in Balinyou Banner (C); the late stage Hedysarum laeve Maxim checkerboards of binding sand dunes in Balinyou Banner (D).

‘Forbidding Grazing’ was first implemented to recover the productivity and carrying capacity of pastures. Livestock were not allowed to graze on FG-designated lands either seasonally or the year-round. In 2007, 3070 km^2 of pasture had been partitioned into year-round FG areas, and the spring restriction of grazing was also implemented in most parts of the pastures to help grass turn green and recover naturally. Pasture coverage was less than 40% and the average height of grass was lower than 10 cm before the FG policy. Pasture coverage reached 85% and the average height of grass reached 80 cm after the FG policy was carried out for several years. The recovery of vegetation enhanced the biomass and productivity of pasture.

‘Restoring Desertified Land’ is a comprehensive recovery measure of desertified land by enclosure and afforestation. From 2000 to 2007, 1200 km^2 of degraded pastures, farmlands and sand lands have been enclosed in the County, and 1000 km^2 have become protected areas. In this area, some fast-growing arbor forests, mixed economic arbors and shrub forests, and artificial forage basement areas and Chinese herb basement areas were established by aerial seeding and planting of seedlings (Fig. 13). Additionally, local government and farmers have returned 192 km^2 of farmlands to pasture and forest, and fixed 282 km^2 of mobile sand dunes using the live *Hedysarum laeve* Maxim checkerboards (Fig. 13).

To resolve the population pressures on aeolian desertified land, central and local government financially supported herders and farmers to emigrate from aeolian desertified land to new immigration sites located near the Xilamulun River (Fig. 13). By 2007, 1300 families with a total population of 4580 people had immigrated to the new sites. Along the river, irrigated farmland with motor-pumped wells and forage basements with good water and soil conditions were established to provide the cereal and forage for new immigrants. According to the policy of EE, each person owns 0.07 ha of irrigated farmland and every family owns 3.33 ha of forage grassland and a 30 m^2 livestock barn. Additionally, the government invests in the infrastructure, welfare facilities and service industries in towns near immigration sites to provide immigrants with the chance of education and employment. Because of the EE policy the income per capita had doubled by 2006 as compared to before.

The Balinyou model of combating aeolian desertification has been certified as effective in local and nearby Counties and has been popularized and improved in other regions of the study area in recent years.

Since the policy of ‘Grain for Green’ was carried out, rapid rehabilitation is occurring in most counties of study area (Table 5).

6. Conclusion

From the field experiments and a typical case of combating aeolian desertification in the study area, it is clear that the rehabilitation of degraded land can be achieved as long as sustainable land-use policies are implemented based on the long-term carrying capacity of the local ecological environment in semi-arid and sub-humid regions. But the rehabilitation of ecosystems is a slow and long-term process. Vegetation recovery on aeolian desertified land needs several years or even several decades, and the restoration of soil properties only occurred in the very thin surface crust at 0-5cm depth after 50 years of sand dune fixing or enclosure. So, the complete rehabilitation of degraded ecosystems will take longer and need long-term sustainable land-use management in the study area. As the arid ecosystem is a coupled human-environmental (H-E) system, the short-term benefits of combating desertification and cultural factors have to

be considered. For example, forbidding grazing and transferring pastoral land into sedentary cultivation and grazing must not harm local people's livelihoods and cultures. The low threshold of system stability makes the arid ecosystem to need more input from outside in order to keep the balance among environment, economy and society, which means more investment of funds, technologies, markets, appropriate regional policies, etc. The regional difference and complexity inside the arid ecosystem has to be taken into account. No constant model can be an answer in the process of combating land degradation. The only criterion for evaluating the model is the sustainable and stable development of local human-environmental ecosystem, even if outer environment might be changing in small scale such as climate change at present.

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18. Root development and carbohydrate reserves as related to persistence of some desert grasses

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Abstract

Buffel grass, also called labeid (*Cenchrus ciliaris* L.); dakhna (*Coelachyrum piercei* Benth.) Bor. and da'ay (*Lasiurus scindicus* Henr.) from United Arab Emirates together with one commercial exotic species, Rhodes grass (*Chloris gayana* Kunth) were grown in pot culture using sandy soil under controlled environment of a green house at the Arid Land Research Center, Tottori University, Japan during 2007-2008. The pots were irrigated daily with 150, 100, 50 and 50 ml tap water during four growth cycles of 34, 37, 51 and 39 days, respectively. The grasses were harvested at the end of each growth cycle, oven dried and weighed. After the fourth harvest, 12 pots (three for each species) were cut each horizontally into four strata (25 cm), the soil washed and the roots collected. Additionally 4 pots, representing the four species were cut vertically and whole roots were collected. The roots were oven dried (80 °C), weighed, ground and used for carbohydrates (NSC) analysis. Rhodes grass and buffel grass maintained the highest DM yield throughout the study with no significant difference between them. This was matched by Dakhna in the first growth cycle only. Recovery after harvest became weak for dakhna and da'ay starting the second growth cycle and stopped completely in the third and fourth cycles. Rhodes grass and labeid showed the most extensive root development in the soil profile, explaining their persistence and high productivity. The highest root accumulation for all grasses was found on the top and bottom strata. Rhodes grass and buffel grass were also the highest in total NSC in their roots over the other two grasses.

Introduction

The Arabian Peninsula is considered a water scarce region. Agriculture consumes most of the water available (76%) mainly for forage production and forestation. The native plant biodiversity of the Arabian Peninsula (AP) comprise over 3500 species (Ghazanfar and Fisher 1998) and represent a great hope for livestock production under the harsh environment of AP. These native species are well adapted to low rainfall, high evaporation rate, and high temperature that prevails in the region (Bőer 1997; Ghazanfar and Fisher 1998; Zahran 1997). The genetic variation existing within these species in relation to environmental stresses must be explored and utilized for forage production. A joint research effort between the National Agriculture Research Systems (NARS) of the AP countries and the International Center for Agricultural Research in the Dry Areas (ICARDA) is focusing on identifying new forages that use less water in the production process. Under this joint effort, collection missions for indigenous plant species were carried out in 6 AP countries (Bahrain, Oman, Qatar, Saudi Arabia, United Arab Emirates and Yemen), where seeds of potential forages were collected (Osman 2005). Some of these native grasses have shown higher dry matter yield, feed quality and water use efficiency than the traditionally grown Rhodes grass (Osman et al. 2008). However, differences have been observed among these grasses with regard to their persistence under repeated cuttings. Ability to withstand frequent

defoliation is believed to be related to carbohydrate reserves in the root system of perennial grasses (Humphreys 1967). In the present study we looked at the root development and carbohydrate reserves in some of these grasses.

Experiment details

Three indigenous grasses from the United Arab Emirates, namely buffel grass, also called labeid (*Cenchrus ciliaris* L.), dakhna (*Coelachyrum piercei* Benth.) Bor., and da'ay (*Lasiurus scindicus* Henr.), together with one commercial species Rrhodes grass (*Chloris gayana* Kunth), were sown in peat moth (2 plants per pellet). The peat moth pellets were transplanted into large PVC pots (110 cm height and 22 cm diameter) filled with sandy soil to 100 cm. The pots were wrapped with insulating sponge which has aluminum foil on its outer surface. There were 20 pots four of these were-controls (no plants). The 20 pots were arranged in a randomized block design (four grasses and one control all replicated four times) on a metal rack 13 cm above ground. Drainage water was collected in plastic pans placed under the pots.

Compound fertilizers NPK (2.415 g per pot), supplying 0.314 gm N, 0.314 g P and 0.386 g K and micronutrients (1.61 g per pot) and calcium hydroxide (4.025 g per pot) were added (top dressing) to all pots before grass-transplanting on July 31, 2007.

At the beginning of the study, irrigation was applied at 500 ml on daily basis using an automatic drip irrigation system fitted with a gauge. Water depletion in the soil profile was monitored in five pots (4 grasses and one control) using needle sensors with KD2 Thermal Properties Analyzer (Decagon Devices Inc., USA). The sensors were installed at 12.5, 37.5, 62.5 and 87.5 cm soil-depth (inserted horizontally) along one side of the pot. The sensors measure Soil Thermal Conductivity (W m^{-1} °C^{-1}), which is later converted to volumetric water content using a calibration curve. The soil moisture was monitored once a week in the 5 pots. On 3 September plants of all pots were cut to ground level and discarded, marking the beginning of the study. Four forage harvests were made at the end of the following growth cycles: 34, 37, 51 and 39 days. Irrigation was adjusted at the beginning of the growth cycles to 150, 100, 50 and 50 ml daily for the four cycles, respectively. In the first cycle irrigation (150 ml) was applied in the morning, while in the last three cycles it was applied morning and afternoon (equal amounts). The pots were fertilized again at the beginning of the second growth cycle with the same fertilizer as applied at the beginning of the experiment.

Data collection

Irrigation, drainage and soil moisture

Irrigation was monitored on daily basis (morning and afternoon) depending on the crop growth cycle. Using four pots (controls with no plants) water was collected from the dripper in each pot in a plastic jar, weighed and poured back into the same pot. Drainage water was collected on daily basis, before the morning irrigation, weighed, recorded and discarded. Total water application and total drainage was computed on weekly basis during crop growth cycles. Soil moisture recording was done once a week by recording the Thermal conductivity (W m^{-1} °C^{-1}) using KD2 Thermal Properties Analyzer. The readings were later on converted into volumetric water content using calibration curve. Temperature and relative humidity inside the green house were recorded (at one hour interval) throughout the experiment.

Dry matter (DM)

At the end of each crop growth cycle (indicated by 10% flowering of Dakhna), the plants were harvested to ground level, oven dried (80○C) weighed and discarded.

Roots

At the end of the fourth growth cycle, 12 pots were cut (with a saw) each into 4 strata (25 cm). The strata were placed on a wire mesh (2 mm) and a jet of water applied to wash the soil. The roots were collected on the mesh, placed in sealed plastic bags containing Ethyl alcohol (75%) and the bags stored in a refrigerator. One replication (4 pots) representing the four grasses were cut vertically, soil washed and the roots collected (whole root) as described above. The roots were then washed with tap water, placed in paper bags, oven dried (80°C), weighed and stored for analysis of non structural carbohydrate (NSC).

Water Use Efficiency (WUE)

The dry matter yield data and the irrigation water data were used to calculate WUE in kg DM per m^{-3}.

Data analysis

The data on shoot DM, drainage water and WUE were analyzed as a complete block design while the data on root DM and carbohydrates were analyzed as split-plot design (Steel and Torrie 1960), using analysis of variance to evaluate statistical significance between species means and root means. Computations were carried out using a statistical package of Systat Software Inc. (SigmaStat 3.5). Tukey Test was used to compare means (p=0.05)

Results and discussion

Grass roots

Both Rhodes grass and labeid showed the most extensive root system in the soil profile (Figure 1). The highest root accumulation was observed at the top and bottom strata of the profile for all grasses (Table 1). Differences among grasses were not significant for non-structural carbohydrates percentage (Table 2). However the differences were significant for total carbohydrates, due to the differences in root development (Table 3).

DM yield

Both Rhodes grass and labeid maintained the highest DM yield throughout the study with no significant difference between them. This was matched by dakhna in the first growth cycle only. Recovery after harvest became weak for dakhna and da'ay starting the second growth cycle and stopped completely in the third and fourth cycles. With the exception of dakhna, none of the grasses produced any flowering during the study. These results are in general agreement with earlier field results, showing that both buffel and Rhodes grass were persistent for two years over other grasses (Osman et al. 2008). This seems to be due to the well developed root systems of the two grasses shown in this study and reported by Humphreys (1967). Different, however, from the present study, field studies have indicated higher persistence of buffel over Rhodes grass (Humphreys 1967; Osman 1979; Osman and Abu Diek 1982; Osman et al. 2008).

Figure 1. Root development in 4 grasses: Rhodes grass (Cg), da'ay (Ls), buffel grass (Cc) and dakhna (Cp) in the PVC cylinders (22 cm diameter) filled with sand to 1-meter depth. The grasses were grown for 196 days under controlled environment at Arid Land Research Center, Tottori, Japan in 2007-2008.

Table 1. Total DM of root system (g/pot) in 4 grasses at 4 strata (a-d)* of 25 cm each under controlled conditions at Arid Land Research Center, University of Tottori, Japan in 2007-2008

Strata	Buffel grass	Dakhna	Rhodes grass	Da'ay	Stratum mean
a	2.44	0.49	2.70	0.19	1.46
b	0.96	0.19	0.98	0.10	0.56
c	0.77	0.15	0.82	0.10	0.46
d	0.88	0.11	1.33	0.13	0.61
Mean	1.26	0.24	1.46	0.13	

** a is top stratum*

s.e of mean of strata	*0.059*
s.e of mean of grass species	*0.155*
s.e of mean of strata within grass species	*0.119*

WUE

Similarly the water use efficiency (WUE) of the species followed the same pattern as the DM yield, with no significant difference between Rhodes and labeid or dakhna in the first growth cycle. However, the differences were significant between Rhodes and dakhna; Rhodes and da'ay in the second growth cycle. WUE could not be computed for dakhna and da'ay in the 3rd and 4th growth cycles.

Table 2. Non-structural carbohydrates (DM %) content in roots of 4 grasses harvested at 4 strata (a-d)* of 25 cm each under controlled conditions of the Arid Land Research Center, University of Tottori, Japan in 2007-2008

Strata	Buffel grass	Dakhna	Rhodes grass	Da'ay	Stratum mean
a	2.29	1.72	2.29	2.17	2.12
b	2.65	6.40	2.06	1.92	3.26
c	2.41	1.86	2.05	1.78	2.02
d	2.58	2.83	2.70	1.49	2.40
Mean	2.48	3.20	2.28	1.84	

** a is top stratum*

s.e of mean of strata *0.301*

s.e of mean of grass species *0.390*

s.e of mean of strata within grass species *0.601*

Table 3. Total non-structural carbohydrates (g/pot) in roots of 4 grasses and 4 strata (a-d)* of 25 cm each under controlled conditions at Arid Land Research Center, University of Tottori, Japan in 2007-2008

Strata	Buffel grass	Dakhna	Rhodes grass	Da'ay	Stratum mean
a	5.43	0.90	6.10	0.43	3.22
b	2.53	1.23	2.00	0.17	1.48
c	1.83	0.30	1.50	0.20	0.96
d	2.58	2.83	2.70	0.17	1.59
Mean	3.01	0.68	3.32	0.24	

** a is top stratum*

s.e of mean of strata *0.285*

s.e of mean of grass species *0.362*

s.e of mean of strata within grass species *0.589*

Drainage water

The drainage water was highest under Da'a in the first growth cycle, which was significantly higher than under Labeid and Dakhna. No significant differences were recorded among the four species in the following growth cycles or when the total drainage of the 4 growth cycles was pooled for the five treatments (four grasses and a control).

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19. Interventions to enhance the water use efficiency of water harvested in dams and reservoirs in the mountains of Yemen

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Abstract

Yemen suffers an annual water deficit of about 900 million m3 due to the limited water resources and the increased demand of the agricultural sector estimated to be as large as 93%. To cope with such demand, the government of Yemen constructed many dams and reservoirs for water harvesting in the mountain areas. A study, conducted to evaluate the water use efficiency from the harvested water by 13 dams in the mountains of the Northern and Central regions in 2004-2005, revealed inefficient utilization due to many technical problems associated with the design and construction and lack of good water use management. In 2006-2006 season, the of area of Mukhtan dam (N 15○ 22/ 53.5 // , E 44○ 19/ 52.4//) in Saawan, Sana'a governorate was selected to introduce modern irrigation system for grape vines and protected agriculture techniques for cucumber production. Water use efficiency was significantly high (3.4 kg/m3) with bubbler irrigation system for grape vines compared to that using traditional surface irrigation (1.8 kg/m3). With cucumber production under greenhouse, the average water use efficiency was 48.5%. The relationship between water consumption and grapes production could be described by equation Y = -0.0014x2 + 17.937x – 36218) with a R2 of 0.7144.

Introduction

Yemen is one of the dry area countries with high poverty. The annual renewable water resources are estimated to be about 2500 million cubic meters, while the water consumption reaches to about 3400 million cubic meters. Agriculture accounts for nearly 93% of total consumption. This deficit in annual renewable water resources is currently being met by pumping underground water, which is getting fast depleted. Of the total cultivated area of 1.15 million hectare, rain-fed, water harvesting and spate irrigation agriculture collectively represent 49%, while the underground irrigated agriculture represents the rest 51% of the total cultivated area. The latter however produces 75% of the total crops and contributes 85% of the value of total production. The ground water irrigation allows greater flexibility in cropping pattern and cultivation of high value crops. As a result the demand for irrigation water from underground resource has rapidly increased, which is leading to the depletion of this available resource.

The construction of dams is one of the important solutions which the Government of Yemen has undertaken to face the problem of water shortage. During the period from1990 to 2008, the Government implemented several projects concerning construction of large dams and checks and canals in the twenty one governorates which reached to 1146 projects. Thirty of these were water structures and dams constructed with total expenditure exceeding 2.138 million Yemeni Rials (One US$=199.5 Rials) executed during January, 2007 to April, 2008. Despite the huge effort, the management of these structures did not get much required attention (www.xinhuanet.com).

Several reports indicated that the static water level (SWL) of wells near Mukhtan, Konazer, and Beryan dams was significantly affected by the distance from the dams. The SWL of wells closer to Mukhtan dam was 9 m while SWL of well at a distance of about 5.7 Km from the dam was 22.6 m (Almhab 2004).

The statistics for the last five years indicate that the cultivation of grapes stands first among the various fruit types in Yemen, with an average cultivated area of 12500 hectares, equivalent to 15% of the total fruit area (MOI 2006). Grapes are cultivated under the traditional surface water irrigation which has low efficiency due to large water losses. The average amount of water applied per season to the most and least frequently irrigated fields was 1342 and 740 mm, respectively, and the mid summer irrigation interval was 4 and 18 days, respectively (Stevens and Cole 1987). Accordingly to AGL, FAO (http://www.fao.org/ag/agl/aglw/cropwater/grape.stm), the water utilization efficiency of grapes for fresh fruits containing about 80 percent moisture is 2 to 4 kg/m3 when grape is grown in the subtropics.

During the last few years cucumber cultivation under protected system is spreading in Yemen as a cash crop. However, the management of the protected agriculture structures is still not very efficient and requires improvement, particularly from the point of view of water management. Cucumber is reported to consumes 290 mm water in green house conditions in a growing season of 3.5 months (http://ressources.ciheam.org/om/pdf/c31/CI020845.pdf).

This paper reports the results of studies on improving the water use efficiency of Mukhtan Dam by using protected agriculture for growing cucumber and adoption of bubbler irrigation in grapes which increased water use efficiency at Mukhtan Dam.

Material and methods

Field surveys were conducted in close collaboration with the General Directorate of Irrigation in the Ministry of Agriculture and Irrigation (MAI). Thirteen dams and water reservoirs were visited, six in the northern highland (including Mukhtan Dam) and 7 in the central highlands.

Collected data covered parameters like: location, dimensions, volume and capacity in addition to hydrological information such as: description and characterization of the surrounding watershed, the average rainfall, the average water runoff in the valley and other measurements. For field data collection a special form was designed for individual interviews with farmers benefiting from the dam or water constructions. The irrigated area was measured and methods of irrigation were identified together with cropping systems and crops grown.

The land of one farmer, Sheikh Saeed Khamees, in Sa'awan location near Mukhtan Dam in Bani Hushish district (Sana'a governorate) was selected to execute the activity that included introduction of a greenhouse for cucumber cultivation as a cash crop and installation of a bubbler irrigation unit for Grape cultivation as a demonstration field. The Arabian Peninsula Regional Program project provided one greenhouse and one localized irrigation unit. The farmer provided the water pump, land and required labor. In the job training for farmers was conducted during construction of the greenhouse. Field days were organized frequently to create awareness among farmers about the technologies and encourage interested farmers to have their own units.

A plastic house (54 x 9 m), with attachments, was installed during the period of study. Cucumber variety "Jolia" was planted in it on 7th December 2004 and on 10th August. The crop water

requirement program designed by the Central Laboratory in Egypt was used for scheduling irrigation in the cucumber crop.

A bubbler irrigation unit for ten grape vines was installed and other ten vines on the same field were left according to farmer's traditional surface method of irrigation for comparison. For irrigation water scheduling, the soil samples were taken from 100 cm depth for determination of the soil moisture content. Crop evapotranspiration was calculated by using of water balance equation.

Microsoft excel program was used for calculation of relation between water and yield and the genstat program was used for statistical analyses of the obtained results.

Results and discussions

Dam parameters and its effect on water table and water use practices in the area

Mukhtan dam is located in Sa'awan area in Bani Hushaish District (Sana'a Governorate) at a latitude N 15○ 22/ 53.5 // and longitude E 44○ 19/ 52.4// . The purpose of constructing the dam is to recharge underground water. The dam bed level is located at an elevation of 2400 m above sea level (asl) and the top of dam level is at 2425 m asl. The capacity of the dam is 550,000 m3. The construction material of the dam is earth and stones. The construction of the dam was completed in 1999 and from that time it has not been cleaned to remove either sediments or algae.

Mukhtan dam collects water from the rainfall (194.8 mm/annum) in the surrounding watershed. Assuming a runoff coefficient of 0.20 the total amount of water reaching the dam is expected to be 199,000 m3 or 36.2% of the total capacity of the dam. Water in the dam is used for irrigation of crops through pumping from open wells in the area surrounding the dam. The open wells were widely located in the areas below the dam.. The spread of open wells reached a distance 700 - 800 meters from the dam. Farmers located further from the dam were not able to use water from the dam. Some of them were forced to purchase land located closer to the dam for drilling open wells to be able to get water for irrigating their crops located further downstream. Water was conveyed by PVC pipes and cloth pipes which contributed to the increase of the cost depending on the distance from the dam.

The system of irrigation in the area surrounding the dam has drastically changed in comparison with the time before dam construction. Irrigation is mainly from open wells after dam construction, while it was from open wells and from floods before the dam construction. Water ownership and water rights were mainly collective from the tube wells before the dam construction but private ownerships of open wells started after the dam construction. This means that some farmers are now using irrigation water from open wells for irrigation of their crops and in addition they use their share from the tube wells in the same area. This happens irrespective of their actual demand for irrigation water. This situation has significantly contributed to the low efficiency of water use in the area.

Accurate figures on the level of underground water change as a result of the dam construction are not available. However, discussions with farmers in the area revealed that the level of underground water changes positively and negatively at a rate of 2-3 meters during the dry season and the rainy season respectively. This is evident in the vicinity of the dam. However, in the case of areas located far from the dam open wells run dry of water if dry season is prolonged (Table1).

Table 1. Effect of Mukhtan dam on underground surface water level

Name of the well	Area, ha	Distance from dam (m)	Water depth (m)			Notes
			Rainy season	Dry season	Difference	
Ali Mohamed Gholyse	0.152	500	10	12	+ 2	-
Mohamad Saleh Abdullah	1.74	700	13	16	+ 3	-
Quaid Saleh Jaber	0.871	1200	10	-	-	No water

Results of water analysis in open wells around this dam indicated that water quality is high for irrigation purposes.

Cucumber production in greenhouse

The introduction of greenhouse cultivation with cucumber was very promising in Sa'awan. The yield of cucumber was encouraging and significant portion of the crop was marketed locally due to high demand for cucumber in the area. There was significant reduction in water use for irrigation due to the use of drip irrigation system in the green house. It also rationalized the use of agrochemicals and generated more income from cucumber as a high quality cash crops.

Table 2 shows the performance of cucumber under greenhouse conditions in the 2004/2005 and 2005/2006 growing seasons. The study indicated that the irrigation efficiency was 93-94% and the water use efficiency was increased by using greenhouse with drip irrigation system, as compared to the values commonly obtained by farmers growing the crop in open fields.

Table 2. Performance of cucumber crop under greenhouse conditions in two seasons

Descriptions	Results	
	2004/2005	2005/2006
Number of the plants in the greenhouse	1008	987
Total yield of the greenhouse, kg	7497	7193
Yield per m^2, kg	15.4	14.8
Yield per plant, kg	7.4	7.3
Amount of irrigation water for planting, mm	27	25
Amount irrigation water during the whole growing period, mm	339	328
Crop water evapotranpiration, mm	316	308
Irrigation efficiency, %	93	94
Water productivity, kg/m^3	49	48

Production of cucumber in the greenhouse resulted in the generation of high income, converting the cucumber crop as a high quality cash crops. The average net return was around 150% of the production cost in the two seasons of the study (Table 3).

Table 3. Return of cucumber cultivation under greenhouse

Descriptions	Amount, Y.R.	
	2004/2005	**2005/2006**
Total income	599760	719300
Production costs	230758	288448
Net income	369002	430852
Income rate, %	160	149.4

Grape production using bubbler irrigation

Irrigation technology had an important and a significant impact on the amount of water used in grape production (Table 4).. The yield of grapes irrigated by bubbler system was significantly higher than the yield of the control (surface irrigation). There was significant decrease in water use because of the bubbler irrigation system as compared to the traditional surface irrigation. The bubbler irrigation technology reduced the amount of water used by 1355 m^3 per hectare as compared to the traditional irrigation method. The water use efficiency under bubbler irrigation was on average 3.4 kg/m^3as compared to 1.8 kg/ m^3 under the farmer's practice. The differences were highly significant ($p = < 0.001$).

The relation between water consumption and grape production was quadratic ($Y = -0.0014x2 + 17.937x – 36218$), with a high coefficient of determination ($R^2 = 0.7144$).

Table 4. Water use efficiency of grape production under bubbler and traditional irrigation methods

Years	Type of irrigation	Rain mm	Spate mm	Irrigation		Etc, m^3/ha	Yield, Ton/ha	WUE, Kg/ m^3
				Number	mm			
2005	Bubbler	218	280	4	142	6400	20.0	3.1
	Farmer	218	280	4	285	7830	11.2	1.4
2006	Bubbler	185	-	7	376	5610	20.8	3.7
	Farmer	185	-	7	504	6890	16.0	2.3
Mean	**Bubbler**	**-**	**-**	**-**	**-**	**6005**	**20.4**	**3.4**
	Farmer	**-**	**-**	**-**	**-**	**7360**	**13.6**	**1.8**

Conclusion

The efficiency of use of water from the dam can be significantly improved by growing cucumber in greenhouse conditions using drip irrigation system and growing grapes under bubbler irrigation

in contrast to the traditional practice of surface irrigation followed by farmers in the area. This will lead to more efficient utilization of scarce resource of water in Yemen.

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20. Effect of A-shaped NFT system orientation on strawberry production

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Abstract

With the current challenging situation regarding water availability in Egypt, there is an increased need for water conservation methods. Nutrient Film Technique (NFT) is a hydroponics technique whereby a very shallow stream of water containing all the dissolved nutrients required for plant growth is re-circulated touching the bare roots of plants in a watertight gully. NFT can therefore be a valuable tool in water conservation. This study was conducted on a private farm at Alexandria desert road to investigate the effect of orientation and side of planting on yield and quality of strawberry produced by an A-shaped system under NFT and substrate, during 2005/2006 and 2006/2007. The experiment included three orientations of A-shaped system: North to South (serving as control), East to West, and North to East; two cultivation sides: side one (S1) and side two (S_2) of A-shaped system; and three vertical levels: higher level (L_1), medium level (L_2), and bottom level (L_3) in each side. Results indicated that the A-shaped system oriented towards North- East provided the highest light intensity to the plants, and resulted in the highest total leaf area, and fruit yield. Cultivating the plants on side 1 significantly increased total yield. There was also a significant effect of the level at which the plants were allowed to grow on total leaf area, and total yield. From the overall results it can be concluded that orienting the A-shaped NFT system towards North- East, instead of the traditional North- South, gave higher yield of strawberry.

Introduction

Strawberry is one of the most important crops for export in Egypt. The major constraints in strawberry production in the field are soil pathogens and nematodes, which lead to the reduction in the leaf area of the plants as well as yield of fruits and lower their quality. These problems normally occur because of the continuous cropping of strawberry on the same soil in the greenhouses in an intensive production system. Cropping can only continue in soil if soil disinfection is carried out by using chemicals, especially methyl bromide (Ozeker et al. 1999), which can pollute underground water and contaminate the produce through its residues. Using methyl bromide for soil disinfection is banned in many countries (Jensen and Collins 1985; Benoit 1989) and it will also be prohibited soon in Egypt. Even the other pesticides, alternatives to methyl bromide, can have adverse effects on human health and environment (Ozeker et al. 1999). Soilless cultivation of strawberry can be a good alternative to solve the problems of soil borne diseases and nematodes, besides providing the advantage of improved plant growth, yield and earliness (Granquvist 1981; Van Winden 1988). Vertical soilless systems provide a possibility of increasing plant density in greenhouse more effectively. It has been reported that planting density could be increased three times with the vertical bag system of 240,000 plants/ha compared to the conventional of 80,000 plants/ha under normal planting in soil (Durner 1999).

There are several methods for growing strawberry in vertical soilless culture systems such as pipe system (Lieten 1997), vertical bag (Ozeker et al. 1999) and "A-shaped" NFT system (EL-Behairy et al. 2001; Ahmed et al. 2002). Nevertheless, substrates used in vertical bags should have higher water holding capacity, well aeration and lower bulk density to avoid weight loads to the greenhouse construction (Paraskevopoulov et al. 1990).

Aeroponic system could be one of the vertical soilless culture systems, which might be used successfully for strawberry production without using any substrate. Among the advantages offered by aeroponic cultivation technique over traditional cultivation are the larger surface area dedicated to cultivation, the improved interception of incident radiation for photosynthesis, higher level of automation, and reduced production costs (Van Os 1986). Ahmed et al. (2002) showed that the vertical level of placing the plants and orientation of their arrangement had a significant effect on the production and quality of strawberry. With vertically arranged containers, generally much larger densities can be accommodated than the densities possible under the horizontal arrangement. However, non-uniform light distribution in vertically arranged rows can have a negative impact on plant growth and ultimately fruit yield (El-Behairy 2008).

Durner (1999) reported that 'Sweet Charlie' strawberry plants grown in vertical polyvinyl chloride (PVC) columns filled with perlite at a plant density of 32 plants/m^2 produced a marketable yield of 11.8 kg.m^2. However, yield per plant was reduced by 40 g with every 30 cm decrease in the height of the vertical column of containers, presumably due to suboptimal light conditions in the lower sections. Takeda (2000) reported that the intensity of the photo-synthetically active radiation (PAR) reaching the plant canopy at the bottom end of a vertical tower of seven styrofoam pots was only 10% of that at the top, and the sub-optimum light conditions in the middle and bottom section of the tower adversely affected strawberry plant growth and fruit yield. Van Looy and Aerts (1982) reported that strawberry plants grown in lower sections of an A-frame trough system experienced partial shading and produced a high number of small and malformed fruits, and increased fruit rot and problems in fruit coloration. Besides affecting fruit yield and quality, harvest efficiency in vertical and multiple tier horizontal systems may also be adversely affected since fruit requires harvesting at different heights.

The aim of this study was to investigate the effect of different orientations, sides and the levels at which the strawberry plants were placed in an "A-shaped" system on yield and quality of strawberry.

Material and methods

The experiment was conducted on a private farm located on Cairo-Alexandria desert road (90 km from Cairo) in two seasons (2005/2006 and 2006/2007). Fresh transplants of strawberry (Fragaria x ananassa) cv. Camarosa were moved out from nursery soil and set up in net pots filled with peat moss and vermiculite (1:1v/v). for use in a NFT system mounted on an " A-shaped system" consisting of a triangular iron frame with dimensions of 100×100×80cm. A PVC pipe (4 inch in diameter) worked as gully fixed on this frames at the height of 40cm from the soil surface (to be the bottom level), 25cm above the bottom level (to be the middle level) and 25cm above the middle level (to be the top level). Plants were placed at a 25cm distance from each other in the holes perforated in the PVC pipe. System was oriented depending on the treatments.

Three factors were tested in this experiment. The first factor included two sides of the A- shaped system, namely S_1 and S_2. The second factor consisted of three vertical levels of placement of the

pots, as mentioned above (L_1, L_2, and L_3, being the top, middle and bottom levels, respectively). The third factor was the orientation of the system: North -South (O_1), East-West (O_2) and North -East (30° from the North, O_3).

The nutrient solution used in the experiments was as described by El-Behairy (1994). Electrical conductivity was maintained between 2.5 and 3.0 mMohs/cm and the pH between 5.5 to 6.0 throughout the course of the experiment. System was irrigated from tank filled with diluted nutrient solution. The nutrient solution was withdrawn by 48 watt submersible pump via 18 mm irrigation pipe to lateral pipes (4 mm diameter), connected to the upper end of the NFT gutter. The flow of the nutrient solution was 2 liters per hour. The nutrient solution was collected from each gutter by a plastic funnel fixed in the lower end of the gutter. The nutrient solution was switched 17 times a day for 15 minutes each time.

Transplants held in net pots were transferred to their final place inside the holes of PVC pipes on 15/10/2005 and 20/10/2006 in the two seasons.

The experiment was arranged in split-split plot design with three replicates. The plant density of each replicate was 40 plants. The following data were collected: 1) Light intensity (foot-candle) received by plants, measured by a digital light meter model FCM-10M (average), 2) total leaf area (cm^2) and 3) total yield (g/plant). Data were statistically analyzed as factorial experiment (Snedicor and Cochran 1980). Duncan's multiple range test was used for comparing the treatment means.

Results

Light intensity: Data in Table 1 show the effect of system orientation on light intensity received by strawberry plant. Plants received highest light intensity in the north- east orientation followed by east- west and then north- south. The differences among the treatments were significant. Plants grown on S_1 side received higher light intensity compared to S_2 and the difference was significant. Plants placed at L_1 received maximum light followed by those at L_2. The plants at L_3 received minimum light. The differences among the treatments were significant.

The highest light intensity was received by the plants cultivated in the system oriented north-south in S_2L_1 followed by east- west S_1L_1without significant differences between them. The lowest light intensity was received by the plants oriented east- west in S_2L_3 setting.

Total leaf area: Data in Table 2 showed that plants oriented north- east recorded the highest total leaf area followed by the plants oriented east- west and the lowest total leaf area was produced from the north-south orientation. Data also showed that the plants grown in S_1 had higher leaf area than S_2 plants. The highest total leaf area was obtained with plants placed at L_1 level, followed by L_2, and L_3 in that order.

The highest total leaf area was obtained with the combination $O_2S_1L_1$. The lowest leaf area value was found with the combination $O_2S_2L_3$.

Total yield per plant: All the main effects were significant. The system oriented north-east recorded, on average, the highest total yield followed by the east- west orientation, while the lowest total yield was obtained from north- south orientation. On average, S_1 gave higher total yield than S_2. On average, L_1 gave the highest total yield followed by L_2 and L_3.

Table 1. Effect of "A-shape NFT" system orientation on mean light intensity (foot/candle) received by plants

Orientation	Side	Levels			
		L_1	L_2	L_3	Means
First season					
(N-S) O_1	S_1	410.75 ab	161.75 j	52.5 k	208.33 E
	S_2	416.75 a	187.5 i	43.5 l	215.92 D
	Mean	413.75 A	174.63 E	48 G	212.13 C
(E-W) O_2	S_1	408.75 ab	351.25 d	292.5 f	350.83 A
	S_2	397 c	43.75 l	30.75 m	157.17 F
	Mean	402.86 B	197.50 D	161.63 F	254.00 B
(N-E) O_3	S_1	407.25 b	330.75 e	253.25 g	330.42 B
	S_2	403 bc	203.75 h	60.5 k	222.42 C
	Mean	405.13 B	267.25 C	156.88 F	276.42 A
Level x side interaction					
	S_1	408.92 A	281.25 B	199.42 C	296.53 A
	S_2	405.58 A	145.00 D	44.92 E	198.50 B
Levels mean		407.25 A	213.13 B	122.17 C	247.51
Second season					
O_1	S_1	407.75 ab	162.00 j	51.00 l	206.92 E
	S_2	413.50 a	183.25 i	45.25 l	214.00 D
	Mean	410.63 A	172.63 E	48.13 G	210.46 C
O_2	S_1	403.75 bc	347.00 d	286.75 f	345.83 A
	S_2	398.75 c	45.75 l	32.50 m	159.00 F
	Mean	401.25 B	196.38 D	159.63 F	252.42 B
O_3	S_1	403.00 bc	326.25 e	246.50 g	325.25 B
	S_2	397.50 c	200.75 h	63.75 k	220.67 C
	Mean	400.25 B	263.50 C	155.13 F	272.96 A
Orientation * side interaction					
	S_1	404.83 A	278.42 B	194.75 C	292.67
	S_2	403.25 A	143.25 D	47.17 E	197.89
Levels mean		404.04 A	210.83 B	120.96 C	245.28

The three-way interaction was significant. The highest total yield was obtained by the plants cultivated in the system oriented east-west with S_1L_1 setting. This was followed by the plant oriented north-east S_1L_1 and S_2L_1 settings. The lowest total yield was obtained by plants cultivated in system oriented east-west with a setting of S_2L_3.

Table 2. Effect of "A-shape NFT" system orientation on total leaf area (cm^2)/ plant

Orientation	Side	Levels			
		L_1	L_2	L_3	Means
First season					
(N-S) O_1	**S_1**	1606.25 j	1543.75 k	1482 l	1544.00 E
	S_2	1686.25 i	1588.75 j	1498.75 l	1591.25 D
	Mean	1646.25 G	1566.25 H	1490.38 J	1567.63 C
(E-W) O_2	**S_1**	2612.5 a	2406.25 c	2240 f	2419.58 A
	S_2	1412.5 m	1320 n	1281.25 o	1337.92 F
	Mean	2012.50 D	1863.13 E	1760.63 F	1878.75 B
(N-E) O_3	**S_1**	2463.75 b	2313.75 d	2090 g	2289.17 B
	S_2	2273.75 e	2116.75 g	2015 h	2135.17 C
	Mean	2368.75 A	2215.25 B	2052.50 C	2212.17A
Level x side interaction					
	S_1	2227.50 A	2087.92 B	1937.33 C	2084.25 A
	S_2	1790.83 D	1675.17 E	1598.33 F	1688.11 B
Levels mean		2009.17 A	1881.54 B	1767.83 C	1886.18
Second season					
O_1	**S_1**	1620.00 j	1545.00 kl	1472.50 m	1545.83 E
	S_2	1687.50 i	1581.25 k	1515.50 l	1594.75D
	Mean	1653.75 G	1563.13 H	1494.00 J	1570.29C
O_2	**S_1**	2615.00 a	2417.50 c	2248.75 e	2427.08 A
	S_2	1426.25 n	1327.50 o	1285.75 p	1346.50 F
	Mean	2020.63 D	1872.50 E	1767.25 F	1886.79 B
O_3	**S_1**	2470.00 b	2317.50 d	2087.50 g	2291.67 B
	S_2	2280.00 de	2130.00 f	2022.75 h	2144.25C
	Mean	2375.00 A	2223.75 B	2055.13 C	2217.96 A
Level x side interaction					
	S_1	2235.00 A	2093.33 B	1936.25 C	2088.19 A
	S_2	1797.92 D	1679.58 E	1608.00 F	1695.17 B
Levels mean		2016.46 A	1886.46 B	1772.13 C	1891.68

Table 3. Effect of "A-shape NFT" system orientation on total yield (g/plant)

Orientation	Side	Levels			
		L_1	L_2	L_3	Means
First Season					
O_1	S_1	320.75 c	209.75 h	117 j	215.83 E
	S_2	329 c	225 g	113.75 j	222.58 D
	Mean	324.88 C	217.38 G	115.38 J	219.21 C
O_2	S_1	377.5 a	347.5 b	267.5 e	330.83 A
	S_2	302.5 d	162 i	91.75 k	185.42 F
	Mean	340 B	254.75 E	179.63 H	258.13 B
O_3	S_1	355.5 b	325.5 c	240 f	307.00 B
	S_2	353.5 b	303 d	210 h	288.83 C
	Mean	354.5 A	314.25 D	225.00 F	297.92 A
Level x side interaction					
	S_1	351.25 A	294.25 C	208.17 E	284.56 A
	S_2	328.33 B	230.00 D	138.50 F	232.28 B
Levels mean		339.79	262.13	173.33	258.42
Second season					
O_1	S_1	317.50 de	210.50 h	159.50 i	229.17 D
	S_2	325.75 cd	224.00 gh	118.00 j	222.58 DE
	Mean	321.63 C	217.25 E	138.75 G	225.88 C
O_2	S_1	374.00 a	344.75 bc	263.00 f	327.25 A
	S_2	304.50 e	164.25 i	94.50 k	187.75 E
	Mean	339.25 A	254.50 D	178.75 F	257.50 B
O_3	S_1	350.50 b	326.25 cd	234.25 g	303.67 B
	S_2	358.00 ab	304.50 e	210.00 h	290.83 C
	Mean	354.25 B	315.38 C	222.13 E	297.25 A
Level x side interaction					
	S_1	347.33 A	293.83 C	218.92 E	286.69 A
	S_2	329.42 B	230.92 D	140.83 F	233.72 B
Levels mean		338.38 A	262.38 B	179.88 C	260.21

Discussion

From the overall results it is clear that orienting the A-shaped NFT system towards north - east instead of north - south or east - west increased the light intensity received by both sides of the system; the increase was about 30% over the north - south orientation and about 19.7 % over the east – west orientation. At the same time, orienting the system north - east reduced the difference in light intensity received on the two sides of the A-shaped setup. Similarly, under this orientation, the differences in the light intensity received at various vertical positions (levels) was also reduced. From that it is clear that orienting the system north - east increased the light received by strawberry plants in the second and third levels compared with the other orientations. This increase of the distribution of the light intensity resulted in an increase in the uptake of N by strawberry plants which increased the vegetative growth as expressed in total leaf area. The increase in the vegetative growth reflected on increase the photosynthesis, which increased the yield. Bish et al. (1997) Hennion et al. (1997), Ahmed et al. (2002) and El-Behairy (2008) found that bigger plants produced higher yields because of higher leaf area that increased the photosynthesis. Anagnostou and Vasilakakis (1994) attributed the low productivity of strawberry to the low level of photosynthetic energy reaching the strawberry plants. Wilson and Copper (1969) found that an increase in light intensity produced bigger stomata in the leaf than in lower light intensity.

In this study, plants grown on the S_1 received about 33% light intensity higher than those plants grown o the S_2 and the percentage increase of the yield was about 18 %. Vlachonasios et al. (1994) and El-Behairy (2008) found that strawberry plants grown in the south side produce higher yield than those grown in the north side because of more light intensity, as also reported by Ahmed et al. (2002) Bish et al. (1997) and Hennion et al. (1997). Plants raised in the upper level gave the highest plant growth and yield as well as fruit quality (data not reported here). Cultivating the plants at the lower level reduced the yield by about 49 % compared with the plant on the top. These plants were exposed to 70 % lower light intensity than those at the top level. This reduction of light intensity reduced leaf area and reduced the photosynthesis which reduced the yield. Ceulemans et al. (1986) mentioned that high light intensity (more than 650µ mol/m^2/sec) is required for increasing leaf area. Takeda (2000) reported that the intensity of photosynthetically active radiation reaching the plant canopy at the bottom end of a vertical tower of seven styrofoam pots was only 10% of that received at the top, and the sub-optimum light conditions in the middle and bottom section of the tower adversely affected strawberry plant growth and fruit yield. Van Looy and Aerts (1982) reported that strawberry plants grown in lower sections of an A-frame trough system experienced partial shading and produced a high number of small and malformed fruits, increased fruit rot, and adversely affected the fruit coloration.

Conclusion

It can be concluded that orienting the strawberry plants in an A-shaped system in the plastic houses installed from north to south (recommended in Egypt) is not the best orientation because both the sides of "A- shaped system" did not receive an equal amount of light intensity. The best orientation should be 30º from North to the West to give chance for plants on both sides and at various levels to receive an equal light intensity to get higher yield and quality.

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21. Prediction of tomato yield under climate change conditions by using simulation model

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Abstract

This study was carried out during the summer season of 2007, at two locations in Egypt (Tall El-kabeer in Ismailia Governorate and Al-Khanka in Qaluobiya Governorate), to assess the impact of three transplanting dates (10 March, 1 April and 20 April) and three levels of nitrogen fertilizer (150, 180 and 210 kg N/fed.) on tomato yield ('Super Strain B' cultivar) under current climatic conditions. The DSSAT (Decision Support System for Agro-technology Transfer) software tool was run with data on weather, soil and experimental results in order to predict tomato yield under climate change conditions. Predicted and measured yields were comparable. The DSSAT was able to simulate tomato crop performance under current conditions with a difference of only 0.3 to 0.6 % from the actual yield. The potential impact of climate change on tomato production was evaluated by simulating different locations, planting dates and N levels with the climate change scenario A_1 by the years 2025s, 2050s, 2075s and 2100s compared to that under the current conditions of 2007 season. Using the future climate data, a yield reduction from -8 to -24% was predicted without adaptation for the years of 2025 to 2100. The negative impact was decreased (-3 to -15%) when planting date was advanced by 30 days from the normal planting date.

1. Introduction

Tomato (*Lycopersicon esculentum* Mill., synonym *Solanum lycopersicon*) is one of the most important vegetable crops grown under outdoor and indoor conditions. It has become an important commercial crop in Egypt as far as the cultivation area (40 % from the total vegetable cultivated area), production, industrial values and its contribution to human nutrition is concerned. Tomato can grow under a wide range of temperatures; however its fruit set is limited to a narrow range. Relatively low or high temperatures lead to poor fruit set. The critical factor in tomato fruit setting is the night temperature, the optimal range being 15-20° C (Went 1945). Fruit set is also low when the average maximum night/day temperature is above 32° C and the average minimum night temperature is above 21 ^{o} C (Moore and Thomas 1952).

Tomato is also highly responsive to application of nitrogenous fertilizers and amongst various horticultural crops, it generally receives a large amount of nitrogen (Parisi et al. 2006). Nitrogen is a unique mineral nutrient because, unlike the other essential nutrient elements,it can be taken up by plants both as cation (NH_4^+) and anion (NO_3^-) (Miller and Donahue 1990).

In the past, a dynamic tomato growth and yield model was developed by Jones et al. (1991) in order to simulate the response to dynamically changing temperature, solar radiation and CO_2 concentration inside the greenhouse. Recently, scientists succeeded to establish a direct single relationship between growth (and yield) and a single climatic parameter such as temperature in a thermal time approach (Rouphael *et al*. 2006).

There is a widely-held scientific conviction that the global climate is changing as a result of the combined anthropogenic forcing due to greenhouse gases, aerosols, and land surface changes. Many pieces of evidence have concluded, with a high degree of probability, that human activities have exerted a substantial net warming influence on climate since 1750 (IPCC 2007). Recent climatological studies found that the global surface air temperature increased from 1850 to 2005 by 0.76º C. There is a linear warming trend over the last 50 years at the rate of 0.13º C per decade (IPCC 2007).

The present investigation was done to study the impact of climate change on tomato productivity, and to find out the best suitable adaptation option to mitigate the negative impacts of climate change on tomato production.

2. Materials and methods

2.1 Field experiment

Field experiments were carried out during the summer season of 2008 at two locations in Egypt (Al-Khanka, Qaluobyia Governorate and Tall El-kabeer, Ismailia Governorate) to assess the impact of three different transplanting dates (10 March, 1 April and 20 Aprilh) and three different levels of nitrogen fertilizer (150, 180 and 210 Kg N/feddan; 2.38 feddan= 1 ha) on tomato yield (Super Strain B cultivar) under current climatic conditions. Plots were arranged in a split plot design with three replications. The transplanting dates were in main plots and N fertilizer levels were in sub-plots. Each sub-plot contained 10 rows, 15 m long and at an iter-row spacing of 0.7 m. The whole amount of N fertilizer was added to plants with irrigation (fertigation) during the period of crop growth. All the recommended cultural practices for growing tomato were performed. Daily weather data, maximum and minimum temperatures (°C), solar radiation (MJ/m2) and rainfall (mm) were obtained for each location (Table 1).

Table 1. Average climatic data during the summer season of 2008 **at two sites ***

Location	Solar radiation (W/m^2)	Temperature (ºC)		Rain fall (mm)
		Maximum	Minimum	
Qaluobiya	169.0	30.4	16.9	0.0
Ismailia	183.0	28.2	17.2	0.0

Data obtained from the Central Laboratory for Agricultural Climate (CLAC), ARC, Egypt.

2.2 Validating the CROPGRO-tomato model with the field experiment

Collected data was used by CROPGRO-tomato model to simulate and predict tomato growth, development and yield. The CROPGRO-model developed by Hoogenboom et al. (1994) was adapted to simulate growth of tomato by Boote et al. (2002). The experiment data were prepared on the basis of IBSNAT (1988) data set. The validation was done by using current daily weather data given in Table 1, soil analysis, genetic coefficients, and crop data for studied regions (Ismailia and Qaluobiya), which were sufficient as input for crop modeling study.

The validation was done by comparing the measured data with the predicted one through the DSSAT program, conducted in three steps, i.e. retrieving the data (converting data to CROPGRO-tomato & IBSINAT), validating the data (comparing between predicted and observed data) and running the model.

2.3 Climate change data

The climatic data under climate change conditions during the years 2025, 2050, 2075 and 2100 of the experimental locations were developed (Table 2) based on the current monthly weather data and the regional temperature increases used in scenario A1 using the MAGICC 4.1/SCENGEN climate model tool (Wigley et al. 2003).

Table 2. Avarage future temperature (^{o}C) data (scenario A_1) for tomato in summer season*

Locations	2025		2050		2075		2100	
	Max. temp.	Min. temp.	Max. temp.	Min. temp.	Max. temp.	Min. temp.	Max. temp.	Min. temp.
Qaluobiya	31.6	18.1	32.4	18.9	33.1	19.6	33.5	20.0
Ismailia	29.4	18.4	30.2	19.2	30.9	19.9	31.3	20.3

** MAGICC 4.1/ SCENGEN climate model.*

2.4 Option to mitigate the negative impacts of climate change on tomato production

The adaptation here is narrowly defined as change in the planting date. A simulation study was carried by shifting the planting date by one month before the current planting dates (March 10th, April 1st and April 20th 2008) in order to study the impact of climate change on production of tomato with A1 scenario.

3. Results and discussion

3.1 Field experiment

Results showed that the main effects and interactions between locations, transplanting dates and N levels were significant in affecting yield per plant.

Plants of the first date (10 March) produced the highest yield and decreased as the planting was delayed (Table 3). These results could be attributed to cumulative effect of gradual increases in the temperature in summer, especially the day temperature (maximum temperature). The earliest transplanting date at Ismailia location recorded the best yields. These results are in agreement

with those obtained by Jamwal et al. (1995). Went (1945) and Went and Cospar (1945) reported that the critical factor in tomato fruit setting is the night temperature, the optimal range being 15 - 20 ^{o} C. Fruit set is also low when the average maximum night/day temperature is above 32 ^{o} C and the average minimum night temperature is above 21 ^{o} C (Moore and Thomas 1952).

Data also indicated that the N levels had a great effect on yield per plant, and the N level of 210 kg/fed produced the higher yield. Interaction between locations and N levels was significant. An application of N at level of 210 kg/fed in Ismailia location recorded the highest value, while the N level of 150 kg/fed in Qaluobiya location gave the lowest values. Interaction between transplanting dates and N levels affected yield per plant, and the application of N at level of 210 kg/fed in the first date recorded the highest value, while the level of 150 kg/fed in the third date gave the lowest value. These results are in harmony with those obtained by Akanbi et al. (2003) and Direkvandi et al. (2008).

3.2 Validating the CROPGRO-tomato model with the field experiment data under Egyptian conditions

A comparison between data obtained through field experiment and the predicted data obtained by the DSSAT software for tomato yield (Kg/ha) is presented in Table 3. The difference between the predicted and observed data ranged from 0.3 to 0.6 %. Paired T-test showed no significant difference between the predicted and observed data. Results of validation experiment indicated that the CROPCRO-tomato crop model can be used successfully to predict the yield under Egyptian conditions. These results are in agreement with those obtained by Heuvelink (1995 and 1996) and Medany (2006) who found that model showed good agreement between measured and simulated fraction of dry matter partitioned into the fruits over time, and vegetative growth (plant height, leaf area, leaf area index, fruit number and yield). Jones et al. (1999) also found that the observed and simulated values for LAI, total plant weight, fruit weight and mature fruit weight of tomato were very close to each other. Rinaldi et al. (2007) reported that the model proved to be a useful decision support system to help the farmers to verify the optimal crop management strategy.

3.3 Expected yield of tomato under climate change conditions by DSSAT

The potential impact of climate change on tomato yield was evaluated by simulating the effect of different planting dates, locations and N levels on tomato production with climate change Scenario (A_1) by the years of 2025, 2050, 2075 and 2100 as compared to that predicted under the current conditions for the year of 2008 (Tables 4-7). The tomato yield differed according to planting dates, locations, N levels and climate change scenario. The difference between current (2008) and predicted yield under climate change increased with time, from -8 to -24 %, by the years of 2025, 2050, 2075 and 2100 (Tables 4-7). The predicted temperature increase affected crop production negatively. The third planting date recorded the highest decrease followed by the second and the first one and Ismailia location recorded higher decrease than Qaluobiya location.

3.4 Option to reduce of the negative impacts of climate change on tomato production

Tables 4-7 showed that climate change scenario (A_1) could decrease tomato yield in different planting dates by the years of 2025, 2050, 2075 and 2100, compared to predicted yield under the current conditions (season of 2008). In order to reduce this negative impact of climate change, changing planting date from Mar. 10th to Feb. 10th could be used. The results indicated that tomato yield increased gradually compared to no-adaptation treatment.

Table 3. Effect of locations, transplanting dates and N levels on actual and estimated tomato yield, during summer season in 2008

Planting dates	N kg/ha	Qaluobiya			Ismailia		
		Predicted kg/ha	Measured kg/ha	% difference	Predicted kg/ha	Measured kg/ha	% difference
10 Mar	150	14044.9	14000.1	0.3	26466.1	26326.6	0.5
	180	16744.7	16664.8	0.5	29143.8	29022.7	0.4
	210	18309.8	18218.4	0.5	31373.9	31193.2	0.6
1 Apr	150	11884.3	11812.4	0.6	12793.5	12720.6	0.6
	180	14831.0	14751.2	0.5	14892.1	14848.3	0.3
	210	16387.5	16304.9	0.5	17325.4	17264.5	0.4
20 Apr	150	7326.4	7297.1	0.4	9889.4	9830.4	0.6
	180	8818.9	8776.5	0.5	12276.8	12226.5	0.4
	210	11208.1	11138.4	0.6	14007.7	13951.6	0.4

Correlation coefficient = 1.00; T – Value = 8.58; P value = 0.00

*Table 4. Effect of location, transplanting date and N levels on tomato yield under futuristic climate change conditions in the year 2025, with and without adaptation intervention**

Planting dates	N levels Kg/fed.	Qaluobiya					Ismailia				
		Predicted 2008 Kg/Ha	Without adaptation 2025 (Kg/Ha)	% of predicted 2008	With adaptation* 2025 (Kg/Ha)	% of predicted 2008	Predicted 2008 Kg/Ha	Without adaptation 2025 (Kg/Ha)	% of predicted 2008	With adaptation* 2025 (Kg/Ha)	% of predicted 2008
Mar., 10th	150	14044.9	12622.1	**-10.1**	13323.0	**-5.1**	26466.1	23493.9	**-11.2**	24822.5	**-6.2**
	180	16744.7	15215.9	**-9.1**	16051.5	**-4.2**	29143.8	26162.4	**-10.2**	27625.4	**-5.2**
	210	18309.8	16821.2	**-8.1**	17734.9	**-3.2**	31373.9	28478.1	**-9.2**	30053.0	**-4.2**
Apr., 1st	150	11884.3	10407.1	**-12.4**	10998.9	**-7.5**	12793.5	11071.5	**-13.5**	11717.5	**-8.4**
	180	14831.0	13135.8	**-11.4**	13874.4	**-6.5**	14892.1	13036.6	**-12.5**	13788.6	**-7.4**
	210	16387.5	14678.3	**-10.4**	15494.4	**-5.5**	17325.4	15340.0	**-11.5**	16214.9	**-6.4**
Apr., 20th	150	7326.4	6269.2	**-14.4**	6632.5	**-9.5**	9889.4	8374.3	**-15.3**	8864.8	**-10.4**
	180	8818.9	7634.5	**-13.4**	8071.9	**-8.5**	12276.8	10518.7	**-14.3**	11127.6	**-9.4**
	210	11208.1	9815.0	**-12.4**	10370.9	**-7.5**	14007.7	12141.9	**-13.3**	12836.7	**-8.4**

** Advancing planting date by 30 days*

*Table 5. Effect of location, transplanting date and N levels on tomato yield under futuristic climate change conditions in year 2050 with and without adaptation intervention**

Planting dates	N levels Kg/fed.	Qaluobiya					Ismailia				
		Predicted 2008 Kg/Ha	Without adaptation 2050 (Kg/Ha)	% of predicted 2008	With adaptation* 2050 (Kg/Ha)	% of predicted 2008	Predicted 2008 Kg/Ha	Without adaptation 2050 (Kg/Ha)	% of predicted 2008	With adaptation* 2050 (Kg/Ha)	% of predicted 2008
Mar., 10th	**150**	14044.9	12324.4	**-12.3**	13018.2	**-7.3**	26466.1	22969.9	**-13.2**	24282.6	**-8.3**
	180	16744.7	14860.9	**-11.3**	15688.1	**-6.3**	29143.8	25585.4	**-12.2**	27030.9	**-7.2**
	210	18309.8	16433.1	**-10.2**	17337.6	**-5.3**	31373.9	27856.9	**-11.2**	29413.0	**-6.3**
Apr., 1st	**150**	11884.3	10195.5	**-14.2**	10775.5	**-9.3**	12793.5	10854.0	**-15.2**	11487.2	**-10.2**
	180	14831.0	12871.8	**-13.2**	13595.6	**-8.3**	14892.1	12783.4	**-14.2**	13520.6	**-9.2**
	210	16387.5	14386.6	**-12.2**	15186.3	**-7.3**	17325.4	15045.4	**-13.2**	15903.0	**-8.2**
Apr., 20th	**150**	7326.4	6129.2	**-16.3**	6502.9	**-11.2**	9889.4	8187.4	**-17.2**	8672.0	**-12.3**
	180	8818.9	7466.0	**-15.4**	7915.8	**-10.2**	12276.8	10286.7	**-16.2**	10888.3	**-11.3**
	210	11208.1	9600.9	**-14.3**	10172.5	**-9.3**	14007.7	11877.2	**-15.2**	12563.5	**-10.3**

**Advancing planting date by 30 days*

*Table 6. Effect of location, transplanting date and N levels on tomato yield under futuristic climate change conditions in year 2075 with and without adaptation intervention**

Planting dates	N levels Kg/fed.	Qaluobiya					Ismailia				
		Predicted 2008 Kg/Ha	Without adaptation 2075 (Kg/Ha)	% of predicted 2008	With adaptation* 2075 (Kg/Ha)	% of predicted 2008	Predicted 2008 Kg/Ha	Without adaptation 2075 (Kg/Ha)	% of predicted 2008	With adaptation* 2075 (Kg/Ha)	% of predicted 2008
Mar., 10th	**150**	14044.9	11893.2	**-15.3**	12581.4	**-10.4**	26466.1	22160.0	**-16.3**	23472.8	**-11.3**
	180	16744.7	14346.9	**-14.3**	15167.4	**-9.4**	29143.8	24693.6	**-15.3**	26139.1	**-10.3**
	210	18309.8	15870.9	**-13.3**	1678.1	**-8.4**	31373.9	26896.8	**-14.3**	28453.0	**-9.3**
Apr., 1st	**150**	11884.3	9848.5	**-17.1**	10430.8	**-12.2**	12793.5	10458.6	**-18.3**	11085.5	**-13.4**
	180	14831.0	12438.7	**-16.1**	13165.5	**-11.2**	14892.1	12323.2	**-17.2**	13053.0	**-12.3**
	210	16387.5	13908.1	**-15.1**	14711.0	**-10.2**	17325.4	14510.1	**-16.3**	15359.0	**-11.3**
Apr., 20th	**150**	7326.4	5911.6	**-19.3**	6279.4	**-14.3**	9889.4	7888.8	**-20.2**	8373.3	**-15.3**
	180	8818.9	7204.1	**-18.3**	7646.8	**-13.3**	12276.8	9915.9	**-19.2**	10517.5	**-14.3**
	210	11208.1	9268.0	**-17.3**	9830.7	**-12.3**	14007.7	11454.1	**-18.2**	12140.5	**-13.3**

**Advancing planting date by 30 days*

*Table 7. Effect of location, transplanting date and N levels on tomato yield under futuristic climate change conditions in year 2100 with and without adaptation intervention**

Planting dates	N levels Kg/fed.	Qaluobiya					Ismailia				
		Predicted 2008 Kg/Ha	Without adaptation 2100 (Kg/Ha)	% of predicted 2008	With adaptation* 2100 (Kg/Ha)	% of predicted 2008	Predicted 2008 Kg/Ha	Without adaptation 2100 (Kg/Ha)	% of predicted 2008	With adaptation* 2100 (Kg/Ha)	% of predicted 2008
Mar., 10th	**150**	14044.9	11353.9	**-19.2**	12042.1	**-14.3**	26466.1	21112.0	**-20.2**	22408.8	**-15.3**
	180	16744.7	13703.9	**-18.2**	14524.4	**-13.3**	29143.8	23539.5	**-19.2**	24967.5	**-14.3**
	210	18309.8	15167.9	**-17.2**	16065.0	**-12.3**	31373.9	25654.4	**-18.2**	27191.7	**-13.3**
Apr., 1st	**150**	11884.3	9375.5	**-21.1**	9960.2	**-16.2**	12793.5	9958.4	**-22.2**	10585.3	**-17.3**
	180	14831.0	11848.5	**-20.1**	12578.1	**-15.2**	14892.1	11741.0	**-21.2**	12470.7	**-16.3**
	210	16387.5	13255.8	**-19.1**	14062.1	**-14.2**	17325.4	13832.6	**-20.2**	14681.6	**-15.3**
Apr., 20th	**150**	7326.4	5618.6	**-23.3**	5986.4	**-18.3**	9889.4	7493.2	**-24.2**	7974.8	**-19.4**
	180	8818.9	6851.4	**-22.3**	7294.1	**-17.3**	12276.8	9424.9	**-23.2**	10022.7	**-18.4**
	210	11208.1	8819.7	**-21.3**	9382.3	**-16.3**	14007.7	10893.8	**-22.2**	11576.0	**-17.4**

**Advancing planting date by 30 days*

Rinaldi (2009) observed that the early sowing times could reduce the adverse effect of climate change on tomato, where 20 days for A_2 scenario and 10 days for B_2 scenario, were enough to eliminate the negative effect on fruit yield. Attaher et al. (2009) indicated that more than 70% of the total sample respondents considered that "changing the cultivars" is the most important adaptation measure to reduce the negative impacts of climate change on agriculture system in the Nile Delta region in Egypt; whereas, increasing irrigation and changing sowing dates came to be the next important adaptation priorities.

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Theme 3: Enhancing resilience of local agricultural communities in drylands through adaptation strategies

Theme 3b: Animal production and pasture management

1. Tolerance to abiotic stresses in Egyptian Barki desert sheep and goats raised under hot-dry conditions: Individual variations

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Abstract

The study was designed to analyze individual variations in physiological responses to heat and the combined stresses of heat and exercise under hot-dry conditions in indigenous Barki desert sheep and goats. Sixty ewes and twenty six does were exposed to natural heat stress under solar radiation in Northern Coastal Zone of Egypt, between 12:00 and 15:00 hr, in July and August. The same animals were also exposed to physical exercise stress by walking for 7 ±0.25 km (with average speed of 115 m/min) under direct solar radiation at similar timing. Biological parameters including; thermal, respiratory and metabolic ones, were measured before and after treatments. Results indicated that both heat and the combined heat and exercise stresses increased significantly ($p<.001$) most of the studied biological measures in both sheep and goats, while tidal volume (TV) decreased significantly ($p<.001$) with these abiotic stresses. Heat production (HP), based on respiration performance and gas exchange, decreased significantly ($p<.001$) with heat stress, and slightly with exercise. Accordingly, the main thermoregulatory mechanisms to tolerate heat stress were to increase respiratory heat loss and to decrease HP in sheep, while goats relied mostly on reduction in HP.

Tolerance to the combined stress of heat and exercise, in both species, depends on shallow rapid panting (increased respiration rate and reduction in TV) and on reducing HP. Respiratory evaporation increased detectably more in sheep than in goats. It is concluded that indigenous Barki sheep and goats can tolerate heat stress, and to lesser extend exercise under heat stress with clear individual variability. A tolerance index was developed to assess individual animal tolerance to abiotic stress, based on the changes in respiration rate (RR), rectal temperature (RT), tidal volume (TV), and heat production (HP) as indicators for comfort, mild and severe stress conditions. Animals were scored, if the change exceeds $\pm 2\sigma$ of the biological measure at rest condition (pre-stress). Accordingly, animals were classified into 5 groups, six does (23%), and ten ewes (17%) showed high tolerance to both heat and exercise stresses. The non-tolerant ewes and does were 13% and 8% of the animals, respectively. Results reflect higher tolerance of goat than sheep to abiotic stress under hot-dry conditions.

Introduction

About 97% of the land area in Egypt is desert and arid. Sheep and goats are the main livestock raised in these areas, and significantly contribute to the livelihood of the communities living there. Environmental conditions in the desert areas are harsh, animals face the challenge of regulating their physiological parameters under the hot-dry conditions, in addition to facing the scarcity of pasture and water.

According to the Intergovernmental Panel on Climate Change (IPCC 2007) "the most likely expectations for the Mediterranean region are increase in annual mean temperatures and maximum summer temperatures more than the global mean; both annual precipitation and number of precipitation days are very likely to decrease and risk of summer drought is likely to increase". These projections reflect increase in abiotic stress to animals in such hot-dry areas, with negative impacts on their performance and thus affecting adversely the livelihood of the vulnerable desert communities and their ability to cope with the expected climatic change. One of the main adaptation strategies to cope with such climatic change is the selection of animals with effective thermoregulatory mechanisms which can be included in their genetic evaluation based on reliable heat stress indicators.

The North-Western Coastal Zone (NWCZ) of Egypt represents the hot dry area in Egypt with annual rain fall <150 ml, with 2-3 months of poor/medium quality range grazing in winter, and scarce vegetation over long summer months. Indigenous Barki sheep and goats are raised there and are known to be adapted and perform well under the prevailing hot-dry conditions (Elsherbini et al. 1984; Abou-Naga et al. 1985).

This study aims to investigate and assess inter- and intra-species variation among the indigenous desert sheep and goats in tolerance to abiotic stresses under hot-dry conditions, and to analyze gene expression related to individual variations in tolerance to abiotic stresses.

Material and methods

Sixty Barki ewes and 26 Barki does at a non-reproductive status, aging 3-5 years, were utilized in the study. They were exposed to heat and the combined stress of physical exercise and heat under solar radiation during July and August 2009. The experiment was carried out at Borg-Arab Research Farm, Animal Production Research Institute, located in the hot dry area of Costal Zone of the Western Desert (CZWD), 45 Km West of Alexandria (Latitude: 31° 31' 12" N; Longitude: 30° 10' 12" E; Elevation: 54 meters). In the heat stress trial, animals were exposed to natural heat under direct solar radiation in the period from 12:00 to 15:00 hr in July and August. After two weeks of rest, the same animals were exposed to physical exercise under heat stress, in which animals were encouraged to walk under direct solar radiation in the period from 12:00 to 15:00, for 7±0.25 km, with an average speed of 115 m/min (simulating grazing on poor pasture). Biological parameters were measured pre-and post-exposure to stresses.

Meteorological parameters such as ambient temperature (AT), relative humidity (RH %), atmospheric pressure, and black bulb temperature were recorded. Temperature-Humidity Index (THI) was calculated according to Hahn et al. (2003). Table 1 presents average meteorological parameters recorded at rest (under shade), and during the exposure to heat and exercise stresses (under direct solar radiation). According to standards given by Hahn et al. (2003) the calculated THI indicates that the animals were exposed to severe heat stress (THI between 108 and 119).

Thermal biological measurements included rectal temperature (RT, °C); skin temperature (ST, °C), and ear temperature (ET, °C); whereas respiratory measurements were respiration rate (RR, resp/min) and respiratory minute ventilation (MV, l/min) measured at rest and post stress for each individual. Tidal volume was calculated as (MV/RR), and rate of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were measured using an open-circuit technique. Exhaled air was analyzed for O_2 and CO_2 using Servomex 570 Gas Analyzer. Heat production (HP) (fasting metabolic rate, kcal.$BW^{0.75}$.day) was calculated using the equation of Brouwer (1965). The measurement of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were made using the open-circuit technique according to Yousef and Dill (1969).

Table 1. Meteorological parameters recorded during the trial

	Rest	Heat	Exercise
Ambient temperature (C^0)	27.41^c	47.39^b	52.25^a
Relative humidity (%)	73.22^a	26.05^b	18.47^c
THI	71.93^c	108.65^b	119.14^a

Numbers followed by the same symbol did not differ significantly (P<.05) according to Duncan (1955)

Analysis of variance for the independent effects of species, stress treatment and their interaction on changes in physiological parameters (pre- and post-treatment) was performed.

A stress tolerance index was developed to assess each animal's tolerance to heat and exercise stress based on pre- and post-exposure changes in the main four biological parameters; RR, RT, TV, and HP. Animals were scored if the change due to the stress treatment exceeded a value of $\pm 2\sigma$ of the biological parameter means, measured under the rest conditions. Accordingly, animals were classified into 5 groups; (1) animals that showed no change, or increase of either RR or TV (most tolerant); (2) animals that showed change in RT alone, RR+TV or RR+RT; (3) animals that showed changes in RT+TV or RR+RT+TV; (4) animals that decreased their HP with any other change in other physiological parameters, and finally (5) animals that increased their HP with any other change in their physiological parameters (least tolerant).

Results and discussion

Inter-species variation

Analysis of variance (Table 2) indicated that differences between the two species were statistically significant (p<.001) only for RR. This finding reflects different ability of the two species in controlling abiotic stress through panting. On the other hand, stress treatment showed significant effects (p<.001) on all the studied biological parameters except TV. For none of the studied traits there was any significant interaction between treatments and species indicating that both species follow similar biological trends in response to abiotic stresses.

Thermal physiological measures (RT, ST and ET) increased significantly (p<.001) with abiotic stress. Changes in RT and ET differed significantly (p<.001) between the two stresses and insignificantly for ST in sheep. For goats RT showed significant differences (P<.001) between the two stresses, but no such differences were noticed for ST and ET. Species difference in ear temperature indicated that ears play significant roles in heat loss in goats than in sheep,

through vasodilatation. Skin temperature is related to external heat load than the internal one. The significant increase in RT with abiotic stress indicated that heat loss in both species was insufficient to dissipate the heat gain. Accordingly, rectal temperature seems to be better indicator for measuring animal physiological response to heat stress than either ST or ET.

Table 2. ANOVA for changes in physiological parameters

Physiological parameter	Species	Stress	Species x Stress
	P	P	P
Rectal temperature (ºC)	0.0697	0.0001	0.4017
Respiration rate (resp/min)	0.0001	0.0001	0.1116
Tidal volume[1] (ml/min)	0.4806	0.6742	0.2243
Heat production (kcal.$BW^{-.75}$.day^{-1})	0.1051	0.0005	0.3349

Table 3. Pre- and post-exposure physiological parameters in sheep and goats

Specie	Parameter	Stress treatment			P
		Rest	Heat	Exercise	
Sheep	**RT**	39.18±0.07^{c}	40.08±0.07^{b}	40.55±0.07^{a}	0.0001
	ST	36.27±0.16^{b}	39.38±0.16^{b}	39.58±0.16^{a}	0.0001
	ET	34.98±0.18^{c}	37.29±0.18^{b}	37.82±0.18^{a}	0.0001
	RR	31.73±3.98^{c}	90.65±3.98^{b}	129.88±3.98^{a}	0.0001
	MV	01.57±0.08^{c}	01.85±0.08^{b}	02.93±0.08^{a}	0.0001
	TV	54.73±1.81^{a}	23.38±1.81^{b}	25.98±1.81^{b}	0.0001
	HP	17.18±1.00^{b}	11.35±1.00^{a}	15.88±1.00^{b}	0.0003
Goat	**RT**	39.04±0.11^{c}	40.05±0.11^{b}	40.67±0.11^{a}	0.0001
	ST	36.74±0.25^{b}	39.59±0.25^{a}	39.12±0.25^{a}	0.0001
	ET	33.62±0.28^{b}	37.56±0.28^{a}	37.71±0.28^{a}	0.0001
	RR	28.69±6.04^{c}	51.54±6.04^{b}	71.77±6.04^{a}	0.0001
	MV	01.45±0.13^{a}	01.32±0.13^{b}	01.53±0.13^{a}	0.0416
	TV	53.81±2.75^{a}	28.74±2.75^{b}	23.39±2.75^{b}	0.0001
	HP	20.01±1.51^{a}	09.56±1.51^{b}	17.51±1.51^{a}	0.0001

Numbers followed by the same symbol did not differed significantly (P<.05) according to Duncan (1955)

Changes in respiratory parameters (RR and MV) showed significant differences between the two stresses in both sheep and goats, but with larger increase in RR in sheep in response to abiotic stress (Table 3). Change in respiratory evaporation (MV) of sheep, in response to exercise stress, was 46.4% as against 5.2% in goats. A significant decrease (p<.001) in TV with both heat and exercise stresses, in the two species, reflected that accelerating panting was a major physiological mechanism in response to abiotic stress.

HP significantly decreased (p<.001) with heat stress in both sheep and goats, while the difference was statistically non significant with the exercise stress in both species. Animals regulate their

response to heat stress mainly by decreasing their metabolic activities. However, they were not able to fully control that with the need to produce more energy for their physical exercise. Sejian et al. (2011) indicated that although Malpura ewes are adapted for long distance walking, the latter affects significantly their body weight, RR and RT; adrenal and thyroid glands hormone plays a significant role in such adaptation.

It is concluded from these results that Barki desert sheep and goats were able to tolerate to some extent the heat and exercise stress, although a significant increase in body temperature (by about 1ºC after exposure and 1.5ºC after exercise) means that they did not reach their upper critical temperature. Khalifa et al. (2005) found that a temperature range of 20 – 27.5 °C is the comfort zone of Egyptian valley goats, while a range of 27.5 – 32 ºC represents moderate heat stress, and severe heat stress occurs at ≥33 °C. In sheep the comfort zone ranged from 20 - 25°C, moderate heat stress zone ranged from 25 – 28 °C and severe heat stress occurred at ≥28 °C.

Intra-species variation

Individual changes in RT due to abiotic stresses ranged between 0 and 2.3 °C in sheep with heat stress, and up to 3.0°C due to exercise stress. Individual changes in goats, ranged between 0 to 2.6°C due to heat stress and between 0.5 and 2.8°C due to exercise stress. Ewes that showed limited changes in RT due to heat tended to show the same under physical exercise (Fig. 1). The same trend was recognized in goats (Fig 5).

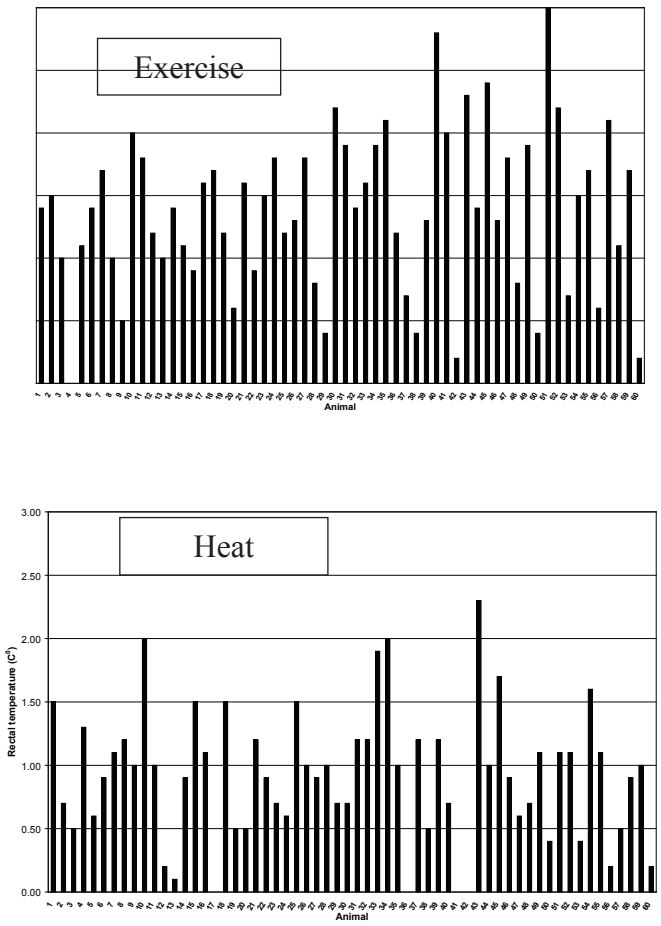
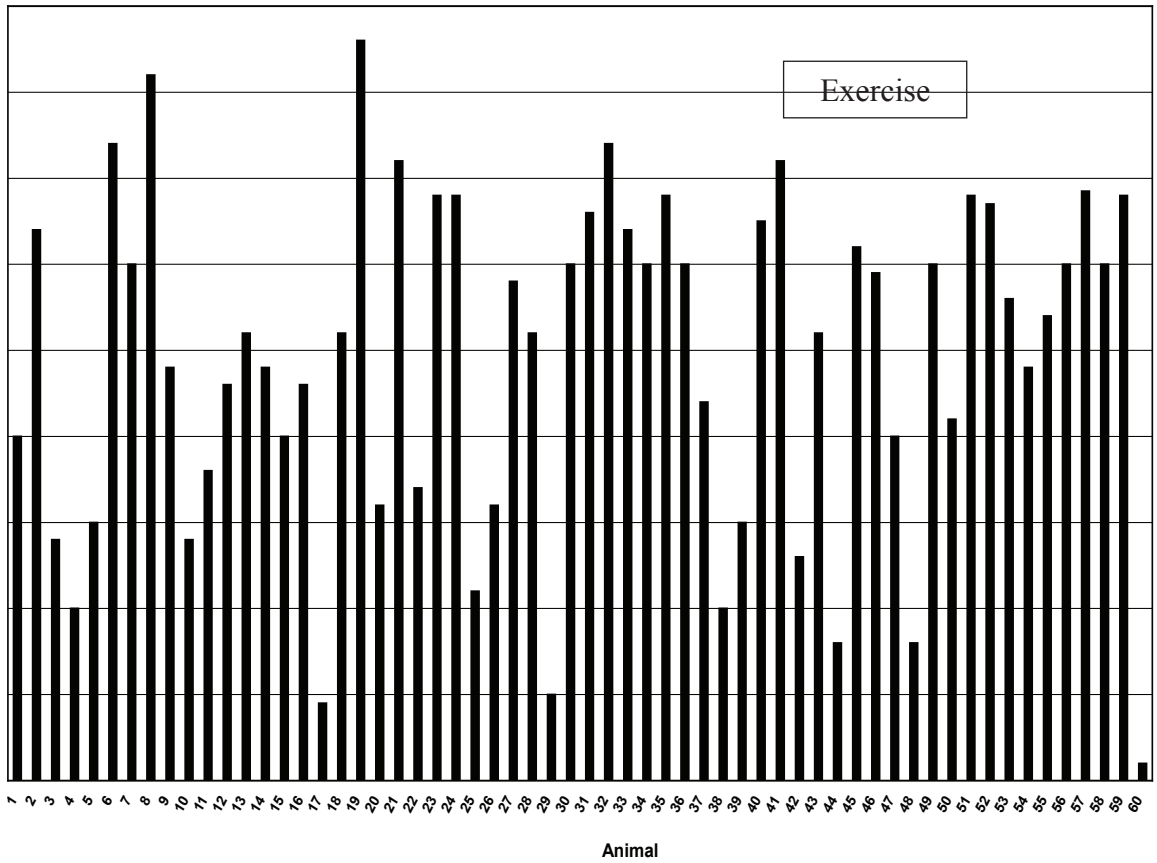


Fig.1. Change in RT due to heat stress and exercise stress in sheep



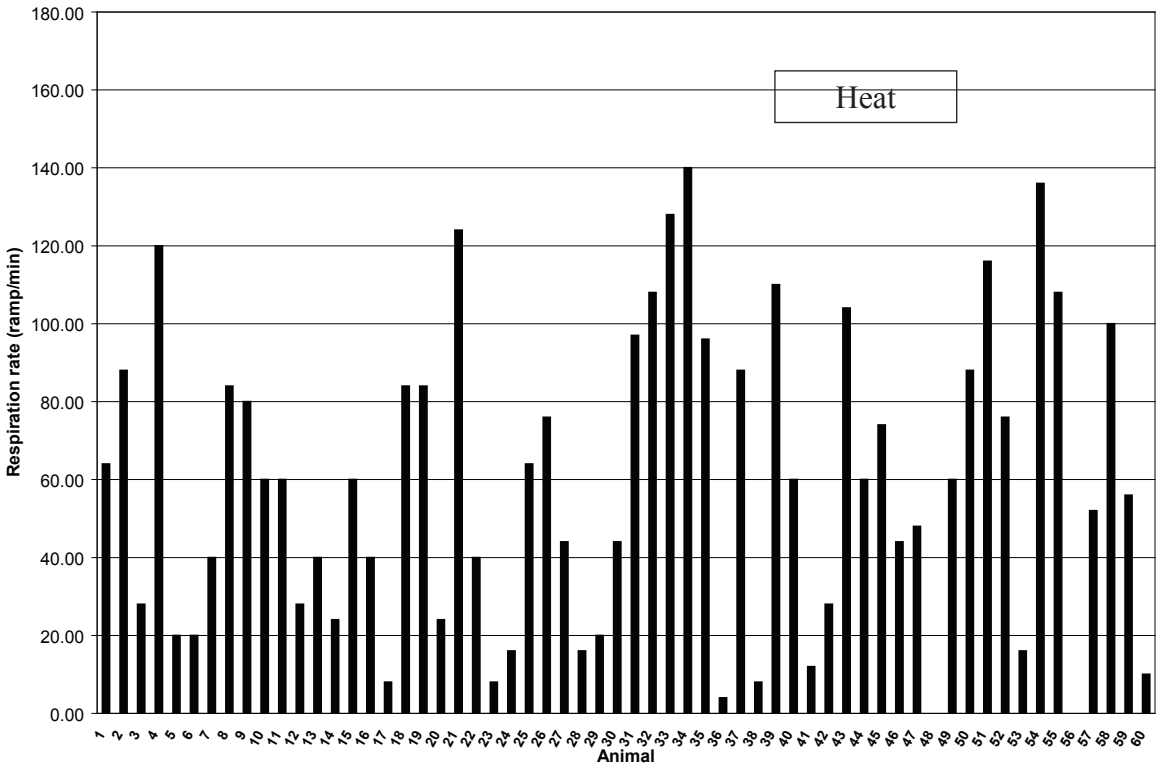
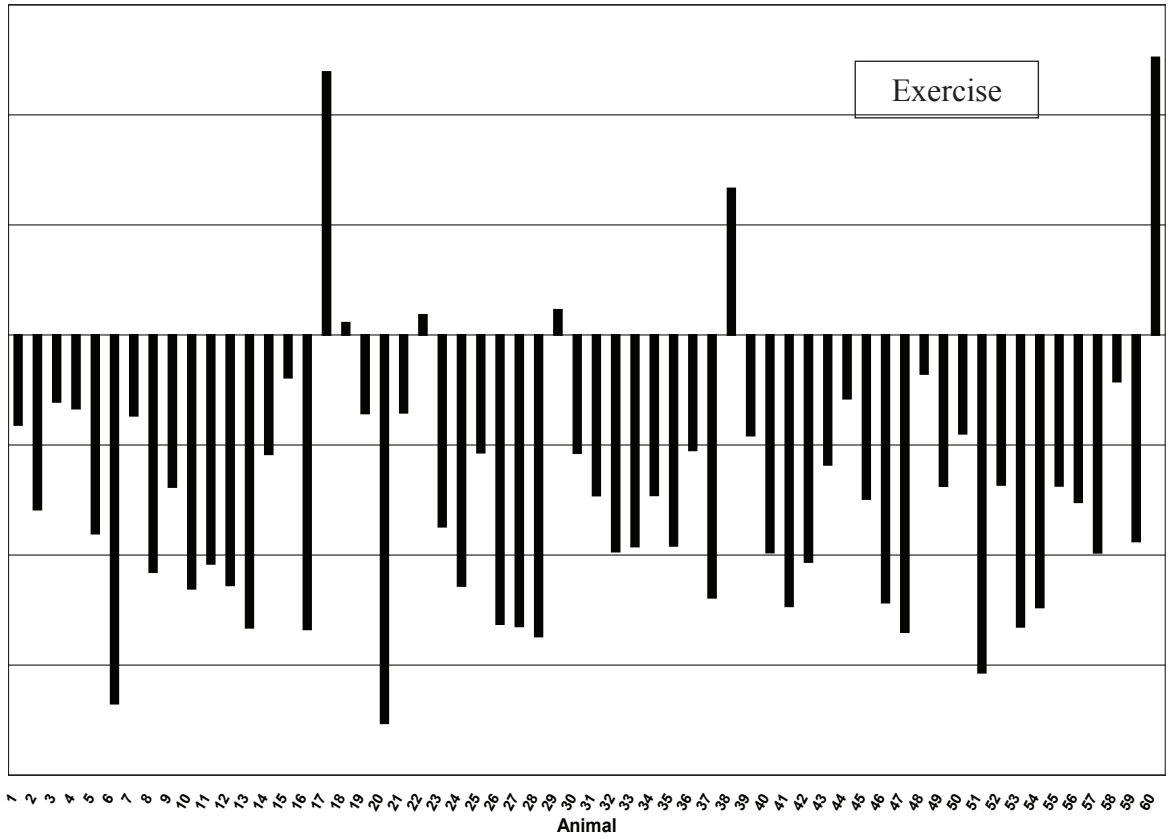


Fig.2. Change in RR due to heat stress and exercise stress in sheep



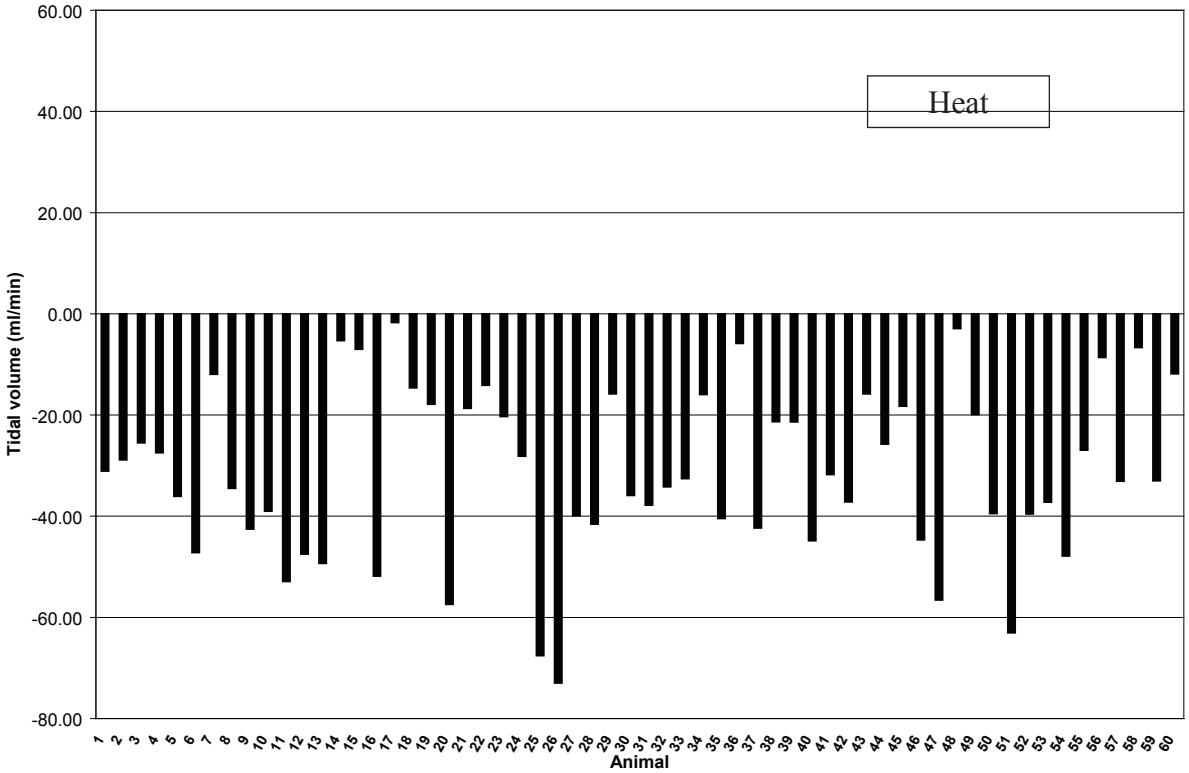
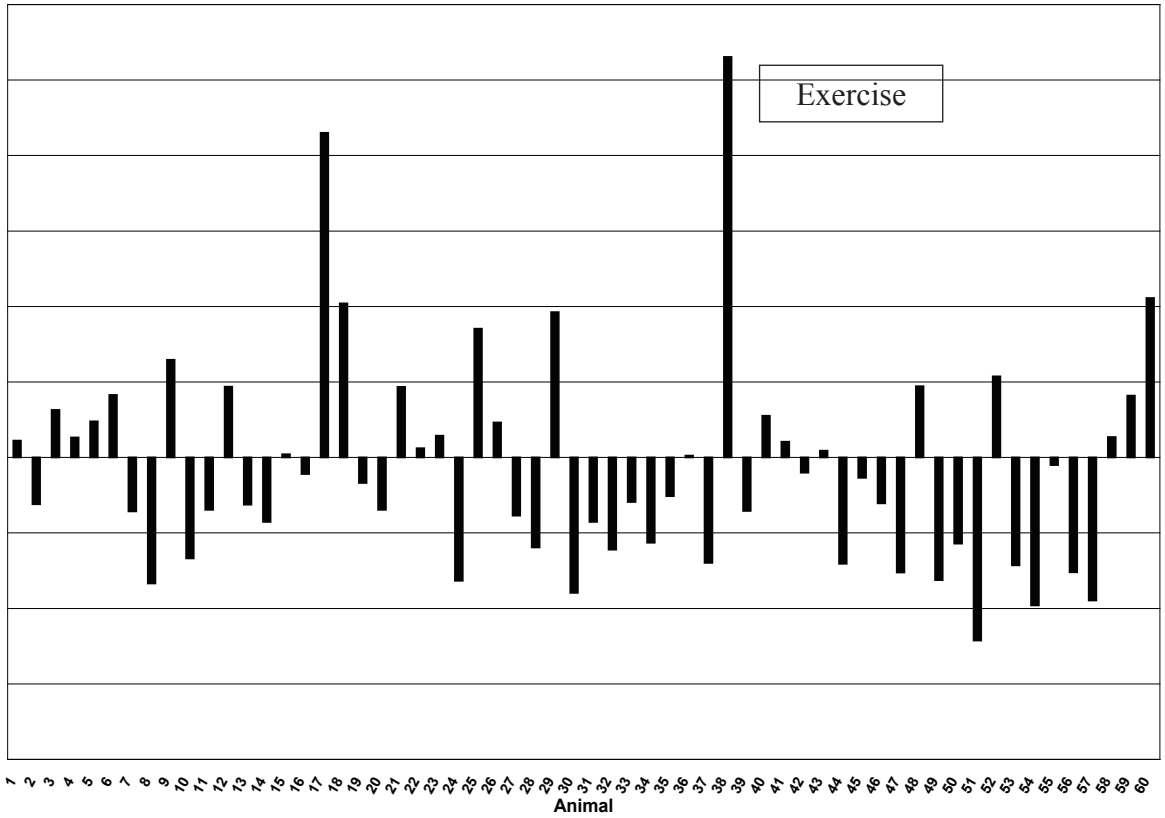


Fig.3. Change in TV due to heat stress and exercise stress in sheep



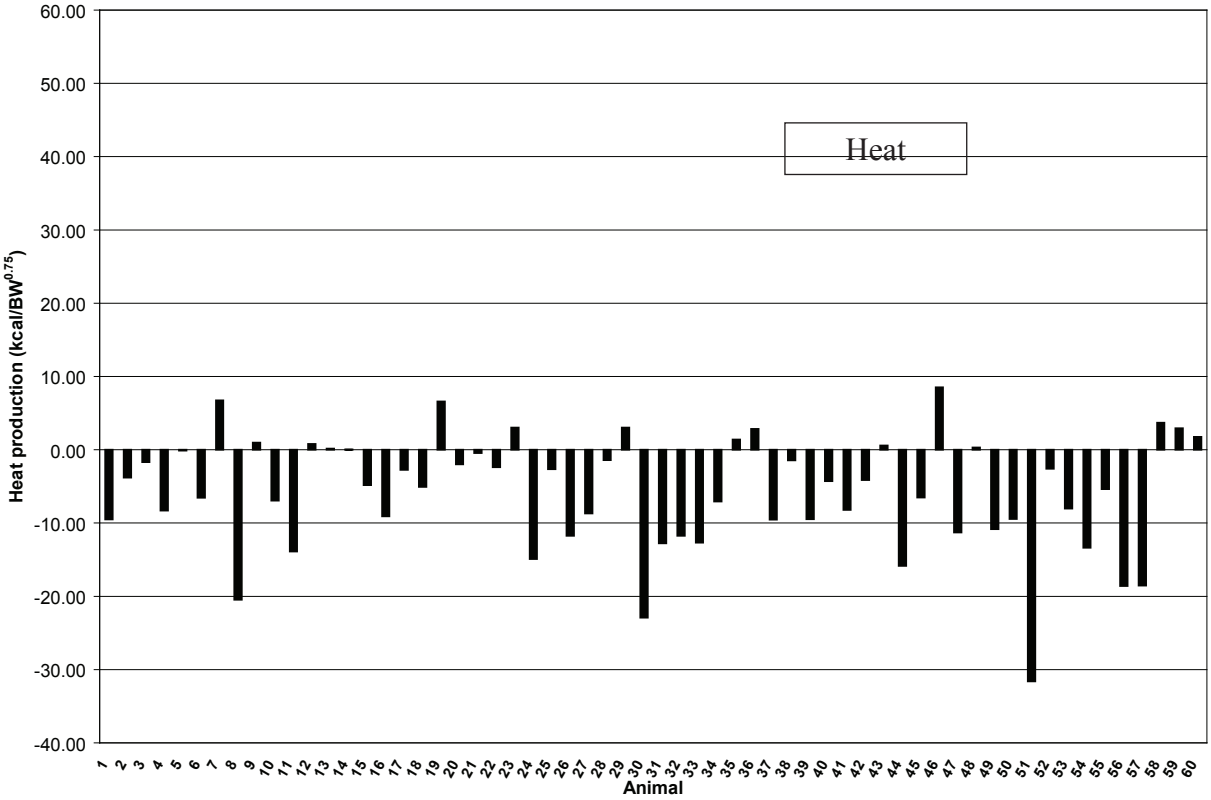
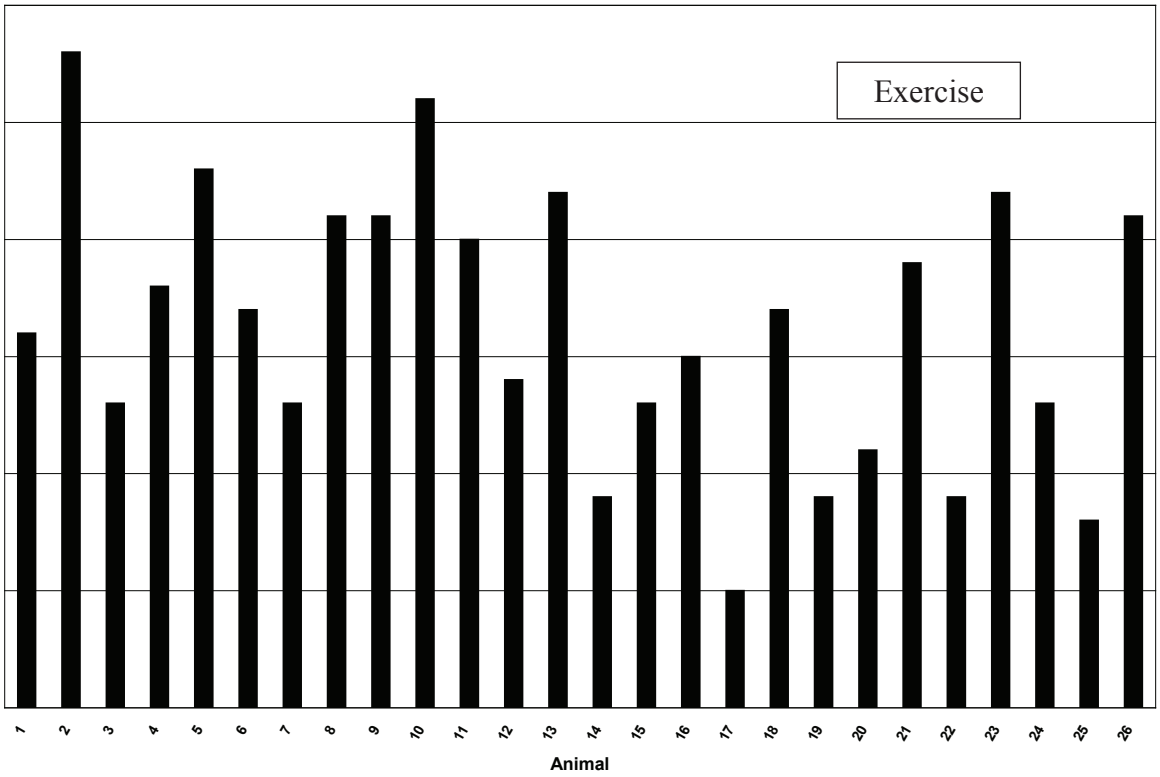


Fig.4. Change in HP due to heat stress and exercise stress in sheep



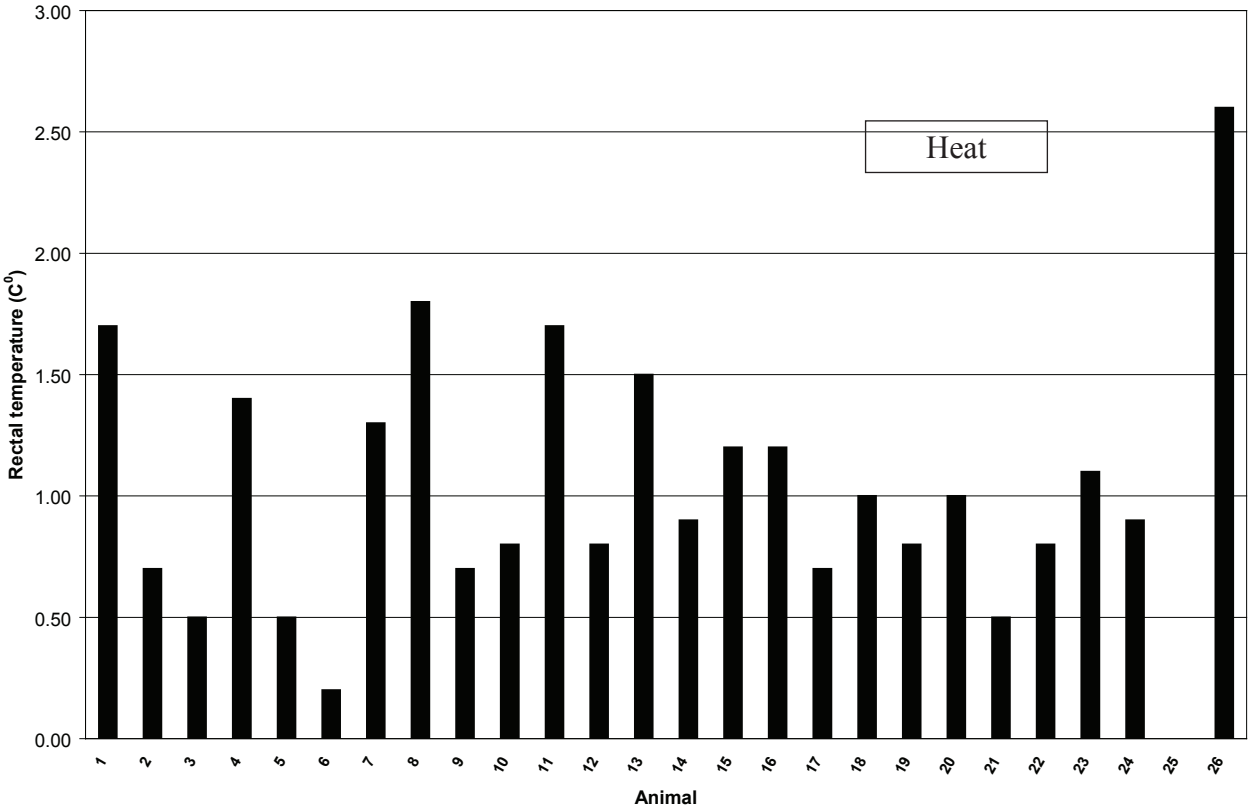


Fig.5. Change in RT due to heat stress and exercise stress in goat

Wide individual variation was seen in RR in response of the studied ewes to abiotic stresses. The change ranged between 0 resp/min up to 140 resp/min with heat stress; and from 4 to 172 resp/min with physical exercise. Ewes showing smaller changes in RR were common under both stresses (Fig. 2) and interestingly the ones that showed low changes in their RT. In goats RR changes showed narrower range; it ranged between 0 and 92 resp/min under heat stress and up to 136 resp/min under physical exercise (Fig. 6).

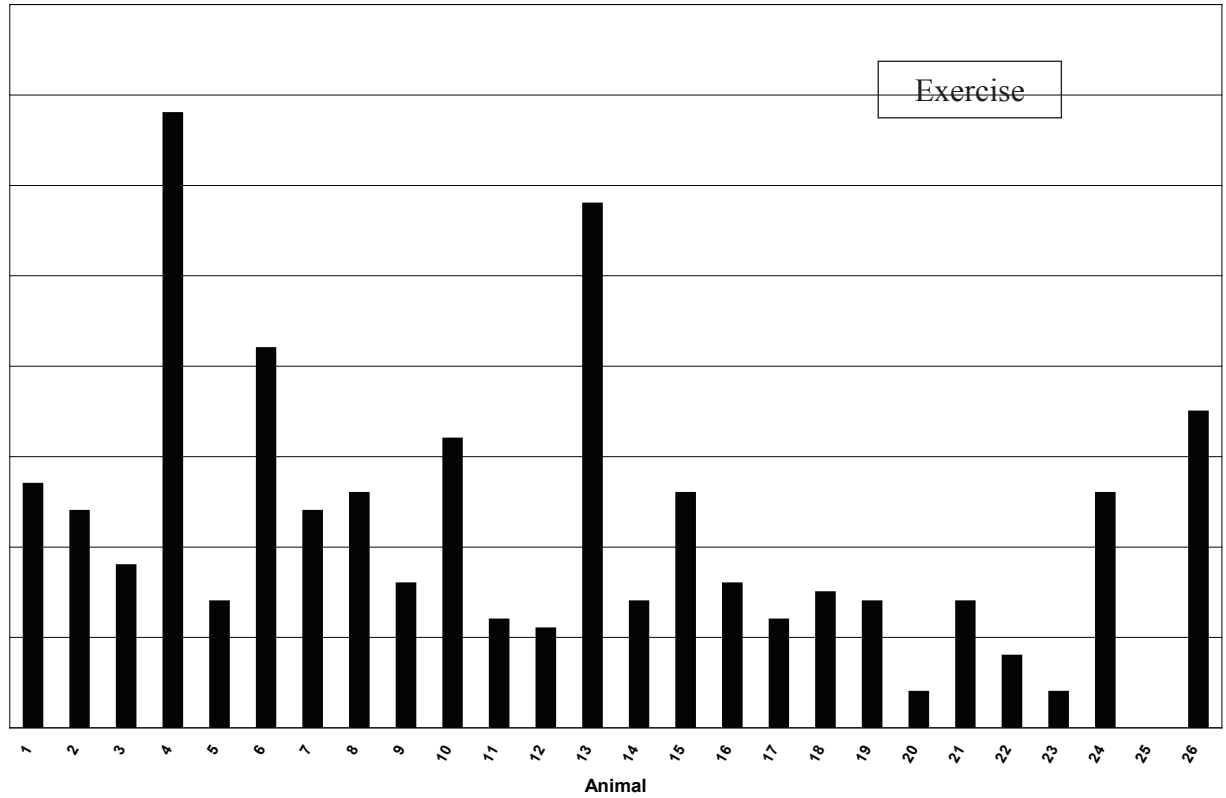
Individual variation in HP in response to heat stress was within similar range in both sheep and goats (-31.6 to +8.5, and from -31.6 to +0.5, respectively). Under exercise stress, some ewes showed extreme changes in HP (more than 50% change of their value at rest in 2 ewes). These ewes were considered as the least tolerant to abiotic stress. The goats study showed similar trend, but the maximum increase in HP was only 20% in 3 does (Fig. 8).

Table 4. Distribution of sheep, according to tolerance score

Stress		Exercise stress					
	Score	**1**	**2**	3	4	5	**Total (%)**
Heat stress	**1**	**2**	**6**	4	1	4	**17 (28.3)**
	2	**2**	11	6	2	1	**22 (36.7)**
	3	1	5	6	1	**1**	**14 (23.3)**
	4	0	0	0	**7**	**0**	**7 (11.7)**
	Total (%)	**5 (8.3)**	**22 (36.7)**	**16 (26.7)**	**11 (18.3)**	**6 (10)**	**60 (100)**

Table 5. Distribution of goats, according to tolerance score

Stress		Exercise stress					
	Score	**1**	**2**	**3**	**4**	**5**	**Total (%)**
Heat Stress	**1**	1	5	2	0	1	**9 (34.6)**
	2	0	4	1	1	0	**6 (23.1)**
	3	0	2	3	0	0	**5 (19.2)**
	4	2	1	1	2	0	**6 (23.1)**
	Total (%)	**3 (11.5)**	**12 (46.2)**	**7 (26.9)**	**3 (11.5)**	**1 (3.9)**	**26 (100)**



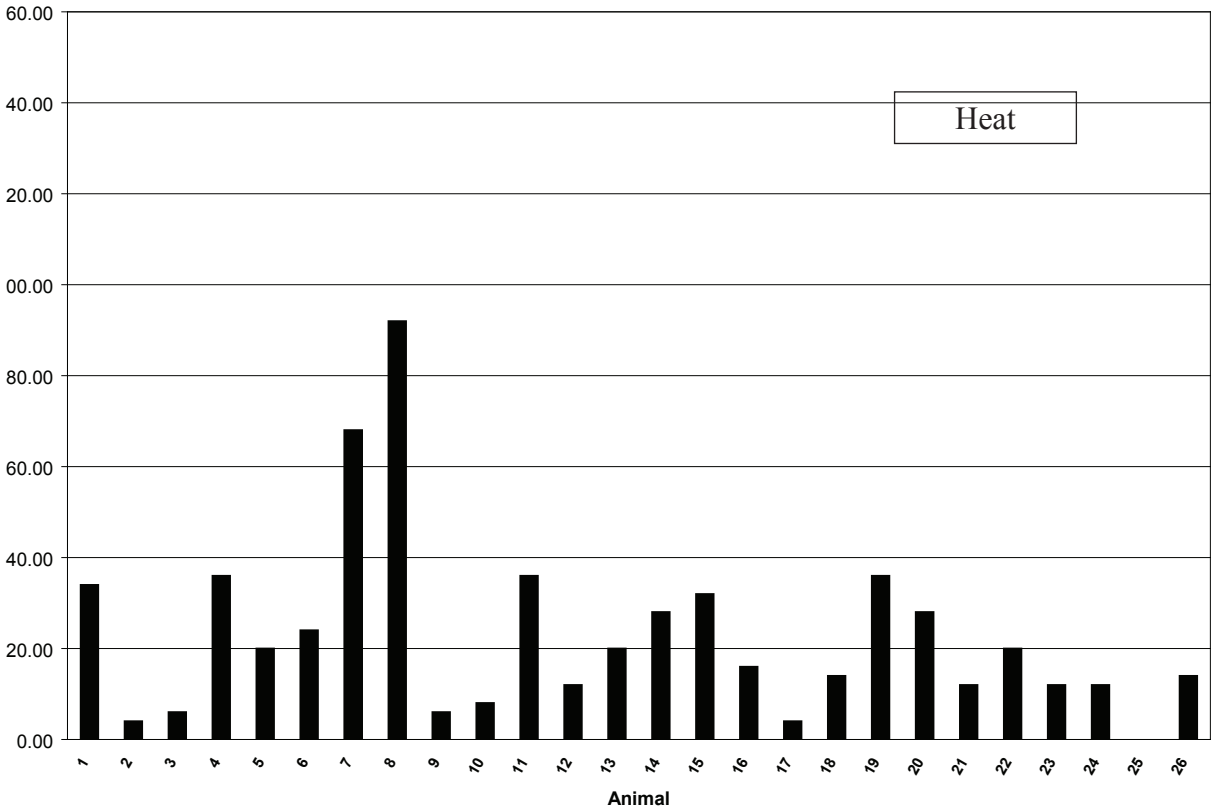
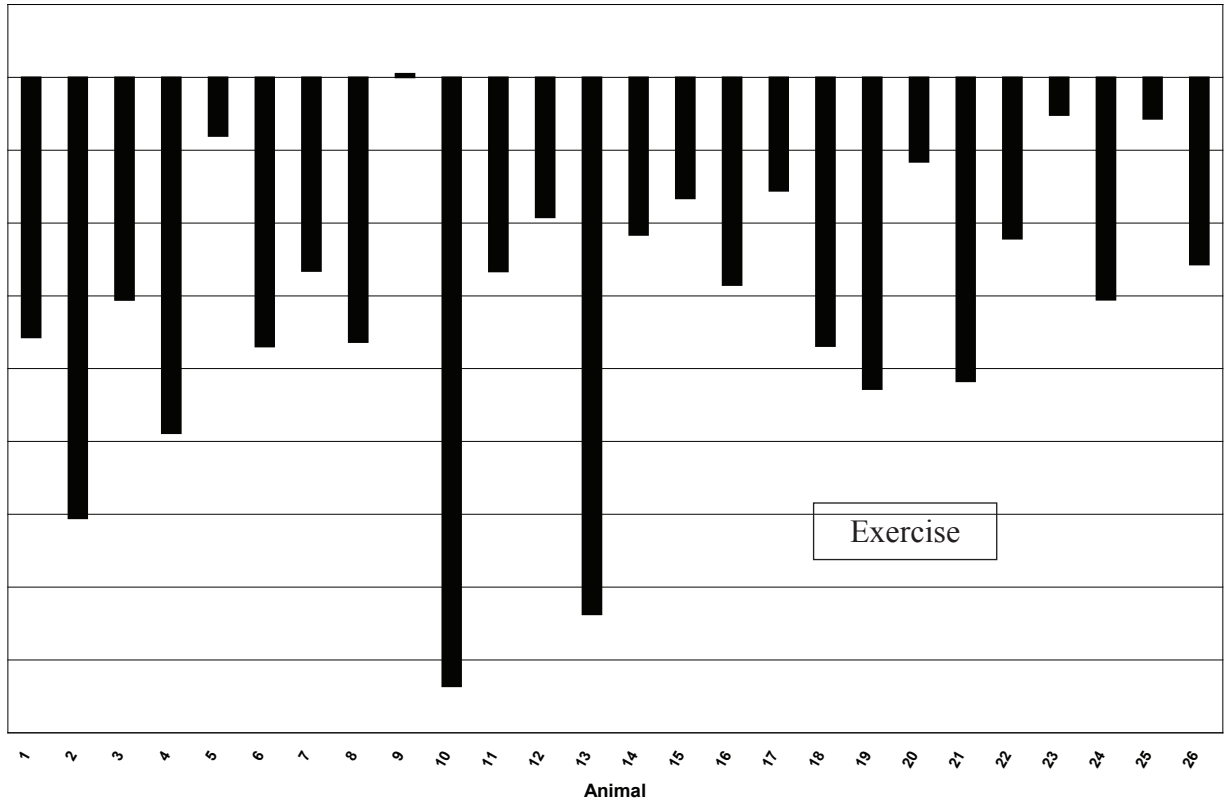


Fig.6. Change in RR due to heat stress and exercise stress in goat



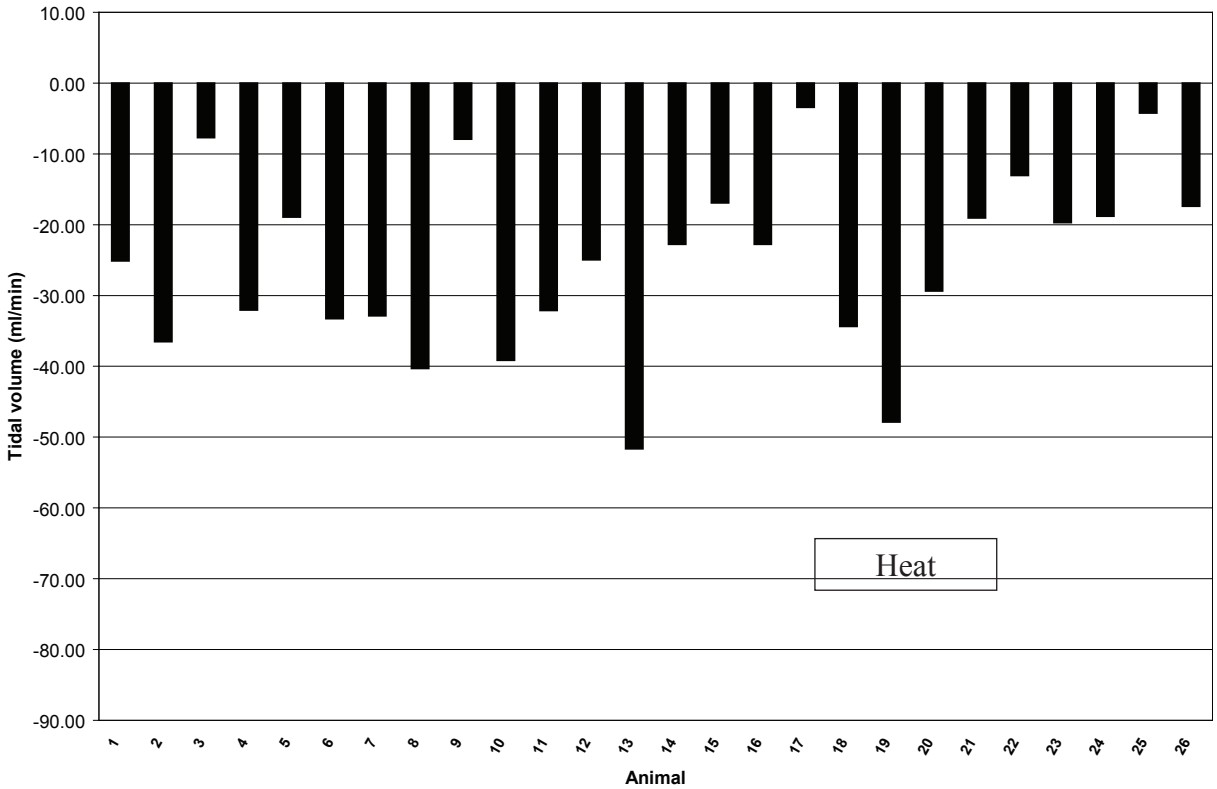


Fig.7. Change in TV due to heat stress and exercise stress in goat

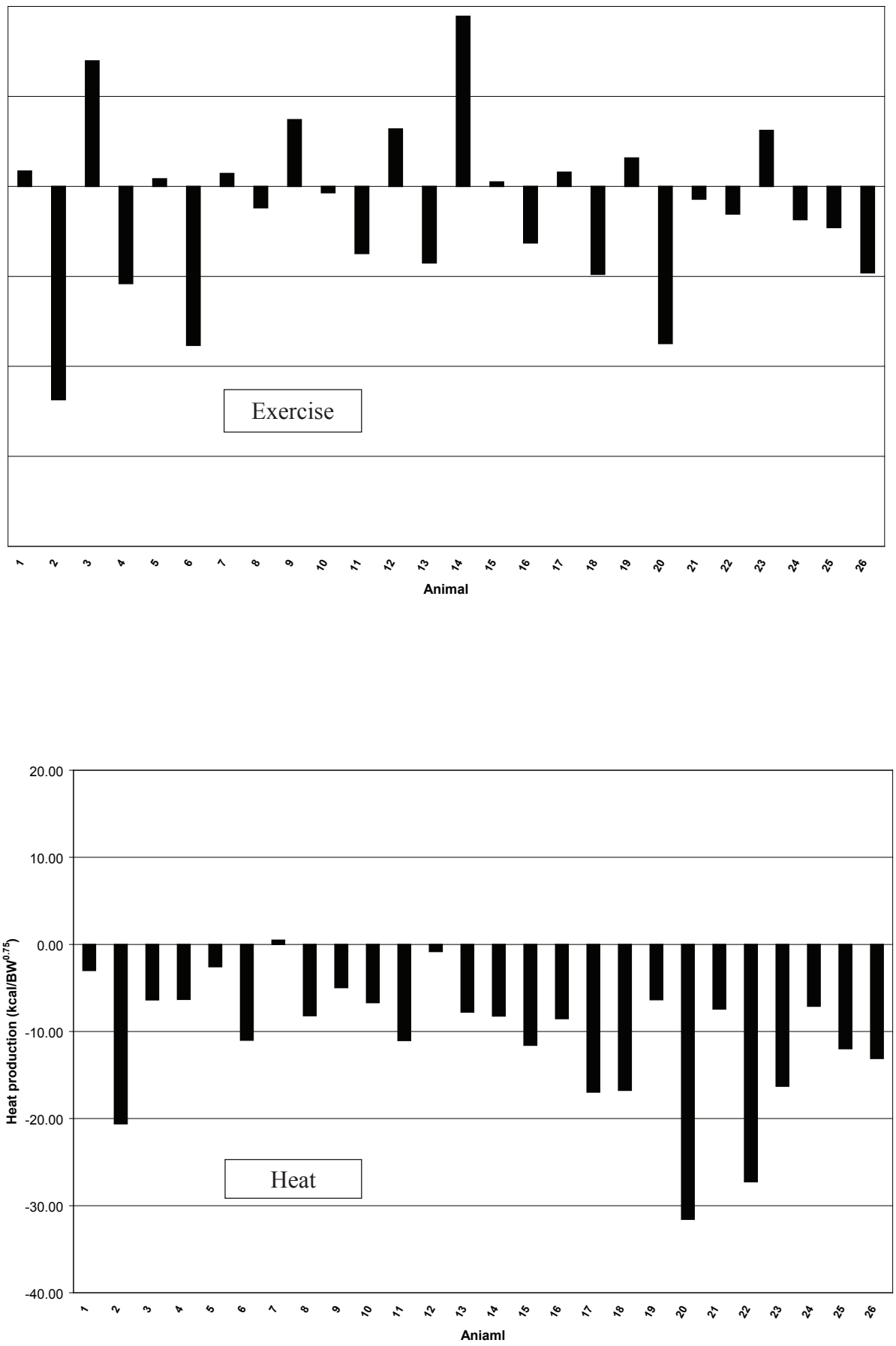


Fig.8. Change in HP due to heat stress and exercise stress in goat

Tolerance index

Tables 4 and 5 show the distribution of animals according to the tolerance index established based on their individual performance in RR, RT, TV and HP. Six goats (23%) and 10 sheep (16%) showed high tolerance score (index value of 1 for either stress and ≥ 2 in the other). The least tolerant animals in sheep and goats were 9 (15%) and 2 (8%), respectively (index value of ≥4 for either stress). Considering exercise stress alone, 5 ewes and 3 does (8% of the sheep and 11% of the goats) showed high tolerance index scores, while 6 ewes and one doe were classified as least tolerant animals to the studied abiotic stresses (score 5). Under heat stress, 17 ewes and 9 does were rated as tolerant, while only 7 ewes and 6 does were classified as sensitive (score 4).

Conclusions

Findings of the present study indicate that the main thermoregulatory mechanism to tolerate the heat stress in desert Barki sheep were to increase their respiratory heat loss (RR and MV) and decrease their HP; while goats rely mainly on the reduction in HP to tolerate heat stress. The mechanism to tolerate the combined effect of physical exercise and heat stress in both species was the shallow rapid panting (increase RR accompanied with reduction in TV). Difference between the two species in RR was highly significant reflecting different ability of the two species in controlling abiotic stress through panting. Indigenous desert Barki goats seem to be more tolerant to abiotic stress under the hot-dry conditions of the North-Western Coastal Zone desert area, than the desert Barki sheep.

Both indigenous Barki sheep and goats showed detectable individual variations in their response to abiotic stress, especially when they were exposed to physical exercise. Physical exercise stress (simulating grazing on poor pasture under heat stress) seems to be a better indicator for tolerance to abiotic stresses under the studied hot-dry conditions than heat stress alone. On the other hand, no single physiological parameter was reliable enough to assess individual tolerance to abiotic stress under hot-dry conditions. The proposed tolerance index worked successfully in identifying tolerant and less tolerant animals in both species. Use of a larger number of animals (especially goats) is recommended to assess further the utilization of such tolerance index in identifying tolerant animals under the studied hot-dry conditions. Functional genomics analysis are planned for investigating individual variation, an approach which can be further utilized as an indicative measure for individual genetic assessment in tolerance to abiotic stress in hot-dry conditions.

Animals that showed physiological indication for tolerance to heat stress alone, tend to show the same trend under physical exercise, with more detectable differences, in sheep. Repeatability of animal tolerance to abiotic stress from one year to another needs to be further assessed. A selection program based on wide screening of indigenous desert Barki sheep and goat populations seems to be promising in establishing nucleus flocks of both species tolerant to hot-dry conditions that can cope better with the expected climatic changes in these areas.

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2. Effect of local feed alternatives on milk fatty acid composition of fat-tailed Awassi ewes

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Abstract

Feed scarcity is the main constraint to livestock production in dry areas. This scarcity is exacerbated by rangeland degradation and the recurrent droughts linked to desertification and climate change. Alternative feeds were proposed as a mean to alleviate grazing pressure and to mitigate desertification. Their successful integration depends on their ability for improving milk production without negatively affecting milk quality. Recently, the human health benefits of fatty acids (FA) have received increasing attention. These include n-3 FA (e.g. α-linolenic acid; ALA), *cis*-9,*trans*-*11*-C18:2 (rumenic acid, a CLA isomer) and *trans*-11 vaccenic acid. While ALA in milk depends on dietary intake and on the rate of escape from ruminal biohydrogenation, milk CLA and *t*11-C18:1 depend solely on the action of ruminal biohydrogenation. The influence of various alternatives on milk FA composition was investigated at ICARDA, Syria, in an experiment with, per diet, ten Awassi ewes (51.0±6.5 kg) allocated in a randomized block design. Diets were isonitrogenous and isoenergetic and had forage: concentrate ratio of 0.3:0.7. Test feeds constituted 0.3 of the diets replacing control diet ingredients (barley straw by lentil straw, olive or Atriplex leaves; and wheat bran/cottonseed meal by olive cake or tomato pomace). Animals were group-fed with 2.5 kg dry matter/day and water *ad libitum*. The experiment lasted for 50 days, where milk was sampled every second week. At unchanged milk and milk fat yield, ALA biohydrogenation increased with intake. ALA proportion was high with olive leaves (0.41% of total FA methyl ester, FAME) and low with olive cake (0.13%) ($p<0.001$). Tomato pomace and olive leaves increased the CLA proportion to 0.66%, compared to 0.42% in control. Olive leaves furthermore affected biohydrogenation in a way that *t*11-C18:1 proportion was highest (1.22% vs. 0.67% with olive cake). The results suggest that it is possible to enhance the potential health benefit of milk by strategically including alternative feeds which at the same time are suitable to alleviate grazing pressure and to mitigate desertification.

Introduction

The harsh climatic conditions in the dry areas of the Mediterranean basin favour sheep and goat production and have supported the development of a number of well adapted sheep and goat breeds. These animals constitute an important component in the agricultural sector of many countries in the dry areas. However, during the last years, this sector has faced many constraints, most importantly feed shortages closely related to a continuous degradation of rangelands. This situation has exacerbated because of the recurrent droughts likely linked to climate change and global warming. In this context, shrubs and local agro-industrial by-products are proposed as alternative feed resources because of their suitability for small ruminant nutrition (Vasta et al. 2008). Alternative feeds often contain anti-nutritional compounds, such as high contents of lignin (olive leaves and cake and tomato pomace), electrolytes (Atriplex), phenols and tannins

(olive leaves). These different compounds might reduce their palatability and digestibility, which could result in a low animal performance. At the same time, many of these feed alternatives are reported to be rich in fatty acids, mainly oleic acid (olive cake), linoleic acid (tomato pomace) and linolenic acid (olive leaves) (Chiofalo et al. 2004; Del Valle et al. 2007; Tsiplakou and Zervas 2008; Molina-Alcaide et al. 2010), which might add value to the food produced from livestock being fed with these diet ingredients.

In addition to other factors related to the feed energy and fiber, the fatty acid (FA) profile in milk and meat is largely affected by the type of lipid ingested (Chilliard et al. 2007). Some ruminant fatty acids have gained more attention in the recent years because of their potential human health benefits, especially the n-3 polyunsaturated fatty acids (PUFA, e.g. α-linolenic acid; ALA) with their antiatherogenic effect and *cis*-9,*trans*-*11*-C18:2 (rumenic acid, a conjugated linoleic acid (CLA) isomer) claimed to be anticarcinogenic (Chilliard et al. 2007).

Because the main aim of searching for feed alternatives was to overcome feed shortages, most research work in this area was devoted to their nutritional value and their potential effect on animal performance. There is a clear lack of knowledge on the effect of these alternatives on milk fatty acids with potential health benefits. The objective of the present study was to test the effect of diets containing underutilized local forages and agro-industrial byproducts on milk yield and quality of lactating Syrian Awassi ewes, with special emphasis on oleic acid, ALA and CLA.

Materials and methods

Experimental design and diets

The experiment was conducted at the International Center of Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria. Sixty fat-tailed Awassi ewes in their second to fourth lactation, weighing on average 51.0±6.8 kg were kept in doors and allocated into six groups in a completely randomized block design. Additionally to body weight, balancing criteria included days in milk (67.2±10.0), milk yield (1.26±0.34 kg/d), milk fat (5.30±1.32 %) and milk protein (5.45±0.62 %). During the 50 days of the experiment, the animals received daily per head 2.5 kg dietary dry matter (DM) where forage constituted 30% and concentrate 70% of DM offered. The diets were isonitrogenous and isoenergetic. The ewes were group-fed and water was offered *ad libitum*. The forage in the control diet constituted by barley straw was substituted by lentil straw, Atriplex or olive leaves, while the concentrate in the same control diet (wheat bran/cottonseed meal) was replaced by olive cake or tomato pomace (Table 1).

Sample collection and analysis

Milking was performed daily at 6:00 a.m. and 4:00 p.m. by machine. Milk yield recording and milk sampling were done weekly. For compositional analysis (fat, protein and lactose), milk samples were analyzed immediately by a Milkoscan 133 B (Foss Electric, Denmark). Milk samples were stored at -20°C for FA analysis. The latter analysis was performed for samples obtained on day 0 and week 1, 3, 5 and 7 of the experiment. Data were analyzed by repeated measurement analysis using the MIXED procedure of SAS (Version 9.1, SAS Institute Inc., Cary, NC), with diet, time and their interaction as effects.

Table 1. Ingredients of the experimental diets (% of DM)[1]

Item	Experiment diet					
	Tradi-tional	Lentil straw	Atriplex leaves	Olive leaves	Olive cake	Tomato pomace
Test feed	–	30	30	30	30	30
Barley straw	30	–	–	–	20	30
Wheat grain	–	–	–	–	20	20
Sugar beet pulp	30	20	30	30	–	5
Wheat bran	10	20	20	20	–	–
Cotton seed meal	20	20	10	10	10	5
Molasses	10	10	10	10	10	10

[1]*Diets individually supplemented with 0.8% of mineral-vitamin mix containing per kg: Ca, 138 g; P, 108 g; Mg, 151 mg; Na, 123.5 g; Cu, 119 mg; Mn, 774 mg; I, 76 mg; vitamin A, 12,500,000 IU; vitamin D_3, 300,000 IU; vitamin E, 0.5 g and with urea at levels of 8, 0, 5, 12, 19 and 16 g/kg dry matter for control, lentil straw, Atriplex leaves, olive leaves, olive cake and tomato pomace diets, respectively.*

Results

The daily amount of feed offered was completely consumed by the ewes across the different test diets and the control diet. Milk yield declined from an average of 1260±340 g/day on day 0 to 887±302 g/day in the seventh week and there was no significant difference among the different diets during the whole experiment.

The type of diet had a slight but significant effect on milk composition during the whole experimental period (Figure 1). The fat content increased for all the groups, reaching the maximum in the third week for the traditional group (7.44±1.07 %), Atriplex leaves (7.31±1.18%), olive leaves (7.16±1.20%) and lentil straw (6.79±0.89%). Fat content reached the maximum in the fifth week for the tomato pomace group (7.5±1.2 %) and the olive cake group (7.4±0.9 %). The difference in milk protein content among groups was not significant except for the tomato pomace group, which showed a low protein content. Milk lactose content was more constant with time, and was enhanced by two by-products (tomato pomace and olive cake) and lentil straw. Olive leaves resulted in a lower lactose content (4.60%) than the control diet (4.58%).

The effect of the diet type on the proportion of the main types of FA according to their saturation degree is shown in Figure 2. Tomato pomace and olive cake diets resulted in a significant increase of the proportion of monounsaturated fatty acids (MUFA) and a significant decrease in saturated fatty acids (SFA). The increase was mainly observed for oleic acid (1.71- and 1.81-fold of control with the olive cake and tomato pomace diets, respectively; data not shown). Olive leaves and lentil straw diets resulted in a significant increase of PUFA proportion in milk fat.

This was due mainly due to the important increase in ALA content with olive leaves diets (2.97-fold value compared to the control diet, Figure 3), *c*-9,*t-11*-CLA (166% increase compared to the control). The tomato pomace diet resulted also in an increase of *c*-9,*t-11*-CLA (1.76-fold of control), but resulted in an overall decrease of PUFA. Additionally, olive leaves and lentil straw diets resulted also in an enhanced proportion of vaccenic acid (*t11*-18:1) in milk fat.

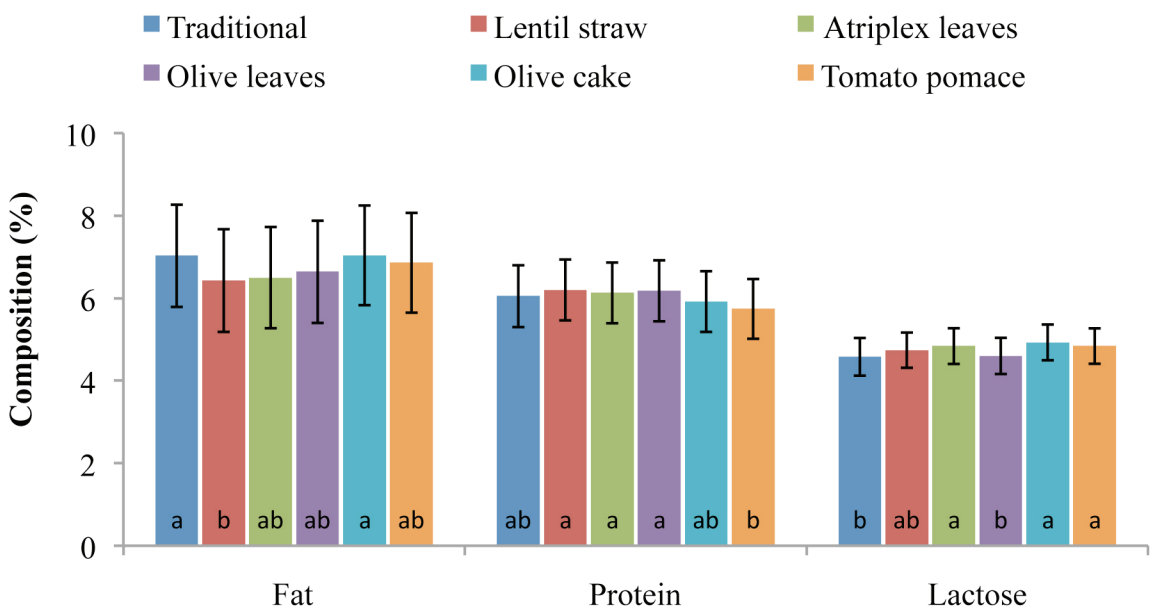

Figure 1. Milk fat, protein and lactose contents for six different diets (bars from left to right): traditional, lentil straw, Atriplex leaves, Olive leaves, Olive cake and Tomato pomace.

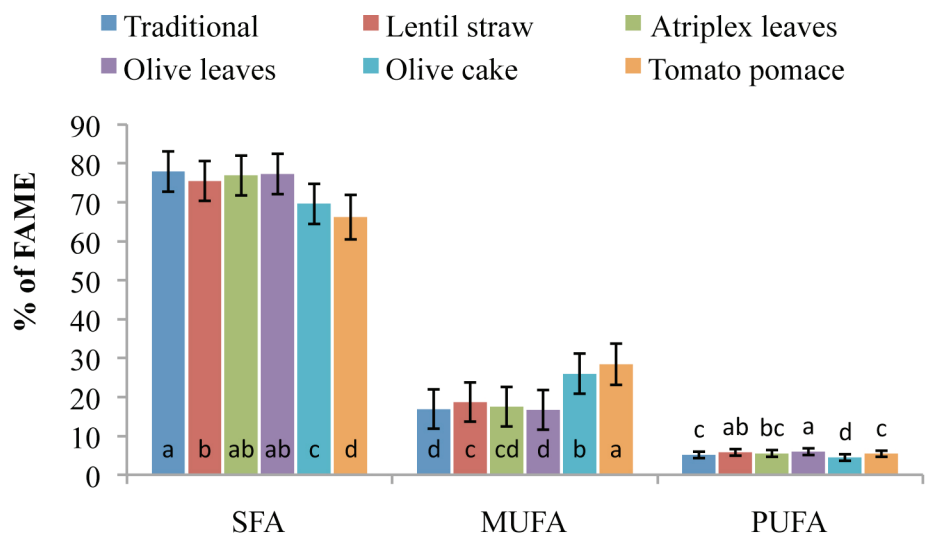

Figure 2: Effect of diet type on the proportions of saturated (SFA) , monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA) in milk fat (% of total fatty acid methyl esters (FAME)). Diets (bars from left to right): traditional, lentil straw, Atriplex leaves, Olive leaves, Olive cake and Tomato pomace.

Discussion

In general, none of the feed alternatives tested in the present study have any pronounced adverse effect on milk yield and composition. This is probably due to balancing diets for energy and nitrogen. The fact that the test feeds made up only 30% of the total diet could have prevented

adverse effects from the antinutritional components because of a dilution effect. The present results support the previous findings of Dutta et al. (2004), who found the same milk yield when lentil straw replaced urea treated wheat straw. Abu-Zanat and Tabbaa (2006) replaced shredded barley straw with Atriplex grazing at 50 and 100%, which did not significantly affect milk yield. Results from Weiss et al. (1997), feeding a diet composed of 60% of ensiled corn with 12% tomato pomace, also indicated that the addition of tomato pomace to the diet does not affect milk yield and composition. Tsiplakou and Zervas (2008) did not observe a significant difference in milk yield and fat and protein contents when they replaced alfalfa hay by air-dried olive leaves, while Chiofalo et al. (2004) reported a higher milk yield when olive cake was fed at 20% replacing beet pulp and alfalfa meal.

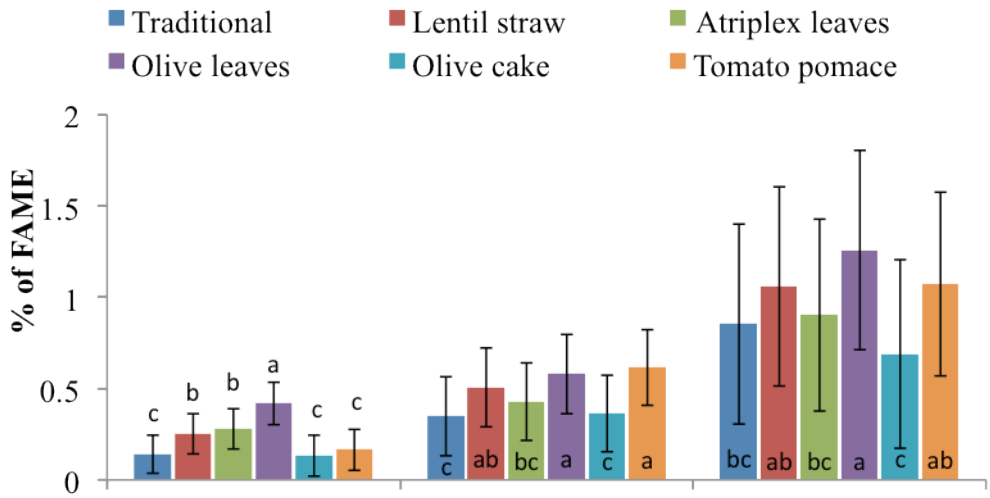

Figure 3: Effect of diet type on the proportions of α-linolenic acid (ALA), rumenic (c-9, t-11-CLA) and vaccenic acids (t11-18:1) in milk fat (% of total total fatty acid methyl esters (FAME)). Diets (bars from left to right): traditional, lentil straw, Atriplex leaves, Olive leaves, Olive cake and Tomato pomace.

Feed lipid profile in addition to energy supply and fiber content are the main factors which can modify the ruminal biohydrogenation and, therefore, the FA profile in the end products (milk and meat) (Chilliard et al. 2007). The most important features in the diets tested in the present study and which have a direct effect on the ruminal patterns were mainly the high oleic acid content of olive cake, the important linoleic acid content of tomato pomace and lentil straw, and finally the high ALA content of olive leaves diet.

The SFA, especially the short and medium chain FA, can be reduced effectively by dietary long chain FA and by the *trans* FA intermediates generated by ruminal biohydrogenation (Chilliard et al. 2007). This explains the low SFA content in milk from the olive cake and tomato pomace diets (and their high content in long chain FA). The increase in MUFA content, mainly represented by oleic acid, could be the result of enhanced dietary intake or mammary desaturation of stearic acid (Chilliard et al. 2007). The significant increase of oleic acid after olive cake feeding was due to its high content in this diet (27% of total FAME). However it was also enhanced by tomato pomace feeding probably because of the high accumulation of stearic acid and its further desaturation.

The biohydrogenation of the unsaturated FA results in a series of intermediates, where the two intermediates, *t11*-18:1 (vaccenic acid) and CLA are of particular interest. Vaccenic acid is an

intermediate product of biohydrogenation of both linoleic acid and ALA (Chilliard et al. 2007). The inclusion of olive leaves in the diet (ALA constituted 9.3% of the FAME in the total diet) resulted in an increased vaccenic acid content. PUFA in milk and meat exclusively originate from feed and depend only on the rate of escape from the rumen without any biohydrogenation (Chilliard et al. 2007). The increment of ALA with the olive leaves diet is therefore due in part to its relatively high concentration in this diet, and also to lower ruminal biohydrogenation due to the relatively high phenolic content (Khiaosa-Ard et al. 2009). Rumenic acid, the most important CLA in milk, is an intermediate in ruminal biohydrogenation of LA, but it is mainly synthesized by Δ^9-desaturation of vaccenic acid in the mammary gland (Grinarii et al. 2000). The increase in rumenic acid correlated with the increase in vaccenic acid with the olive leaves, tomato pomace and lentil straw diets.

Conclusions

The alternative feeds tested in the present study, although supposed to contain some antinutritional components (high fat content, high phenols or excessive levels of electrolytes), did not have any detrimental impact on milk yield and its fat and protein contents when offered in isonitrogenous and isoenergetic diets. Furthermore, some of these feeds enhanced the proportion of FA with potential health benefit in milk fat. This concerned for instance oleic acid with olive cake and tomato pomace feeding, α-linolenic acid and vaccenic acid with olive leaves and lentil straw feeding, and finally, rumenic acid with tomato pomace, olive leaves and lentil straw feeding. The results showed that the use of alternative feeds can be efficient because it sustains the same performance, and can also add value to the end products (better nutraceutical value). Thus, in this case the development of strategies to cope with feed scarcity in regions already suffering from climate change even resulted in an added value to the dairy products.

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24. Rangeland vegetation assessment in the eastern and western regions of Libya

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Abstract

Rangeland in the dry areas of the Southern Mediterranean basin extends over large areas, constituting one of the dominant forms of land use in the area. These are often hot spots of biodiversity and are threatened by farming encroachment, overgrazing and climate change. Thus, there is an urgent need to rehabilitate and better manage these lands. However, the first step before engaging in any rangeland rehabilitation and management project should be map and assess rangeland condition. The purpose of this study was to investigate the current status of rangeland vegetation in Libya. To meet this objective, a team from ICARDA and ARC-Libya conducted a vegetation assessment across several sites in the eastern and western parts of Libya during the spring of 2010. Conventional sampling techniques for rangeland monitoring and assessment including quadrates and line intercept as well as near-earth remote sensing technology were adopted. Vegetation parameters recorded were standing biomass, cover, frequency and density. Preliminary results indicated that total biomass and plant density were significantly different by region: 172 kg DM/ha and 42 plant/m^2 for the east compared to 524 kg DM/ha and 93 plant/m^2 for the west. Percent green cover as estimated by the digital charting technique showed differences between and within the two regions. Sixty species from 22 families were observed in the eastern region compared to 88 species from 26 families in the western region. The differences were not reflected in the plant diversity and richness as the two regions showed similar results in vegetation cover (26%), species richness (10 species) and Shannon diversity index (1.8). Annual species were dominant in the east and had low biomass while perennial shrubs dominated the west. The information gathered in this study can provide baseline data needed for a proper future monitoring of these natural resources.

Introduction

Libya lies along the southern coast of the Mediterranean in North Africa; it has a total area of about 1,759,540 km^2, of which more than 90% is desert. The climate is typical Mediterranean, with erratic rainfall. Area under agriculture, and arid and semi arid rangelands is limited to a narrow strip along the Mediterranean coast. Desertification ranks high among the important consequences resulting from climate change in these areas and Libya is potentially one of the countries most at risk from the effects of climate change because it has limited natural resources (water and soils); and more than 95% of its people live in coastal zone which is threatened by sea level rise (El Tantawi 2005).

As too many heads of livestock feed on these diminishing areas, plants disappear quickly under the stresses of overgrazing and lack of water (El Tantawi 2005). Most of the pastoral lands in Libya have open access. This accelerates overgrazing leading to desertification.

Degraded arid and semi-arid rangelands associated with loss of vegetation cover and plant diversity in North Africa could result in total desertification of these ecosystems by 2050 or earlier (Abahussain et al. 2002). Scarcity of water (aridity), overgrazing and changing the rangeland to rain-fed agriculture had caused destruction of natural vegetation cover (reduction of bio-productivity and invasion of new species) and induced wind and water erosion (UN 2001).

Our objectives were to evaluate trend in vegetation characteristics including vegetation cover, composition and biomass as well as rangeland condition in the two areas. An understanding of the extent of change in the vegetation caused by livestock grazing, and of the capacity for vegetation recovery following livestock removal will also facilitate better planning and management of rangeland resources in Libya.

Material and methods

Study sites

This assessment was carried out in the eastern and western regions in Libya. Selected sites lie immediately south of and parallel to the mountain region, having an average annual rainfall between 150 and 200 mm. The production system is characterized by an integrated barley-range-livestock production. Most of the large flock owners use the rangeland to graze sheep and goats. Production system in the area is barley- rangeland- livestock.

Eastern region: Six sites, located around 40-70 Km south Al Baida city in the green mountain district, 200 Km east of Benghazi, were assessed in this region (Fig. 1) The sites are characterized by Mediterranean climate with hot summer and cold winter with 150-200mm average annual rainfalls. Soils are silty to calcareous with stones covering large parts of the surface area and having a range of slopes from 0 to 25 %. Barley cultivation was a common practice, especially in the depressions with deep soil, before the involvement of the farmers in the project in 2009. Originally, all the selected sites for improvement were State land before it was distributed to the farmers through different projects. In this region, the Vegetation Project fenced 25-50 ha area and handed over the fenced area to the farmers to settle on that land.

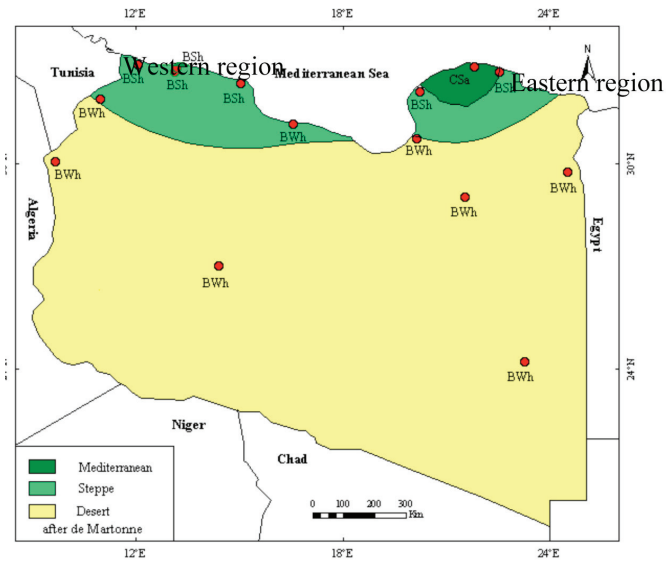

Figure 1. Climate type in Libya after the Koppen and de Martonne climate classification schemes.

Western region: Eight sites were assessed in this region, the sites being located approximately 100 km south west of Tripoli in the Gharyan area. Each field ranged from 25-100 ha in area, based on the landscape. It was fenced and terraced for harvesting rainwater before distribution to farmers by the Ghrayan Terraces project. In case of deep soil the area given to the farmers was about 25 ha, while if the land was unfit for cropping the size would be larger.

Vegetation cover

For each site, the line intercept method was used for quantifying herbaceous cover (Owensby 1973; Barabesi and Fattorini 1998; Bonham 1989). This technique is rapid, accurate to determine bare ground and cover, including vegetation, litter, rocks and biotic crusts. A starting point was established for the center of the field based on its orientation to the sampling area. From this point, two 100 m transect lines were established to cover the area. Observations at specified intervals (1 m) were recorded. Percent cover was calculated as the proportion of the transect line covered by each species (Canfield 1941).

Plant density and biomass

Plant density and biomass production were measured in ten 1 m × 1 m quadrates randomly distributed across the landscape. Above-ground biomass was harvested manually by clipping 2.5 cm above soil surface within each quadrate. This height represents a typical standing crop height after the plants have been grazed. All plants were identified and counted. Clipped plant material was oven dried (72 hr at 70°C), weighed and dry matter calculated. The percentage of total standing biomass for above-ground plant parts was determined for all species present.

Indices of species diversity and richness

The Shannon-Wiener Diversity Index,(Shannon and Weaver 1949), was used to measure species diversity in each site. The index was calculated using the following equation:

$$H = -\sum pi \times \log(pi),$$

where pi is the probability of occurrence of the i species to the total number of species in the plant community. Richness was calculated as the number of species recorded (Stirling and Wilsey 2001).

Digital image processing for percent cover

VegMeasure software (Louhaichi and Johnson 2001), developed at Oregon State University, uses an algorithmic manipulation of color hues to separate image characteristics like bare ground and plant cover. Due to technical reasons, only seven sites were included for study by this technique in the western region. Data from these measurements were compared with each other and with measurements from on-the-ground point-sampling.

Statistical analysis

Data were analyzed using a T-test to compare the different vegetation parameters between the two regions and ANOVA for the site comparison within each region in GenStat (Payne et al. 2009).

Results

Sixty species from 22 families observed in the eastern region compared with 88 species from 26 families from the western region (Table 1). Sites within each region were compared using ANOVA.

Table 1. Species recorded in the eastern and western region in Libya

Species	Family	Life form	Eastern region	Western region
Adonis microcarpa	*Ranunculaceae*	annual		√
Adonis cupaniana	*Ranunculaceae*	annual	√	
Adonis dentata	*Ranunculaceae*	annual	√	
Aegilops spp.	*Poaceae*	annual		√
Aizoon hispanicum	*Izoaceae*	annual	√	
Allium ampeloprasum	*Liliaceae*	perennial	√	
Anthemis arvensis	*Asteraceae*	annual		√
Anabasis articulata	*Chenopodiaceae*	perennial	√	√
Anacyclus monanthes	*Asteraceae*	annual	√	√
Anagalis arvensis var caerulea	*Primulaceae*	annual	√	
Argyrolobium uniflorum	*Papilonaceae*	perennial	√	
Artemisia campestre	*Asteraceae*	perennial		√
Artemisia herba alba	*Asteraceae*	perennial	√	√
Asparagus stipulatus	*Liliaceae*	perennial	√	√
Asphodelus microcarpus	*Liliaceae*	perennial	√	√
Asteriscus pygmaeus	*Asteraceae*	annual		√
Astragalus asterias	*Papilonaceae*	annual		√
Astragalus hamosus	*Papilonaceae*	annual		√
Astragalus sp.	*Papilonaceae*	perennial		√
Atractylis Serrattuloides	*Asteraceae*	perennial	√	√
Avena barbata	*Poaceae*	annual	√	√
Basia sp.	*Chenopodiaceae*	perennial	√	
Bifora testiculata	*Apiaceae*	annual	√	
Bromus tectorum	*Poaceae*	annual	√	√
Bupleurum spp.	*Apiaceae*	annual		√
calendula arvensis	*Asteraceae*	annual		√
Calendula officinalis	*Asteraceae*	annual		√
Calendula sp.	*Asteraceae*	annual		√
Carex stenophylla	*Cyperaceae*	perennial	√	√
Centaurea spp.	*Asteraceae*	perennial		√
Cinara spp.	*Asteraceae*	annual	√	
Convolvulus spp.	*Convolvulaceae*	perennial		√
Crepis spp.	*Asteraceae*	annual		√
Didymus bipinnatus	*Brassicaceae*	annual	√	√

Dipcadi seratinum	*Liliaceae*	perennial	√	
Echium sp.	*Boraginaceae*	perennial		√
Enarthrocarpus lyratus	*Brassicaceae*	annual		√
Enarthrocarpus strangulatus	*Brassicaceae*	annual		√
Erodium spp.	*Geraniaceae*	annual		√
Onopordum espinae.	*Asteraceae*	perennial		√
Oxalis pes-caprae	*Oxalidaceae*	perennial	√	
Papver hybridum	*Papaveracea*	annual		√
Peganum harmala	*Zygophyllaceae*	perennial		√
Pennisetum setaceum	*Poaceae*	perennial	√	
Phlomis spp.	*lamiaceae*	perennial	√	
Picris damascena	*Asteraceae*	perennial		√
Pituranthus tortuosus	*Apiaceae*	perennial	√	√
Plantago albicans	*Plantaginaceae*	perennial	√	√
Poa bulbosa	*Poaceae*	perennial	√	√
Polygonum equistifomis	*Polygonaceae*	perennial	√	√
Ranunculas spp.	*Ranunculaceae*	annual	√	
Reaumuria vermiculata	*Tamariaceae*	annual	√	√
Reseda alba	*Resedaceae*	annual		√
Roemeria procumbens	*Tamariaceae*	annual	√	
Salsola tetrandra	*Chenopodiaceae*	perennial	√	
Salvia ceratophylla	*lamiaceae*	perennial	√	
Salvia clandestina	*Lamiaceae*	perennial		√
Salvia eagyptiaca	*Lamiaceae*	perennial		√
Salvia lanigera.	*Lamiaceae*	perennial		√
Salvia spinosa	*Lamiaceae*	perennial		√
Schimus barbatus	*Poaceae*	annual		√
Scilla peruviana	*Liliaceae*	perennial		√
Stipa capnsis	*Poaceae*	perennial		√
Stipa lagascae	*Poaceae*	perennial		√
Stipa sp.	*Poaceae*	perennial		√
Stipa tenuissims	*Poaceae*	perennial		√
Scrophularia canina	*Scropholariaceae*	perennial	√	√
Sinapis arvensis	*Brassicaceae*	annual	√	
Thymelaeai hirsuta	*Thymealaeceae*	perennial		√
Thapsia garganica	*umbeliferae*	perennial	√	√
Thymus capitatus	*lamiaceae*	perennial	√	√
Uriginia maritima	*Liliaceae*	perennial	√	√
Vicia amphicarpa	*Papilonaceae*	annual	√	
Vicia sp.	*Papilonaceae*	annual	√	√
Ziziphus lotus	*Rhamnaceae*	perennial	√	√

Both total biomass and plant density were significantly different (P<0.001, and 0.003) with 172 kg/ha biomass and 42 plant/m^2 for the eastern region (Table 2) compared with 524 kg/ha biomass and 93 plant/m^2 for western region (Table 3). The differences in biomass and plant density were not reflected in the plant diversity and richness (average number of species recorded over the region) as the two regions showed similar results in percentage vegetation cover, species richness and Shannon diversity index. This can be partly explained by the fact that the annual species with there low biomass dominated in the eastern region compared with abundance of some perennial shrubs species in the western region.

Table 2. Comparison between different sites at eastern region

Site	Biomass kg/ha	Plant/m^2	Vegetation cover %	Shannon Index	Species richness
1	322	55	36	2.51	17
2	375	39	24	2.13	11
3	29	38	15	1.63	9
4	140	79	30	1.78	9
5	120	24	42	1.75	10
6	47	17	9	1.33	5
Avg.	172.2	42	26	1.85	10.1
LSD 5%	129.6	49.8	12.2	0.75	5.1

Table 3. Comparison between different sites at western region

Site	Biomass kg/ha	Plant/m^2	Vegetation % cover	Shannon Index	Species richness
1	541	97	35	2.40	15
2	414	25	26	1.95	10
3	403	47	31	1.99	11
4	1543	132	40	2.04	10
5	66	44	30	2.09	12
6	323	58	30	1.75	9
7	314	199	11	1.67	6
8	586	142	16	1.02	4
.Avg	524	93	27	1.86	9.6
LSD 5%	483.9	112.3	9.19	0.5	3.8

Total biomass showed great variability within each region. In the eastern region (Table 2), total biomass ranged from 29 kg DM/ha to 375 kg DM/ha compared with 66 kg DM/ha to 1543 kg DM/ha in the western region (Table 3). Maximum number of plant per m^2 recorded in the eastern region were 79 compared with 199 for the western region (Table 2 and 3). Results showed high correlation (r^2=93) between Shannon diversity index and number of species recorded in each site for vegetation cover (Figures 2 and 3).

Results from the image analysis (Fig. 4) for the different sites showed similar results with the

measurements made on the ground using point-sampling methods (Tables 4 and 5). Percentage vegetation cover recorded in the eastern region was 13.7% compared with 21% in the western region.

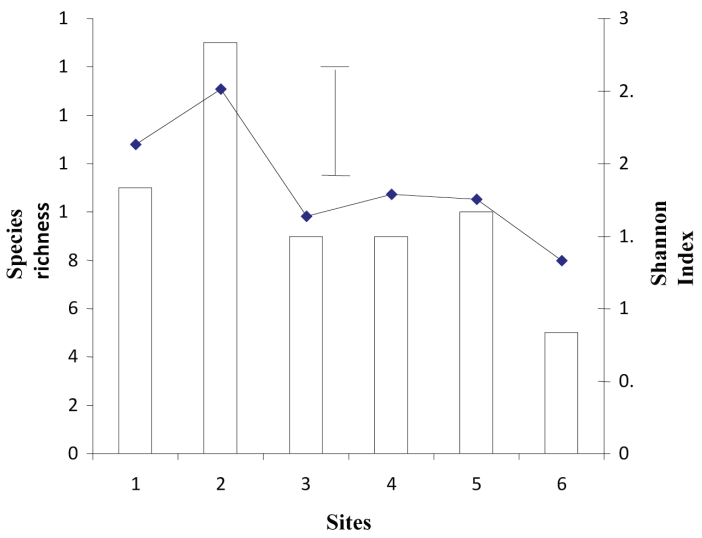

Figure 2. Shannon Diversity Index and species richness in six rangeland sites in the eastern region of Libya, March-2010.

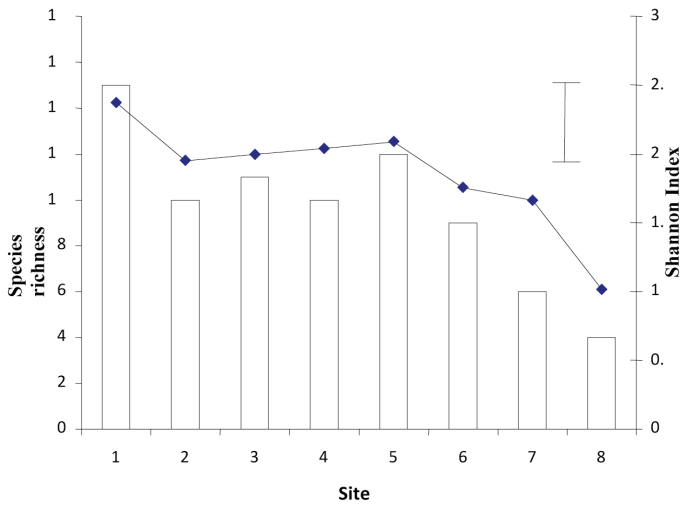

Figure 3. Shannon Diversity Index and species richness in six rangeland sites in the western region of libya, March-2010.

Discussion

Rangeland degradation in semi arid rangeland of Libya is a common phenomenon with a few exceptions. The variation between sites within each region is due to the level of protection and to the extent of barley cultivation in the depressions with deep soil. Intensive rangeland protection programs have been adopted under which large areas of pasture land (about 2.5 million hectares) has been fenced in various ecological zones; the fenced areas are divided into subdivisions for regulated rotational grazing (Ben-Mahmoud et al. 1984; Palls 1980).

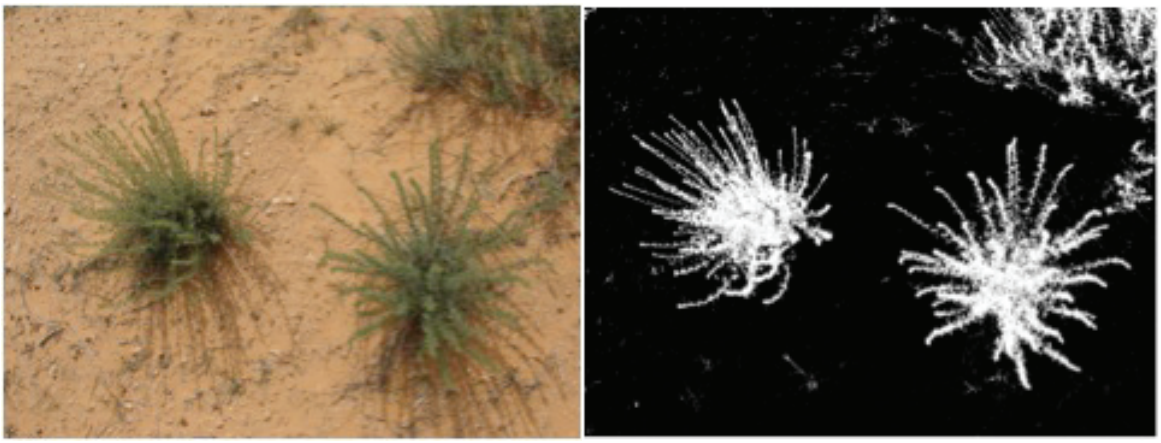

Figure 4. Image processing using VegMeasure software, original image (left) and processing image (right).

Table 4. Vegetation and bare ground analysis for the eastern region sites by VegMeasure software

Cover (%)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Avg.
Avg. vegetation	19.81	20.85	6.34	10.33	21.00	3.83	13.70
Avg. bare ground	80.19	79.15	93.66	89.67	79.00	96.17	86.30
Min. vegetation	4.62	10.37	0.89	1.89	1.25	0.02	3.20
Min. bare ground	65.07	65.64	84.23	74.12	36.32	87.79	68.90
Max. vegetation	34.93	34.36	15.77	25.88	63.68	12.21	31.10
Max. bare ground	95.38	89.63	99.11	98.11	98.75	99.98	96.80

SE for vegetation cover 10.29; P for vegetation cover 0.001

Table 5. Vegetation and bare ground analysis for the western region sites by VegMeasure software

Cover (%)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Avg.
Avg. vegetation	28.44	27.47	23.11	29.78	15.08	15.69	12.26	20.51
Avg. bare ground	71.56	72.53	76.89	70.22	84.92	84.31	87.74	79.49
Min. vegetation	9.69	19.75	8.44	5.64	5.18	0.97	7.73	79.49
Min. bare ground	55.83	59.66	64.22	46.50	65.29	49.79	78.22	62.22
Max. vegetation	44.17	40.34	35.78	53.50	34.71	50.21	21.78	37.78
Max. bare ground	90.31	80.25	91.56	94.36	94.82	99.03	92.27	91.86
Std. Dev.	3.63	2.05	3.20	2.56	1.64	3.59	2.80	2.78

SE for vegetation cover 10.36; P for vegetation cover 0.001

Past studies showed a drastic decrease in above-ground biomass during the last three decades. Gintzburger (1986) estimated the dry matter of rangeland dominated by *Aristida pungens* and *Retama raetam* in the arid Jefara plain (200 mm rainfall) by 2,000 kg/ha. A monitoring study conducted at El-Witia area in Libya in 1997 showed sever natural rangeland degradation in

the coastal zone of Libya as there was 52% reduction in vegetation and 227% increase in the formation of sand dunes during the 10 years period from 1986-1996 (Ben-Mahmoud et al. 2000).

Our results showed clearly the degree of rangeland degradation in the eastern and western regions of Libya. Out of the thirteen sites monitored, only one site recorded high biomass production (1,543 kg/ha). For the remaining sites, biomass ranged from 29 to 586 kg/ha. To reverse this trend in rangeland degradation, an effort is needed through water harvesting techniques and transplanting and direct seeding of indigenous species and selected prominent introduced species for rehabilitation of degraded rangeland areas combined with a proper grazing management. There is also a need for integrated systems such as alley cropping of barley and shrub (cactus, *Atriplex*, *Acacia*, etc) especially in the depression sites.

The differences in biomass and plant density were not reflected in the plant diversity and richness. This can be partly explained as the annual species with there low biomass dominated in the eastern region compared with abundance of some perennial shrubs species in the western region.

Conclusion

Rangeland monitoring and assessment is an essential step towards any rehabilitation and sustainable management of degraded rangelands. This paper attempts to investigate the current status of semi arid rangeland in the eastern and western regions of Libya in order to set up a proper rehabilitation program. The differences in land use between the two regions and between sites within each region reveal the differences in human impact on rangeland condition. Out of the thirteen sites assessed only one site recorded having high biomass in the western region (1,500 kg/ha). Barley cultivation is dominant especially in the low land, while in the foothills overgrazing is widely spread. Species diversity index over the two regions is similar; yet, the high number of perennial plants recorded in western region is an indication of slight grazing pressure on rangeland. Results show clearly a decrease in landuse / vegetation cover, which is probably related to change in the climate and human activity, such as overgrazing, cultivation, removal of natural vegetation and other anthropogenic activities. In conclusion, rangelands in the semi-arid regions of Libya are at risk of degradation. Management plan for rangeland is certainly needed such as introduction of native and exotic fodder shrubs, direct seeding of native species using different soil disturbance methods and above all implementation of participatory approach to work with rangeland communities.

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Theme 3: Enhancing resilience of local agricultural communities in drylands through adaptation strategies

Theme 3c: Stress physiology

25. The ability of sedum plant to tolerate different environmental stresses

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Abstract

Globally arid and semiarid areas are facing salinization of soils along with the acute shortage of water resources. The utilization of marginal waters for agriculture is getting considerable importance in such regions. During the experiment reported here, plants of sedum (*Sedum aizoon* var. *floibundum*), which are tolerant to the water stress, were tested for growth parameters in response to irrigation with diluted sea water with four salinity levels (0.7, 15, 30 and 46 dS m^{-1}). The evapo-transpiration was affected negatively by the salinity treatments. The electrical conductivity of the soil and drainage water increased significantly with higher saline water. Fresh water gave the highest plant biomass whereas diluted sea water apparently decreased plant biomass with increasing salinity. However, the conjunctive use of sea water with higher dilution gave more sedum biomass yield than less diluted sea water. Water deficit increased with increasing salinity level. The ratios of dry and fresh plant weights were significantly increased with increasing salinity levels. The ability of the plant to survive under sea water irrigation was due to its mechanism in keeping water in its leaves and tolerating water stress condition caused by salts accumulation in the root zone. Sedum survival under heat, water and salinity stress conditions considered as a unique feature that is needed in this changing world.

Introduction

The fresh water resources available for agriculture are declining quantitatively and qualitatively. Therefore, the use of lower-quality supplies will inevitably be practiced for irrigation purposes to maintain economically viable agriculture. Several countries have adopted the use of marginal water for irrigation to overcome water scarcity (Oron et al. 2002). The management of poor quality water is the critical challenge for a sustainable agricultural production system.

Sedum is the plant species which successfully develops groundcover especially in the hot and dry climate. It is a perennial plant, which grows under natural moisture condition in shallow and marginal quality soil (Stephenson 1994). Sedum potentially offers resistance to dry conditions and can prevent fire. It is commonly named as stone-crop because it grows well in the rocky areas; it retains substantial amount water in its thick leaves. It is easy to propagate sedum plants.

The tiny leaf or piece of the stem that touches the ground can produce the root system. Some types of sedum invasively prevail on the soil surface but can easily be controlled since the roots never go deep (Stephenson 1994).

The studies on the growth and survival of sedum under saline water conditions are scanty and not well documented. Therefore the objective of this study was to monitor sedum response to saline water irrigation either by surface or sprinkler method.

Materials and methods

The pot experiment was carried out in a glasshouse at the Arid Land Research Center, Tottori University, Japan. The relevant properties of the soil used during the experiment are shown in Table 1. Soil texture was determined by the pipette method. Exchangeable cations were leached from the soil with neutral ammonium acetate and their concentrations were determined using a Polarized zeeman atomic absorption spectrophotometer (Model Z-2300 Hitachi corp, Japan). The cation exchange capacity (CEC) was measured according to the procedure described by Jackson (1965). Electrical conductivity and pH of the soil: water suspensions (1: 5) were also measured. Sand dune soil was placed in 4 L pots.

Table 1. Selected physico-chemical characteristics of the soil

Property	Value
EC (1: 5) water	0.03 dS m^{-1}
pH	6.36
Exchangeable K^+	0.06 $cmol_c$ kg^{-1}
Exchangeable Ca^{2+}	0.34 $cmol_c$ kg^{-1}
Exchangeable Mg^{2+}	0.45 $cmol_c$ kg^{-1}
Exchangeable Na^+	0.10 $cmol_c$ kg^{-1}
Cation exchange capacity	2.40 $cmol_c$ kg^{-1}
Bulk density	1.47 g cm^{-3}
Infiltration rate	30.0 mm min^{-1}
Hydraulic conductivity	0.05 cm sec^{-1}
Texture	Sand

Sedum (*Sedum aizoon* var. *floibundum*) was planted in 24 pots at the planting density of 4 plants per pot during July 2005. One group of the pots was irrigated with the saline water directly on the surface of the soil and the other group of pots was showered by the same water. A basal dose of NPK liquid fertilizer was added to the pots in the irrigation water. Irrigation with saline water was started after 14 days of planting. Saline water treatments consisted of four EC_w levels: i) fresh water (0.7 dS m^{-1}), ii) saline (15 dS m^{-1}), iii) highly saline (30 dS m^{-1}), and iv) sea water (46 dS m^{-1}). Sea water was diluted by tap water to achieve these EC_w levels. Four saline water treatments were combined with two types of irrigation methods e. g., surface or normal irrigation (N) and shower or sprinkler irrigation (S). Plants were irrigated twice a week depending on the loss by evapo-transpiration (ETc) which was estimated by gravitational meathod. Extra water at the rate of 10% was added for leaching purpose. Evaporation was measured by using evaporation pan (Class A). Drainage water was regularly collected and the electrical conductivity (EC_d)

was measured by calibrated conductivity meter (Horiba DS-14). Air temperature and relative humidity were measured during the day as well as night by Hobo meter (Pro series, onset, USA). Prior to the harvesting of the plants for their fresh and dry weight, plant height and leaf area (by portable area meter LI-3000A) were also measured. Post-harvest soil samples were collected from each pot up to a depth of 0-20 cm. Data were analyzed statistically for analysis of variance (ANOVA) and the means were compared at the probability level of 5% using least significant difference (LSD) test (Kinnear and Gray 1997).

Results and discussion

During the experiment weather fluctuated with the average glasshouse temperature of 29 °C and humidity of 74 %. Changes in the temperature and humidity during the experiment are shown in Figure 1. Under fresh water treatment the plants exhibited the highest values of evapo-transpiration as compared to saline water treatments (Fig. 2). In general the higher level of evapo-transpiration and accumulation of salts on the soil surface was caused by high temperatures over the time.

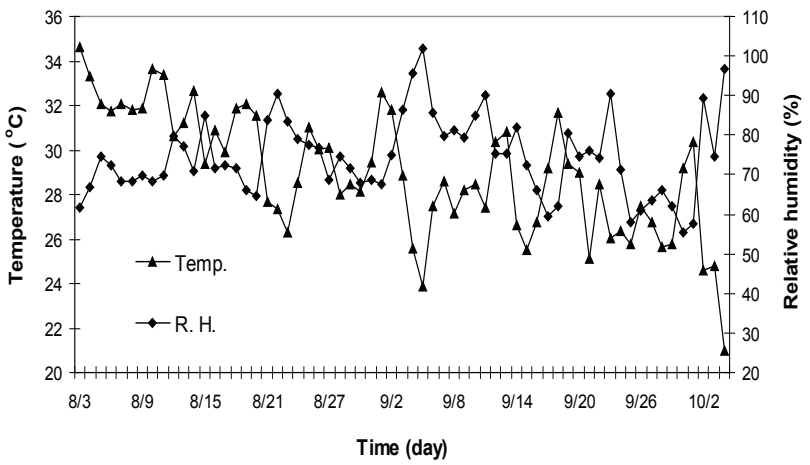

Figure 1. Variations in temperature and humidity during study period.

Fresh water encouraged evaporation process more than saline water. Maximum evapo-transpiration occurred with good quality water. Since the plants absorb water in saline conditions with higher pressure therefore the water losses through transpiration are retarded. Thus the magnitude of the evapo-transpiration was inversely related to the amount of salts in the irrigation water. Reduced bioavailability of water and retarded plant growth under saline irrigation produced poor evapo-transpiration in the system. Water density, viscosity and formation of salt crust are factors that could reduce evaporation and maintain higher water in the soils. Al-Busaidi and Cookson (2005) reported that salt crust formation on the soil surface due to saline irrigation inhibited evaporation and reduced leaching efficiency. It has been reported that salt accumulation in root zone causes the development of osmotic stress and reduces plant development (Heakal et al. 1990; Abdul et al. 1988).

Salinity of drainage water reflects the occurrence of salts in the soils and the quality of the irrigation water. As expected the lowest salinity in the drainage waster was recorded under normal water treatment whereas the enhanced salinity level occurred with diluted or undiluted sea water

applications (Fig. 3). Since the drainage is a leaching process, the leaching fraction at the rate of 10% transported sufficient salts out of the soil in the drained water. Therefore, the leaching at such fraction could be acceptable in the soils irrigated with higher saline waters. Shalhevert (1994) also reported that leaching is the key to the successful use of saline water for irrigating crops. Oron et al. (2002) reported that high saline water has an agricultural potential under proper management of irrigation. By increasing the volume of irrigation water, the soil salinity may be reduced due to water percolation below the root zone (Petersen 1996).

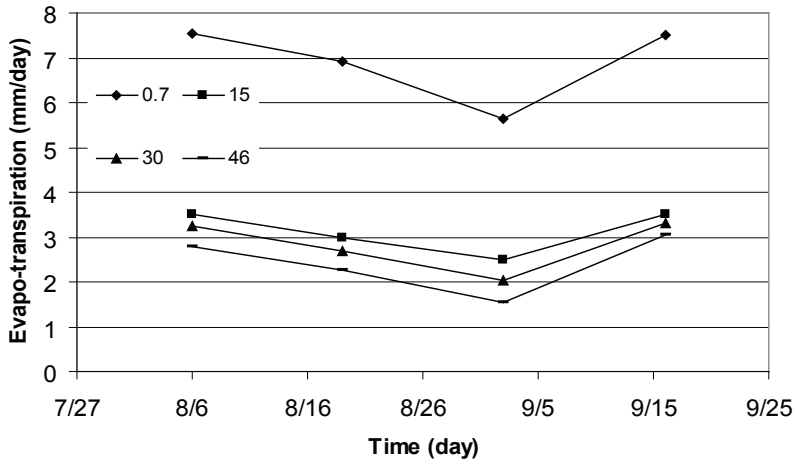

Figure 2. Variability in the evapo-transpiration as affected by saline treatments.

Application of irrigation water with certain level of salts results in the deposition of soluble salts in the soils. Evaporation and transpiration of irrigation water eventually leads to accumulation of excessive amounts of salts in the soils unless an adequate leaching and drainage system is in place (U.S. Salinity Laboratory Staff 1954).

Usually soil salinity is monitored either from the drainage water or through analyzing soil samples. During the study, a low electrical conductivity of soil was noted under normal water whereas sea water irrigation largely increased the salinity level of soil (Fig. 4). The saline water accumulated salts in the soil in spite of the leaching process. Petersen (1996) reported that the accumulation and release of salts could depend on the quality and quantity of irrigation water, soil type and plant response. Abu-Awwad (2001) reported high salt concentration on the soil surface due to evaporation.

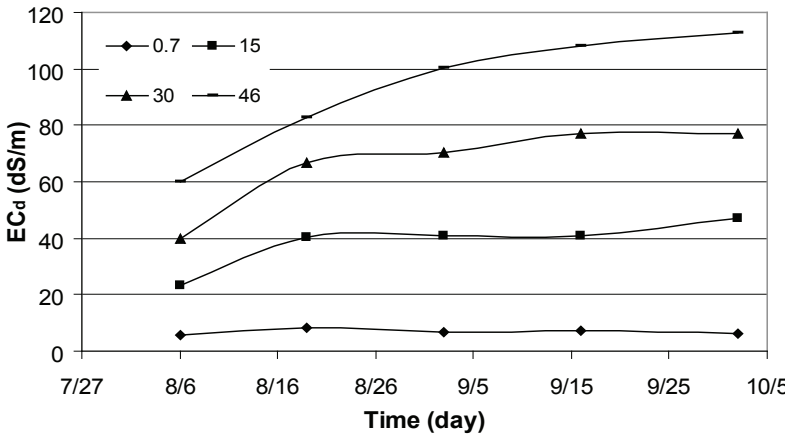

Figure 3. Drainage water salinity as affected by saline water treatments.

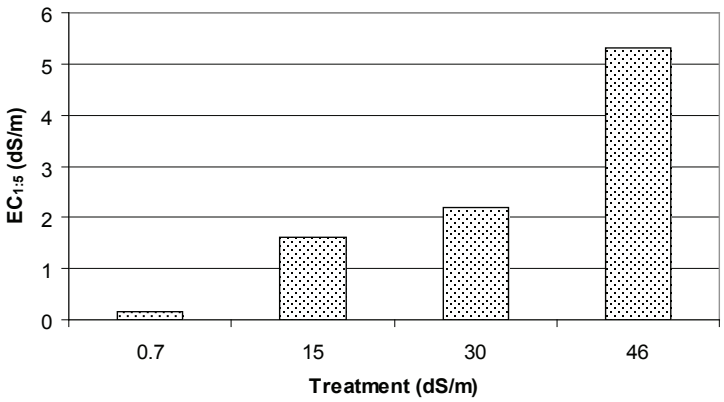

Figure 4. Soil salinity under different saline irrigation treatments.

Plant parameters were the function of irrigation water treatments. Sedum plant grew well under non-saline conditions. Highest plant fresh and dry biomass, plant height and leaf area were noticed with normal irrigation water. While, sea water treatment gave the lowest values of the plant parameters (Table 2). Soil salinity was the main reason behind the lower plant growth whereas the effects of irrigation methods were statistically found insignificant. Sedum plants accumulated more salts and leaf injuries were seen especially under high saline treatments. The physiological thickness of the sedum leaves with higher water absorbing potential could possibly facilitate sedum plants to survive under high saline conditions. There is a general consensus that higher salinity profoundly impairs plant growth (U.S. Salinity Laboratory Staff 1954). The response of crops to salinity could depend upon plant species, soil texture, water holding capacity and composition of the salts. Abu-Awwad (2001) reported that saline soils with considerable soluble salts interfered with the growth of crop species. Heakal et al. (1990) reported that dry matter yield of plants decreased with increasing salinity of irrigation water.

Table 2. Plant parameters as affected by salinity level (EC) of irrigation water and method of irrigation (N, surface irrigation; S, sprinkler)

Treatment EC x Method) (of Irrigation	Plant height (cm)	Leaf area (cm^2)	Fresh weight (g)	Dry weight (g)
(N) 0.7	31	11	355	44
(S) 0.7	25	10	314	39
(N) 15	20	5	69	22
(S) 15	20	4	57	16
(N) 30	17	3	39	17
(S) 30	16	3	43	18
(N) 46	14	2	42	17
(S) 46	14	2	35	20

Significant differences were found in the fresh and dry weights of plant among the irrigation treatments. Tissue water deficit increased with the increasing salinity (Fig. 5). The ratio of dry weight to fresh weight of the plants therefore increased significantly with the increasing level

of salinity treatments. The stress caused by the ion concentrations allows the water gradient to decrease, making it more difficult for water and nutrients to move through the root membrane (Volkmar et al. 1998). Accumulation of salts in the root zone affects plant performance through creation of water deficit and disruption of ion homeostasis (Munns 2002), which in turn would cause metabolic dysfunctions. The differences in the water content of the plants between the irrigation methods could reflect the efficiency of surface irrigation which can provide enough water to the plant without physically touching the leaves. Sprinkler irrigation adds salts directly on the leaves and may disturb its normal functions. The interaction effect of salinity level and method of irrigation was significant in affecting plant height and biomass but not the leaf area (Table 3).

Volkmar et al. (1998) reported that plants grown in saline soils have diverse ionic compositions and concentrations of salts. The fluctuations in the salts concentrations could be related to the changes in the water source, drainage, evapo-transpiration, and solute availability. The two major environmental factors that currently reduce plant productivity are drought and salinity and these stresses cause similar reactions in plants due to water stress (Serrano 1999).

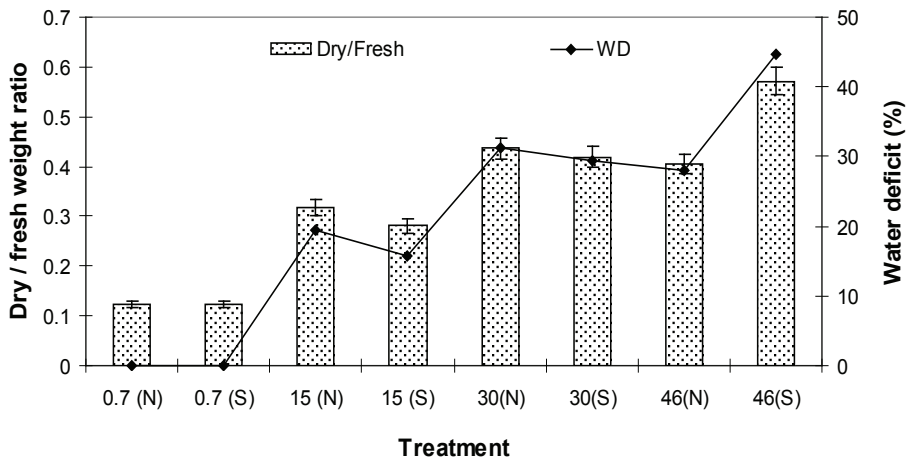

Figure 5. The ratio of dry to fresh weight and water deficit (WD) as affected by the saline treatments.

Table 3. Summary of two-way analysis of variance on the effects of saline water and irrigation method on plant parameters

Parameter	Saline water (S)	Irrigation method (I)	S x I
	P-value		
Plant height	0.0001*	0.0001*	0.0002*
Leaf area	0.0001*	NS	NS
Fresh weight	0.0001*	0.0001*	0.0001*
Dry weight	0.0001*	0.0006*	0.0001*

* *denotes the level of significance at P value < 0.05 and NS denotes non-significance.*

Conclusion

Our experiment confirmed that sedum plants can tolerate salinity stress and can also survive with water deficit conditions. The irrigation with increasing levels of salinity in the water remarkably affected the evapo-transpiration rate, salts accumulation in the soils and plant biomass production. We attribute the continuation of sedum growth with increased salinity to the potential of sedum plant to maintain high moisture content in the thick leaves under stress conditions. The use of sea water up to certain dilution could be an option for sedum production in water scarce areas.

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26. Alleviation of the potential impact of climate change on wheat productivity using arginine under irrigated agriculture in Egypt

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Abstract

Agriculture is inherently sensitive to weather and climate. Adaptation of an appropriate management strategy is one of the likely decisions to cope with the impacts of changing climate. This study was designed to explore the role of arginine (0.0, 2.5 and 5.0 mM) in increasing the tolerance of wheat cultivar (sakha-93) to two late sowing (23/12 and 23/1) dates, simulating the effect of climate change, beside the normal sowing date (23/11) in Egypt. The field experiment was conducted at the Agricultural Research Station of National Research Centre located in Shalkan Province, Kaluobia Governorate, Egypt. Foliar application of arginine with 2.5 mM arginine treatment induced 8.0% increase in grain yield of the plants sown late on 23/12 and could reduce the reduction percentage in grain yield from 41.22 to 26.22% at 23/1 sowing date as compared to optimum date. From this study it could be concluded that, arginine could alleviate the adverse impact of climate change during late sowing of wheat and reduce expected reduction of economic yield in semi aired region under irrigated agriculture.

Introduction

Agriculture is inherently sensitive to weather and climate. Adaptation of an appropriate management strategy is one of the likely decisions to cope with the impacts of changing climate. Optimum sowing date plays an important role in wheat yield production. Delay of wheat sowing date reduced wheat yield as a result of exposure to high temperature, which reduce season length (Abd El-Monem 2007 and Mostafa et al. 2009).

The stimulative effect of arginine as polyamine precursor on growth and yield component of crops has been observed in the past and has been attributed to its serving as a protective agent for plants under extreme environmental conditions. The objectives of this study were to determine the effect of arginine on yield attributes and yield of wheat sown on normal or delayed sowing dates under irrigated conditions in Shalkan Province, Kaluobia Governorate, Egypt.

Materials and methods

Field experiments were carried out at the Experimental Station of NRC in Shalakan Province, Kalubia Governorate, Egypt to explore the role of arginine (0.0, 2.5 and 5.0 mM) in increasing the tolerance of wheat cultivar (Sakha-93) to two late sowing dates (23/12 and 23/1), as compared to the one planted on the normal sowing date (23/11). Experiment was conducted in split plot design with four replications with a net plot size of 3 x 3.5 m. Sowing dates and arginine levels were allocated in main and sub plots, respectively. Arginine treatments were sprayed one month from sowing.

All standard agronomic practices for wheat cultivation were used uniformly across all the treatments. Wheat plants were manually harvested in the last week of May. At harvest, data on wheat yield and its components were determined. Analysis of variance (ANOVA) for split plot design was conducted using M-STAT-C statistical analysis program (MSTAT 1988).

Weakly maximum and minimum temperatures data were obtained for Shebeen El- Kanater region as representative of Shalakan region through the 2005/06 growing season (Fig 1).

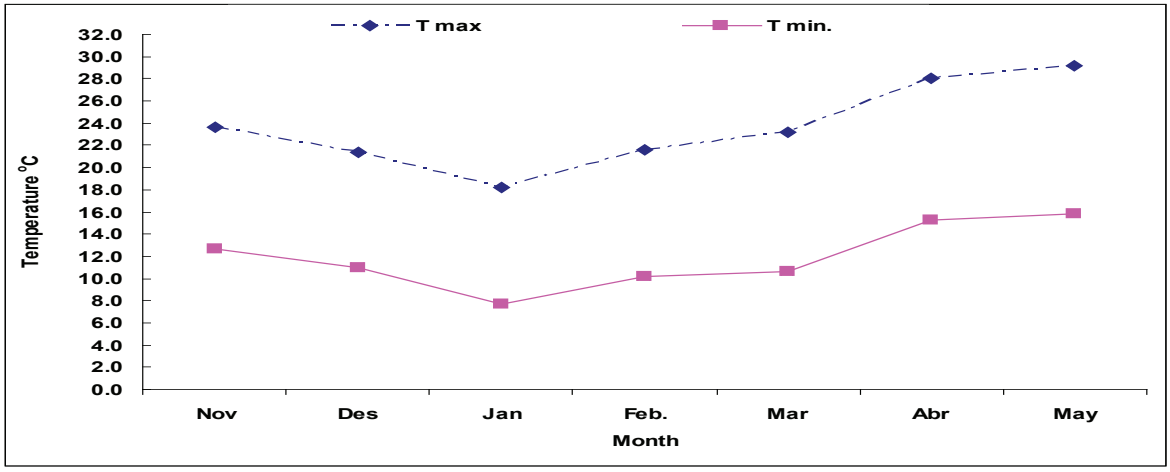

Figure 1. Maximum and minimum temperature for Shebeen El-Kanater during growing season of 2006/07.

Results and discussion

Plant height and graint yield components

Data in Table 1 showed that sowing wheat plant at the last week of November (23/11) resulted in the most optimum growth and the maximum values for variou yield components at harvest. These results could be attributed to the appropriate weather conditions prevailing during growth season when the crop was planted on 23 November, which is also the currently recommended optimum date of sowing wheat in the region. Delaying the date of sowing for 30 and 60 days induced significant reduction in all components of yield (Table 1). The decrease in these parameters can be attributed to the shortening in the total growth duration and exposing plant at critical stages of its growth to high temperature stress under delayed sowing dates.

Foliar application of different arginine concentration (2.5 and 5.0 mM) one month after sowing exhibited significant increase in all the yield parameters under normal as well as late dates of sowing. The maximum increase in all parameters was obtained by using 2.5 mM arginine. Spraying of 2.5 mM arginine treatment increased plant height by 10.24% and 3.97%, spikes number/0.25 m^2 by 10.24% and 3.97%, spike length by 7.89% and 9.28%, spike weight by 8.75% and 6.76%, spike grain weight by 33.18% and 49.65%, spikelets number/ spike by 14.08% and 13.33, grain spike ratio by 22.46% and 40.17%, and 1000-grain weight by 11.92% and 11.17% at sowing date delayed for 30 and 60 days, respectively as compared to the corresponding unsprayed controls. The positive increase in the yield components of wheat in response to arginine is in agreement with those obtained by Iqbal and Ashraf (2005) and El–Bassiouny et al. (2008).

Abd-El-Monem (2007) and Mostafa et al. (2009) showed that the improvement in the yield components of wheat in response to arginine treatment may be due to the stimulatory effects of arginine in increasing vegetative growth, and promotion of antioxidant enzymes, endogenous poly amines and endogenous amino acids.

Wheat yield

Sowing wheat plant at 23 November gave the maximum grain, straw and biological yields (Table 2). Similar results were reported by several other investigators (Ouda et al. 2005; Eid et al. 200; Abd El-Monem 2007; Mostafa et al. 2009; Hamam and Khaled 2009). Sowing wheat on late dates (23/12 and 23/1) significantly decreased grain, straw and biological yields as compared with plants sown on recommended sowing date (23/11). The reduction percentage reached to 10.39% and 41.22% for grain yield, 12.22% and 33.40% for straw and 11.59 and 35.98 for biological yield fed^{-1} when sowing date was delayed for 30 and 60 days, respectively (Table 2).

The decrease in yields of wheat plant at both late sowing dates can be attributed to decline in spike weight, grain spike weight, 1000 grains weight and spike noumber/0.25 m^2 and other yield components (Table1). These results are in good harmony with those obtained by Singh and Pal (2003), who found that, late sowing caused shortening in the total growth duration and significant reduction in the biological and economic yields through reduction in the number of spikes per pot, number of grains per spike, weight of 1000 grains and grain dry weight per shoot. Ouda et al. (2005) reported that, sowing wheat in late dates reduced seasonal length, and resulted in a reduction in grain, straw and biological yields. This could be attributed to reduction in the rate of leaf appearance as a result of water stress which reduces assimilate production by tillers and consequently reduces wheat grain and straw yields.

Table 1. Wheat yield and its components as affected by spraying with arginine at different sowing dates

Treatment		Plant height (cm)	Spike (s)				spikeletes noumber/ spike	Grain spike ratio	1000-grains wt. (g)	Yield (ton fed^{-1})		
Sowing date	Arginine (mml)		No/ 0.25 m^2	Length (cm)	Weight (g)	Grains wt (g)				Grain	Straw	Biological
23-Nov-05.	0.0	86.50	108.00	10.00	3.35	2.26	18.50	0.67	49.21	2.51	4.51	7.02
	2.5	93.75	126.25	11.50	3.74	2.59	20.75	0.69	56.20	2.99	6.31	9.30
	5.0	87.50	118.00	11.50	3.58	2.36	18.75	0.66	52.12	2.84	5.69	8.53
23-Des-06.	0.0	83.00	101.00	9.50	3.20	2.11	17.75	0.66	42.13	2.25	4.32	6.57
	2.5	91.50	130.00	10.25	3.48	2.81	20.25	0.81	47.15	2.70	5.38	8.08
	5.0	86.60	120.00	9.88	3.36	2.26	18.75	0.67	45.14	2.69	5.31	8.00
23-Jan-06.	0.0	69.25	85.00	9.38	2.22	1.41	15.00	0.64	36.00	1.48	3.27	4.75
	2.5	72.00	116.75	10.25	2.37	2.11	17.00	0.89	40.02	1.85	4.36	6.21
	5.0	70.25	100.25	9.50	2.33	1.72	15.75	0.74	38.04	1.75	4.17	5.92
LSD 5%		1.17	15.56	1.00	0.37	0.33	1.53	0.14	1.49	0.41	0.35	0.68
Mean of Main effects:												
Sowing date	23./11	89.25	117.42	11.00	3.56	2.40	19.33	0.68	52.51	2.78	5.50	8.28
	23./12	87.03	117.00	9.88	3.35	2.39	18.92	0.71	44.81	2.55	5.00	7.55
	23./1	70.50	100.67	9.71	2.31	1.75	15.92	0.75	38.02	1.69	3.93	5.63
LSD 5%		0.84	10.90	0.50	0.18	0.20	1.28	0.08	0.08	0.19	0.08	0.55
Sprying Arginine (mml)	0.0	79.58	98.00	9.63	2.92	1.93	17.08	0.66	42.45	2.08	4.03	6.11
	2.5	85.75	124.33	10.67	3.20	2.50	19.33	0.80	47.79	2.51	5.35	7.86
	5.0	81.45	112.75	10.29	3.09	2.11	17.75	0.69	45.10	2.43	5.06	7.48
LSD 5%		0.68	8.98	0.57	0.21	0.19	0.89	0.088	0.86	0.08	0.16	0.43

Abd El- Monem (2007) and Mostafa et al. (2009) concluded that, exposure of wheat plants to high temperature stress due to late sowing (15/12) could lead to reducing the vegetative and

reproductive phases in wheat and consequently in reduced grain, straw and biological yields as compared to plants sown at normal date (15/11). Moreover, Hamam and Khaled (2009) reported that reduction in flag leaf area, spike length and kernel weight because of delayed sowing caused great reduction in grain yield. Mohanty (2003) made similar observations.

Foliar application of arginine at 2.5 and 5.0 mM on normal or delayed sown wheat exhibited significant increase in wheat yield in comparison to untreated plants. Arginine treatment at 2.5 mM concentration induced 8.0% increase in grain yield of the plants sown at 23/12 and decrease the reduction percent in grain yield from 41.22 to 26.22%, straw yield from 33.40 to 11.41 and biological yield from 35.98 to 16.44% at 23/1 sowing date as compared to the normal date of sowing. This was because of the stimulatory effect of arginine on different yield components (Table 1).

Conclusion

From this study it could be concluded that, arginine could alleviate the adverse impact of climate change, as simulated by late sowing of wheat, and can reduce the expected reduction of economic yield in semi aired region under irrigated agriculture because of climate changes. There is however a need to have more precise investigation of the mechanism by which this effect of argenin is achieved.

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27. Effect of artificial Zeolite on growth under saline irrigation in Qatar

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Abstract

For targeting zero emissions, coal fry ash is converted to the Ca-type artificial zeolite (Chubu Electric Power Co. Ltd., Japan). It has a porous and crystalline structure, a high CEC of about 300 cmol (+)/kg, and a large specific surface area. Therefore, its application in the soil can be expected to improve the water and nutrient holding capacity of soil and prevent salinity. The leaching, loss of moisture by perculation and salinity are serious problems on sandy soils in the dry lands. To assess these effects on dry land, experiments were conducted using saline irrigation (EC=6.4dS/m, Na+568ppm, and Ca2+ 417ppm) in Qatar. A 2% zeolite application increased the soil water content 2-folds over the control at 20cm depth, although, there was no change at the ground level. The growth of vegetables was decreased by the half reduction of the supplied fertilizer; however, application of zeolite recovered the growth under this condition. Zeolite improved the early growth of vegetables and turf. The surface soil in a zeolite-free plot became hard and showed salt accumulation and salt crust, which probably inhibited the sprouting of turf. However, the addition of only 1% zeolite reduced these problems and 2% zeolite increased growth by about 3-folds compared to the zeolite-free plot at 113 days after planting. This indicates that zeolite can potentially reduce salt damage. Thus, it can be expected that using artificial zeolite would be effective for plant production and soil conservation in dry lands due to its water and fertilizer holding and salt masking abilities.

Introduction

For agriculture in the drylands, water shortage and soil salinization and sodification are major production constraints. The soils with the electrical conductivity (EC) of saturation extracts exceeding 4 dS m^{-1} are classified as saline soils and those exchangeable sodium percentage higher than 15 are classified as sodic soils (US Salinity Laboratory Staff 1954). It is desirable to amend the saline soils by leaching salts with enough amount of irrigation water. However, irrigation water with a low EC is not easily available in the dryland conditions. The amendment of sodic soil necessitates application of gypsum and sulfur. The ameliorative effects of Ca and K on plant growth under Na-rich media have been widely recognized (Grieve and Fujiyama 1987).

Artificial zeolite made from coal fry ash is a kind of synthetic inorganic material with high surface area having negative charge. It therefore has a high cation exchange capacity (Kikuchi 1999), which is important for soil fertility as it hold ammonium and other cations and permits their availability to the plant roots over an extended period of time, acting almost as a slow release fertilizer (Perrin et al. 1998).

Chubu Electric Power Co., Inc. (CEPCO) have one of the world's largest coal-fired power stations with an output of 4,100MW. CEPCO have successfully recycled 90% coal ash from this power station into ingredients for cement and structural materials. For targeting zero emissions,

CEPCO recently developed technology to convert coal ash into high quality synthetic zeolite, which further promotes the re-use of coal ash. Production of the zeolite commenced in October 2004. The production facility can produce 3,000 tons of the zeolite annually.

The studies in the past showed that application of Ca-type artificial zeolite improved the beet growth on saline and sodic soil by increasing the uptake of Ca and K and correcting the cation imbalance caused by high Na (Yamada et al. 2002). Addition of Ca-type zeolite improved the growth of several plants by causing the recovery of water absorption and/or recovery of Ca^{2+} and K^{+} absorptions and restriction of Na^{+} absorption in high sodic soil (Yamada et al. 2007).

This set of experiments was conducted to study the effect of artificial zeolite on plant growth under saline irrigation. We hypothesized that artificial zeolite will prevent the negative effects of salinity, which is very important for dry land agriculture and greening the dry area landscape. The salinity stress is caused not only by limited availability of water but also by the use of a large amount of fertilizer that increases the salt concentration in the soil solution and/or underground water. It is hypothesized that the amounts of irrigation water and fertilizer can be reduced by applying zeolite because of its high retention of water and nutrients on its surface.

Materials and methods

Characteristics of CEPCO's artificial zeolite: This zeolite can maintain 112.2 % (w/w) water. Further, it has a high CEC of about 300 $cmol^{(+)}/kg$ and a large specific surface area (Table 1).

Table 1. Properties of artificial zeolite produced by CEPCO

Characteristic	**Artificial zeolite**
Cation Exchange Capacity ($cmol^{(+)} kg^{-1}$)	330
Average Particle Diameter (μm)	37
Specific Surface Area (m^2/g)	28
Unit Weight (g/cm^3)	0.8
Electric Conductivity (mS/cm)	1.56
pH	7.0
Components (% weight):	
Na_2O	5.5
CaO	5.2
SiO_2	49.5
Al_2O_3	30.5
Fe_2O_3	4.2
MgO	0.4
K_2O	0.6

We tested the safety of zeolite for acute oral toxicity in mice LD50 Value (> 4,000 mg/kg); for primary skin irritation index (PII) in rabbits (negligible); fish acute toxicity test (96-hour LC50 Value > 10,000 mg/L); and heavy metals leaching test (As, Ba, Cd, Cr, Pb, Se, and Ag were not

detected) according to the standard procedures approved by OECD and EPA(Environmental Protection Agency). The material was found safe.

Experimental treatments: We conducted three experiments in Al Seyliya, Qatar. The purpose was to find out whether zeolite can save water and fertilizer and protect plants from salinity in water (4500 ppm TSS; 570 ppm Na). Experiments 1, 2, and 3 investigated the effects of artificial zeolite on plants used for greening landscape (rose, *Gazania* and *Pennisetum setacum 'Rubrum'*), vegetables (beet root, Swiss chard, and spinach) and turf, respectively. The treatments included conventional and reduced irrigation, normal and reduced rate of fertilizer application and application of no zeolite vs. 1 and 2% zeolite. In experiment 1, a shading treatment was included by installing a shading cage to control the water use by plants.

The soil of the experimental field: It was prepared by first removing the limy mother soil of the area up to 30 cm depth, then filling in a mixture of the sand dune soil, town compost and crushed bentonite in the ratio of 70 to 20 to 10. Then as a final step, 1 or 2% of artificial zeolite was well mixed with the soil uniformly, depending on the treatment. The amount of artificial zeolite was 3 or 6 kg per square meter for 1 or 2 % of amended soil.

Irrigation water: Water used was from underground source. The chemical composition is shown in Table 2. The salt contents, especially sodium and calcium, were very high, and the EC was 6.4 dS/m (approximately one tenth of seawater).

The amount of water applied under full (traditional) and reduced irrigation treatments in the experiment on greening plants is given in Table 3**.**

Table 2. Chemical composition of the underground water used for irrigation

			Concentration ($cmol_c$/L)							**EC**
K^+	Na^+	Ca^{2+}	Mg^{2+}		Cl^-	SO_4^{2-}	NO_3^-	NO_2^-	PO_4^{2-}	(dS/m)
0.12	2.47	2.08	1.68		3.26	2	1.72	trace	trace	6.4

Table 3. Amount of water (Liters/ m^2 /day) applied under traditional irrigation and reduced irrigation

Irrigation	**October**	**November**	**December**	**January**	**Total**	**Relative**
Traditional	15.4	6.8	6.8	1.5	30.5	100
Reduced	7.7	1.7	1.7	0.4	11.5	38

Results and discussion

Effect of zeolite on water retentively and growth

In Experiment 1 the effect of zeolite (2%) application, watering and shading was studied.
To study the effect of zeolite application on water retention in the soil, soil water content was

measured at ground level and 20 cm depth level. There was no change at ground level due to zeolite application. However, the water content almost doubled at a depth of 20cm when zeolite was applied (Fig 1.). Therefore using artificial zeolite can be expected to maintain high water content.

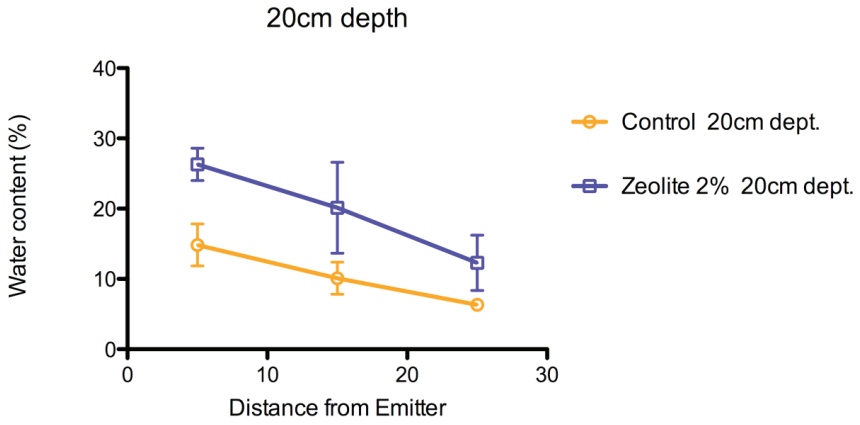

Figure 1. Effect of zeolite application on the water content of soil at 20 cm depth.

Table 3 shows the amount of irrigation water applied in the experiment on greening plants. Irrigation water in the traditional irrigation decreased as the season advanced. The amount of water under reduced irrigation was almost half of that under full irrigation in October, and one fourth in November.

After 3 months of water treatment, rose plants showed better growth under shading, with zeolite treatment (Photo 1), while Gazania's growth was reduced by shading treatment. Watering treatment did not show a clear difference in growth.

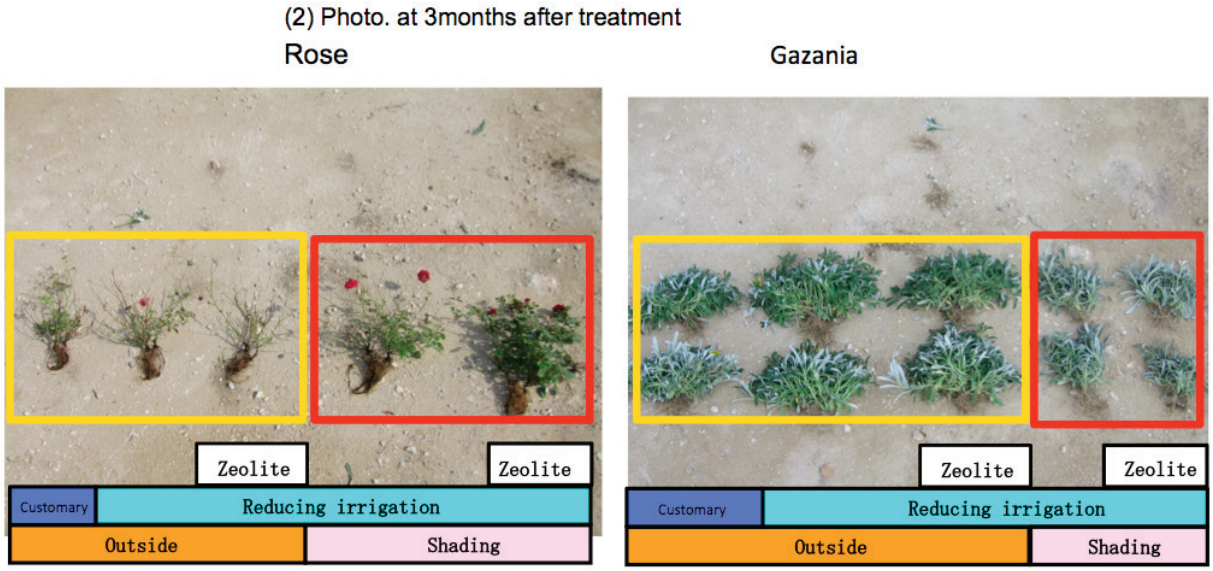

Photo 1. Effect of zeolite(2%) application, reducing irrigation level and shading on the growth of rose and Gazania three months after the start of treatments.

After 8 months of irrigation treatment, there was a difference in the growth of *Pennesetum rubrum* due to the reduction in the irrigation. However, zeolite treatment did not show positive effects on growth. Water saving is more important in this situation than getting better growth of greening plants. The amount of irrigation in Qatar can therefore be reduced as compared to the traditional irrigation.

Effect of zeolite on reducing the irrigation water needs in vegetables

In Experiment 2, the dry weight of Swiss chard was reduced by the decrease in watering, especially under the reduced fertilizer treatments, due to water shortage at 63DAT. But it could be overcome by the application of 2 % zeolite under the reduction fertilizer treatments (Fig. 2). This result indicates water holding ability of zeolite.

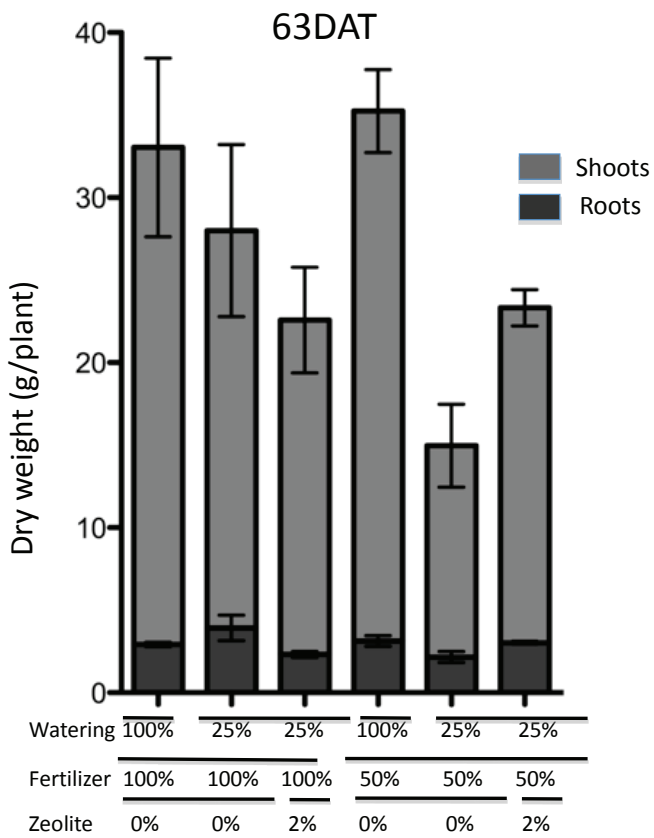

Fig. 2. Effect of Zeolite on reducing watering on Swiss Chard

Effect of zeolite on reducing the need of fertilizer

The results of fertilizer treatments are shown in Fig.3. The growth of Swiss chard and spinach was decreased by the reducing the supply of fertilizer to half. Nevertheless, zeolite application made-up for the insufficient fertilizer, although this effect was evident in only 1% application of zeolite. Under the zeolite-free condition, the fertilizer easily leached below the rhizosphere, while in the presence of zeolite, the fertilizer nutrient ions were retained on its extensive surface because of high cation exchange capacity, and were available for absorption by the plants gradually. It has been reported that zeolites can be used to supply NH_4 or K to plants as a slow release fertilizer.

Effect of zeolite to mask the effect of high salt concentration in irrigation water

As previously explained, the growth of roses in Experiment 1 was improved by the application of zeolite when the rose plants were grown with poor quality irrigation water (Photo 1). The study of the Na content in leaves showed that it was reduced by zeolite application, presumably by of ability of zeolite to prevent Na uptake (Fig.4).

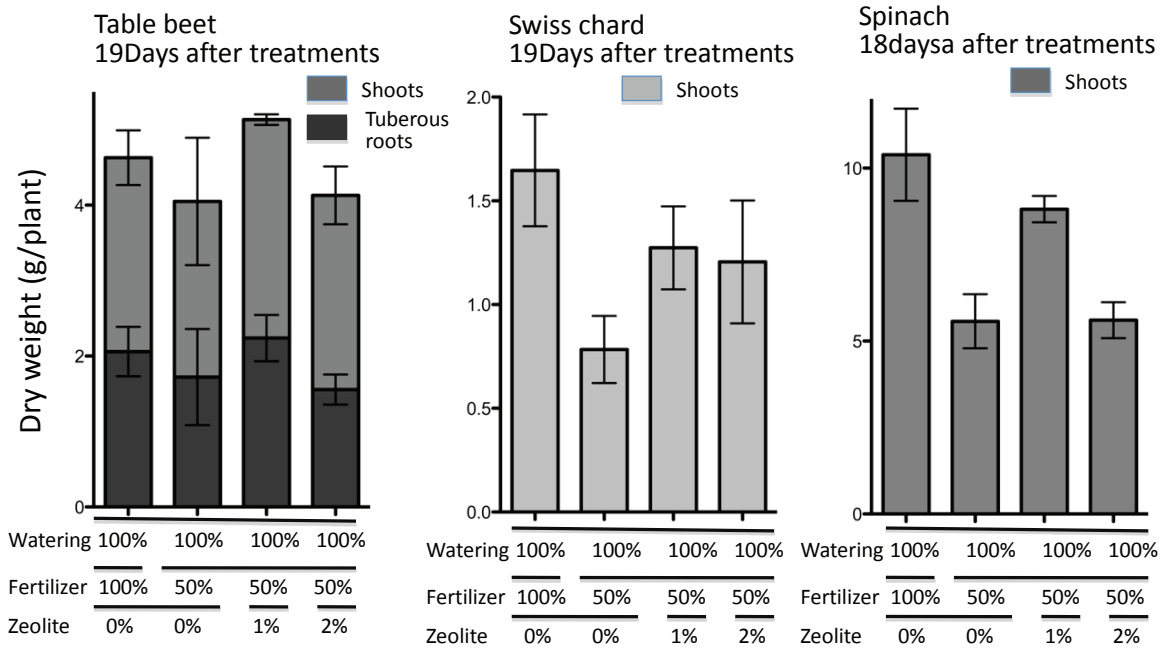

Fig. 3. Effect of Zeolite on reducing fertilizer need

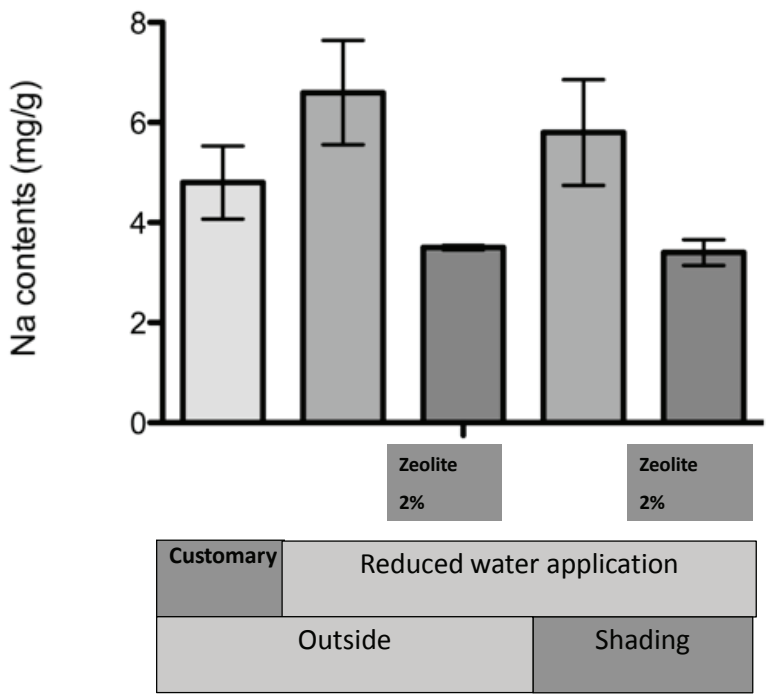

Fig. 4. Na content of rose leaves as affected by different treatments.

In Experiment 3, the effect of zeolite on the growth of turf was investigated. Turf is an important plant for greening the landscape. In this experiment, water was supplied by a sprinkler. The turf grass *Paspalum* sp. is salt and drought tolerant. After the planting of rhizomes, shooting was promoted by the daily irrigation of 18 L water per square meter. The surface soil in the zeolite-free plot became hard and showed salt accumulation and salt encrustation (Fig. %).. These factors inhibited the sprouting of *Paspalum* in this zeolite-free plot. However, application of zeolite, even at 1%, reduced these problems and increased growth by 1.4 folds as compared to the zeolite-free plot after 78 days from planting (DAT). The turf was mowed to 4 cm at 113 and 169 days after planting. The application of 2% zeolite increased the dry weight of mowed material by about 3 times of the zeolite-free plot at 113 DAT. A further increase in dry weight could be seen during the second mowing (Fig. 5).

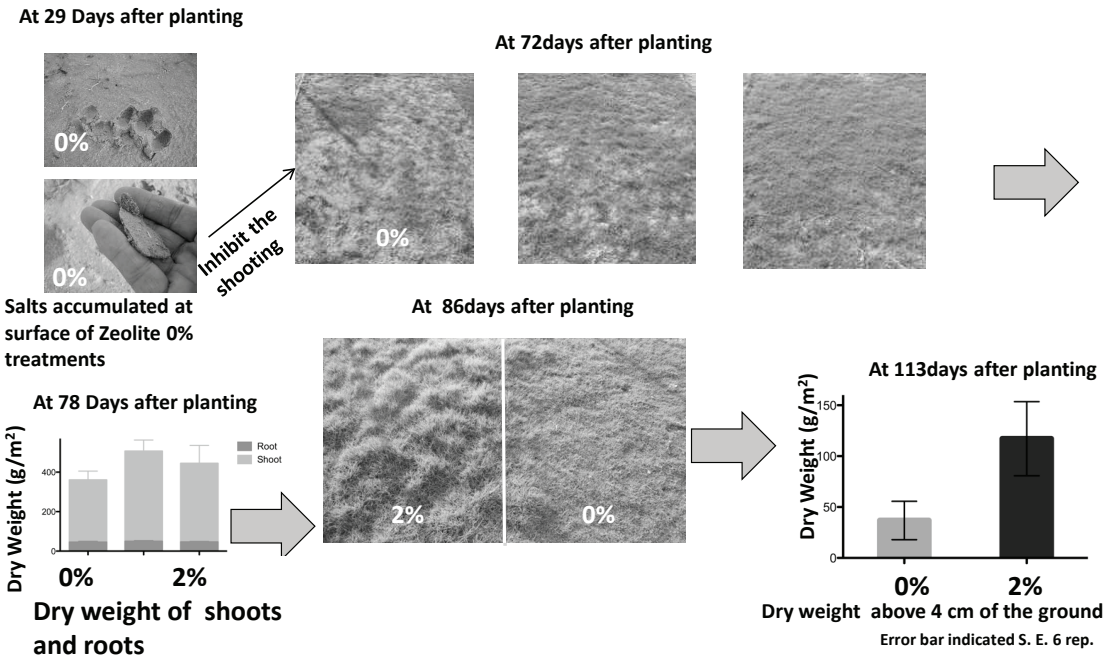

Fig. 5. Effect of Zeolite on turf grass (cv. Paspalum***)***

Conclusion

The results presented above show the general merits of the application of artificial zeolite to the soil in Qatar as diagrammatically depicted in Fig. 6.. The soil in Qatar is based on limestone bedrock. Therefore for agriculture, people breakdown and remove the limestone bedrock and commonly add new sandy soil mixed with compost. In the sandy bed, fertilizer and water percolate down easily and plants face the risk of salinity problems. With the addition of artificial zeolite, water and minerals are held in the soil and are supplied to the plant gradually. Thus, the pollution of the underground water is avoided.Thus, using artificial zeolite would be helpful in plant production and soil conservation.

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28. Effects of Na^+ and Ca^{2+} on root cell wall composition in two soybean cultivars differing in salt tolerance

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Abstract

Salinity is one of the major limiting factors in agriculture in the world which severely inhibits crop growth and yield, especially in arid and semi-arid regions. In plants, cell wall is the primary framework that fulfils structural, protective and growth-regulating functions during its life cycle. However, little is known about the changes in cell wall composition (including pectin, hemicelluloses and cellulose) under salinity. Calcium was widely reported to affect cell wall structure and alleviate salinity stress. Thus, this study was to investigate the effects of both sodium and calcium on root cell wall composition in two soybean (*Glycine max* (L) Merr) cultivars, Tousan69 (salt-sensitive cultivar) and Dare (salt-tolerant cultivar), and clarify the relationship between cell wall composition and the salinity tolerance. Results showed that salt inhibited root growth while calcium application recovered it, and this recovery effect was more prominent in Dare (88% recovery) than in Tousan69 (65% recovery). The cell wall polysaccharide, especially pectin, decreased significantly by salinity, but this decrease was more severe in Tousan69 (53%) than in Dare (30%). Calcium application restored it, in Dare, pectin content was restored to 109%, while in Tousan69, it was 84%, and the restoration extensiveness was parallel to the recovery of root growth in two cultivars. The maintained cell wall polysaccharide was essential for cell division and elongation under salinity. These results suggested that changes in cell wall composition have a close relationship with the regulation of root growth under salinity. The difference in salt tolerance between the two tested cultivars can partly be explained on the basis of the changes in the cell wall composition in response to salinity. The alleviation effect of calcium on salinity stress is related to the maintenance of cell wall composition, especially the pectin content.

Introduction

Salinity is one of the most limiting factors in agriculture in the world as it severely inhibits crop growth and yield, especially in arid and semi-arid regions. In general, salinity imposes two kinds of stresses on plant tissues: one, a water deficit resulting from the relatively high solute concentrations of the soil; and two, ion cytotoxicity resulting from high ion concentrations that are inimical to plants (Blumwald et al. 2000; Zhu 2002). Recently, more and more researches

imply that salt affects plant growth mainly by non-nutrient ion accumulation rather than reduction in water availability (Hamed et al. 2004; Attia et al. 2008). Thus, the mechanisms for tolerance of the salt-specific effects of salinity are of two main categories: those minimizing the entry of salt into the plant, and those minimizing the concentrations of salt in the cytoplasm (Munns 2002). The first mechanism involves prevention of ion from entering into the cell, and the second is based on ion compartmentation in the cell.

Cell wall is an important structure in plants. It determines cell shape, glues cells together, provides essential mechanical strength and rigidity, and regulates cell growth and development (Cosgrove 2005). It is also the first barrier to protect plants from various abiotic and biotic attacks and stresses. Cell walls in higher plants are made up of complexes of cellulosic microfibrils and a non-cellulosic matrix composed of pectins, hemicelluloses and proteins (Fernanda et al. 1997). The high degree of structural complexity of plant cell wall constituents plays an important role in plant growth, and they also respond quickly to many adverse environmental conditions. Piro et al. (2003) reported that water stress caused a decrease of uronic acid, glucose and xylose amount in wheat root cell wall. Hossain et al. (2006) showed that aluminum treatment increased the uronic acid content in pectin, and glucose, xylose and arabinose content in hemicellulose in wheat. Under salinity, it was suggested that the growth reduction was related to the decrease in the plastic extensibility of the growing cell walls, because salt ions affected cell wall metabolism and caused rigidity of cell walls which would inhibit cell elongation and expansion (Zhong and Läuchili 1993; Neumann et al. 1994; Neumann 1997). Furthermore, as the cell wall contains many structural proteins and enzymes, exposure to excessive ion condition may demolish these proteins and enzymes, which would result in affecting the whole plant growth adversely (Neumann et al. 1994).

Calcium is an essential nutrient for plant growth and development, and numerous studies have showed its alleviation effect on salinity stress. In plant, about 50% of this essential element is bound in the cell wall, which indicates a close link between calcium and cell wall. It maintains the physical integrity of the cell wall and regulates the activities of cell wall associated enzymes (Cramer 2002). It also plays an important role in the synthesis of cell wall materials and regulating of cell wall extensibility (Ito and Fujiwara 1967; Ezaki et al. 2005). These protecting effects are more prominent during salinity stress, where Na^+ can compete with Ca^{2+} and displace it from the cell wall, while calcium-treated plants have shown less change in cell wall physical properties during salinity stress (Picchioni et al. 1991; Nonami et al. 1995).

Although the role of calcium in salt toxicity has been largely studied, to our knowledge, its role in salinity stress through affecting cell wall property is still less known. In this study, we used two soybean cultivars (salt sensitive cultivar 'Tousan69' and salt tolerant cultivar 'Dare'), to investigate whether cell wall compositions varied in different species in response to salt stress and whether exogenous calcium affected the cell wall composition in a different way in the two cultivars.

Materials and methods

Plant growth and treatment: Seeds of salt sensitive soybean (*Glycine max* L. Merr. cv. Touzan 69), and salt tolerant soybean (*Glycine max* L. Merr. cv. Dare) were surface sterilized in 0.5% NaClO for 15 min and then rinsed thoroughly with distilled water. Seeds were further imbibed in distilled water for 3 h, prior to germination in the dark at 25 °C for 48 h. Uniform seedlings were transplanted into hydroponic culture and treated with 6 treatments: 0 or 40 mM NaCl combined

with 0, 0.5 and 2 mM $CaCl_2$. All the culture solutions were well aerated and adjusted to pH5.5 with either HCl or NaOH. After treating for 14, 24 and 40 h, root length was measured. For cell wall analysis, roots were well washed with distilled water and blotted dry. About 30 segments of 0-5 mm root tips were excised with a razor blade from the seedlings. The root segments were then wrapped in aluminum foil and frozen immediately in liquid nitrogen for 1 h and stored at -80 °C until cell wall analysis. The experiments were conducted in a growth chamber (SANYO MLR-350 HT, Japan) at a relative humidity of 60% without light at constant 25 °C.

Cell wall extraction: Cell wall components were extracted according to the method of Tanimoto and Huber (1997) with slight modifications. Root segments were cut and homogenized with a mixture of ice-cold 50 mM Tris-HCl buffer, pH 7.4, and Tris buffer-saturated phenol using a Biomixer (Model NS-51, Microtec Co. Ltd., Tiba, Japan). The homogenate was centrifuged for 15 min at 3400 rpm at 10 °C. The supernatant was discarded and the residue containing cell walls was further washed with cold Tirs-HCl, ethanol, acetone, a mixture of methanol and chloroform (v:v=1:1), and again with acetone, and ethanol. The residue was treated with 0.2 mg mL^{-1} Pronase® protease (Calbiochem, EMD chemicals Inc. Germany) in 0.05 M phosphate, pH 7.0, containing 5% ethanol for 16 h at 30 °C to remove proteins. The insoluble pellet was considered as the cell-wall material.

Fractionation of cell-wall polysaccharides: The cell-wall material was fractionated into four fractions: pectin, hemicellulose I (HC I), hemicellulose II (HC II) and cellulose. The pectin fraction was obtained by extracting the cell wall with 50 mM CDTA (trans-1, 2-cyclohexanediamine-N, N, N', N'-tetraacetic acid) in 50 mM acetate buffer, pH 6.5 for totally 22 h at 23 °C. In order to extract remaining polyuronides, cell walls were further extracted 3 times with CDTA at 100 °C for 1 h each. HC I and II were sequentially extracted with 1 M and 4 M KOH thrice at 4, 16, and 4 h respectively, then cooled in an ice bath and neutralized with glacial acetic acid. Residual insoluble sediments were successively washed with 10 % (v/v) acetic acid, water and ethanol and dried at 60 °C on a Lacom Dry Oven (LDO-600SM, Iuchi Seieido Co., Ltd., now, ASONE Corporation, Japan). This was designated as the cellulose fraction. It was dissolved in a small amount of 72% (v/v) sulfuric acid and diluted with water when measured.

Total sugar and uronic acid analysis: The total sugar content in each fraction was quantified by the phenol-sulfuric acid method (Dubois et al. 1956), using glucose (Wako Pure Chemical Industries Ltd., Japan) as standard. Cell-wall uronic acid content was assayed by m-hydroxydiphenyl colorimetric method according to Blumenlrantz and Asboe-Hansen (1973), using galacturonic acid (Wako Pure Chemical Industries Ltd., Japan) as standard.

Analysis of cell-wall ions: Root segments were homogenized with ice-cold distilled water using a Biomixer (as described previously). The homogenate was centrifuged at 3000 rpm for 30 min at 2 °C, and the sediment was further washed and centrifuged 2 times. The residue (considered as the cell-wall material) was dried at 60 °C in a Lacom Dry Oven (LDO-600SM, Iuchi Seieido Co., Ltd., now, ASONE Corporation, Japan). The oven dried tissues were digested in a HNO_3-HCl (3:1, v/v) mixture and Ca^{2+} and K^+ concentrations were determined with an atomic absorption spectrophotometer (ASC-6100, Shimadu Corporation, Japan).

Statistical analysis: All data were subject to ANOVA of SAS V8.0, and means were compared using Duncan's multiple ranges tested at the 5% level of probability.

Results

Root growth: Root elongation was inhibited by salinity treatment in both the cultivars, but it was suppressed more in Tousan69, whose root length was reduced by 23%, 41% and 53% after 14, 24 and 40 h treatment, while in Dare, it only decreased by 20%, 34% and 43%, respectively (Table 1). Calcium application did not affect root elongation under control condition, but partially recovered root growth under salt stress in the two cultivars. In Tousan69, the recovery of root elongation was similar by application of either low (0.5 mM) or high (2 mM) calcium concentration at all three experiment periods. While in Dare, the high concentration of calcium recovered root elongation more than the low concentration, especially after 24 and 40 h treatment. Furthermore, the recovery effect of calcium was more prominent in Dare (88% recovery) than in Tousan69 (65%), particularly after long period of treatment.

Table 1. Effect of NaCl and $CaCl_2$ on root elongation of salt-sensitive Tousan69 and salt-tolerant Dare after 14, 24 and 40 h treatments

Cultivars	Salt (mM)	Ca (mM)	Root length (mm)		
			14h	24h	40h
Touzan 69	0	0	48.6 a	67.8 a	94.5 a
		0.5	49.4 a	68.0 a	96.3 a
		2	49.6 a	67.9 a	93.6 a
	40	0	37.0 b	39.9 c	44.4 c
		0.5	37.5 b	48.7 b	62.7 b
		2	36.4 b	48.0 b	61.1 b
	Salt		**	**	**
	Ca		NS	NS	*
	Salt ×Ca		NS	NS	NS
Dare	0	0	48.3 a	65.0 a	86.0 a
		0.5	47.6 a	62.5 a	88.6 a
		2	50.2 a	66.3 a	92.0 a
	40	0	38.5 b	43.0 d	48.7 d
		0.5	38.4 b	49.1 c	64.3 c
		2	41.9 b	54.4 b	75.5 b
	Salt		**	**	**
	Ca		NS	**	**
	Salt ×Ca		NS	**	**
Cultivar			**NS**	**NS**	**NS**
Salt			**	**	**
Ca			**NS**	**	**
Cultivar ×Salt			**NS**	**	**
Cultivar × Ca			**NS**	**NS**	*
Salt × Ca			**NS**	**	**
Cultivar ×Salt × Ca			**NS**	**NS**	**NS**

*Values are means of 15 replications. Means within a column of one cultivar followed by different letters are significantly different (P=0.05). * and ** indicate significance at the 0.05 and 0.01 probability levels, respectively; NS, not significant.*

Total sugar content: Total sugar content in cell wall pectin decreased significantly by salinity treatment in both cultivars, while application of calcium recovered it (Table 2). In Tousan69,

application of calcium at both low and high levels only partially recovered, while in Dare, low level of calcium application showed full recovery. Total sugar contents in other cell wall fractions (HC I, HC II and cellulose) were not affected by both salt and calcium in Tousan69. But in Dare, in the HC I and HC II fractions, it decreased by salinity treatment and recovered again by calcium application.

Table 2. Total sugar content of cell wall in root tips of salt-sensitive Tousan69 and salt-tolerant Dare

Cultivar	Salt (mM)	Ca (mM)	Total sugar content (mg g-1 FW)			
			Pectin	Hemicellulose I	Hemicellulose II	Cellulose
Touzan 69	0	0	6.26 a	1.39 a	2.38 a	4.59 a
		0.5	5.18 ab	1.16 a	1.96 a	4.19 a
		2	4.94 b	0.99 a	2.22 a	3.97 a
	40	0	3.22 c	1.02 a	2.05 a	4.12 a
		0.5	4.88 b	1.10 a	2.12 a	4.10 a
		2	4.42 b	0.99 a	1.72 a	3.85 a
	Salt		**	NS	NS	NS
	Ca		NS	NS	NS	NS
	Salt × Ca		**	NS	NS	NS
Dare	0	0	5.30 ab	1.50 a	2.36 a	4.81 a
		0.5	4.47 b	0.78 b	1.65 c	5.83 a
		2	5.92 ab	0.97 b	1.86 bc	4.01 a
	40	0	4.23 b	1.31 a	2.01 ab	4.18 a
		0.5	5.41 ab	1.13 ab	2.03 abc	4.08 a
		2	6.20 a	0.99 ab	2.13 ab	4.18 a
	Salt		NS	NS	NS	NS
	Ca		**	NS	NS	NS
	Salt × Ca		**	*	*	NS
Cultivar			**NS**	**NS**	**NS**	**NS**
Salt			**	**NS**	**NS**	**NS**
Ca			*	**NS**	**NS**	**NS**
Cultivar ×Salt			**NS**	**NS**	**NS**	**NS**
Cultivar × Ca			**	**NS**	**NS**	**NS**
Salt × Ca			**	*	**NS**	**NS**
Cultivar ×Salt × Ca			**NS**	**NS**	**NS**	**NS**

Values are the means ± SE (n=3). Means within a column followed by different letters are significantly different.
** and ** indicate significance at the 0.05 and 0.01 probability levels, respectively; NS, not significant*

Uronic acid content: Salinity treatment decreased uronic acid content in cell wall pectin significantly in both cultivars (Table 3). In Tousan69, it decreased by 49%, but in Dare, it was only 34%. Exogenous application of calcium recovered the pectin uronic acid content in both cultivars. In Tousan69, it recovered by 84%, while in Dare, it recovered by 109%. The uronic acid content in other cell wall fractions (HC I, HC II and cellulose) was not affected by either salt or calcium in both cultivars, except an increase in the cellulose fraction of Dare under salinity.

Table 3. Uronic acid content of cell wall in the root tips of salt-sensitive Tousan69 and salt-tolerant Dare

Cultivar	Salt (mM)	Ca (mM)	Total sugar content (mg g-1 FW)			
			Pectin	Hemicellulose I	Hemicellulose II	Cellulose
Touzan 69	0	0	3.76 a	0.02 a	0.03 a	0.17 a
		0.5	3.74 a	0.06 a	0.03 a	0.25 a
		2	3.57 a	0.05 a	0.07 a	0.13 a
	40	0	1.93 b	0.10 a	0.14 a	0.34 a
		0.5	3.31 a	0.03 a	0.10 a	0.21 a
		2	3.16 a	0.02 a	0.03 a	0.21 a
	Salt		*	NS	NS	NS
	Ca		NS	NS	NS	NS
	Salt × Ca		NS	NS	NS	NS
Dare	0	0	3.78 a	0.02 a	0.04 a	0.12 b
		0.5	3.378 a	0.04 a	0.04 a	0.04 c
		2	3.968 a	0.05 a	0.05 a	0.11 bc
	40	0	2.94 b	0.09 a	0.02 a	0.21 a
		0.5	4.15 a	0.04 a	0.01 a	0.11 bc
		2	4.14 a	0.03 a	0.03 a	0.07 bc
	Salt		NS	NS	NS	NS
	Ca		*	NS	NS	**
	Salt × Ca		**	NS	NS	NS
Cultivar			**NS**	**NS**	**	**NS**
Salt			*	**NS**	**NS**	**NS**
Ca			*	**NS**	**NS**	**NS**
Cultivar ×Salt			**NS**	**NS**	**NS**	**NS**
Cultivar × Ca			**NS**	**NS**	**NS**	**NS**
Salt × Ca			*	**NS**	**NS**	**NS**
Cultivar ×Salt × Ca			**NS**	**NS**	**NS**	**NS**

Ion accumulation in the cell wall of root tips: Cell wall potassium content decreased by salinity treatment in both the cultivars, but this decrease was more prominent in Tousan69 (reduced by 84%) than in Dare (reduced by 59%) (Table 4). Exogenous application of calcium at both low and high concentrations increased K content to the normal level in both cultivars. The interaction between cultivar and salt, and between salt and calcium application showed significant difference, but no difference was found because of the interaction of cultivar, salt and calcium application in K content in root tip cell wall.

Similar with the change of K content, Ca content was also greatly decreased by salinity treatment, and it decreased more in Tousan69 (48%) than in Dare (38%). Calcium application increased Ca content significantly both with and without salinity treatment. In Tousan69, low and high levels of calcium application showed the same effect in cell wall Ca content in the root tips, while in Dare, the Ca content increased with increasing exogenous calcium concentration. In addition, the

interaction between cultivar and calcium application, and between salt and calcium application was significant.

Table 4. Potassium and calcium contents (ug g-1 FW) in the root tip cell wall of salt-sensitive Tousan69 and salt-tolerant Dare.

Cultivars	Salt (mM)	Ca (mM)	K	Ca
Touzan 69	0	0	95.4 a	56.7 c
		0.5	66.9 a	141.9 a
		2	66.4 a	142.4 a
	40	0	15.1 b	29.3 d
		0.5	85.1 a	92.4 b
		2	89.9 a	98.3 b
	Salt		**	**
	Ca		**	**
	Salt ×Ca		**	NS
Dare	0	0	75.5 b	46.4 e
		0.5	95.5 b	132.3 b
		2	144.5 a	159.0 a
	40	0	30.6 c	28.6 f
		0.5	85.3 b	75.2 d
		2	88.4 b	113.8 c
	Salt		**	**
	Ca		**	**
	Salt ×Ca		**	**
Cultivar			**NS**	**NS**
Salt			**	**
Ca			**	**
Cultivar × Salt			*	**NS**
Cultivar × Ca			**NS**	**
Salt × Ca			**	**
Cultivar × Salt × Ca			**NS**	**NS**

Values are the means ± SE (n=3). Means within a column followed by different letters are significantly different.
** and ** indicate significance at the 0.05 and 0.01 probability levels, respectively; NS, not significant.*

Discussion

Plant cell wall fulfils its structural, protective and growth-regulating functions during the life cycle of a plant. Cell wall also constrains the rate and direction of cell growth, exerting a profound influence on plant development and morphology. In the present study, we have analyzed the effect of salinity on cell wall composition in the root tip of salt sensitive and salt tolerant soybean cultivars both in the absence and presence of calcium application. Results showed that cell wall polysaccharides, especially pectin, decreased significantly by salinity stress, and application

of calcium prevented the decrease. These results revealed that there were close relationships between the salt tolerance and the changes in cell wall composition. Furthermore, calcium was able to alleviate the effects of salt stress on root growth and cell wall content.

In plants, when cells grow, their size is determined by their walls that typically extend 10 to 100 folds (Roberts 1994). Thus, plant cell must deposit new wall substrates that integrate seamlessly into the old wall to prevent it from becoming thinner and weaker (Cosgrove 2005; Proseus and Boyer 2006). In this study, we analyzed the cell wall content in the region of 0-5 mm from root tip, where this region is considered as an elongation zone in soybean and the cells grow much more quickly than other root region, thus, the maintenance of wall substrates in this region is very crucial. Under salinity stress, both cultivars showed a decrease in total wall substrates, but salt tolerant Dare showed less decrease than salt sensitive Tousan69, which was consistent with the less inhibition of root growth in Dare than in Tousan69. The inhibition of root growth caused by salinity can result from a reduction in cell elongation as well as an inhibition of cell division. Because the amount of cell wall substrates constrains both the cell elongation and division, the maintenance of a high level of cell wall substrates could benefit to keep cell growth occurring under salinity. This may be one of the mechanisms for the salt tolerance ability of Dare as compared toTousan69. The similar result was also reported by Piro et al. (2003) in wheat under water stress: the cell wall polysaccharides decreased less in the drought tolerant cultivar than in the drought sensitive cultivar.

In plant cell wall, pectin encompasses a range of galacturonic acid-rich polysaccharides, and these polysaccharides with free carboxyl radicals have considerable potential for interaction with ions and low-molecular-weight compound (Willats et al. 2001). Thus, pectin is the part that provides numerous binding sites for cations, including Ca^{2+} and Na^{+}, and this may be an important factor in the resistance to the ion toxicity (Schmohl and Horst 2000; Popper and Fry 2003; Proseus and Boyer 2006). In our study, salinity decreased the pectin content more severely in Tousan69 than in Dare (Table 3). The less amount of pectin in the cell wall of Tousan69 may result in less binding of toxic ions and lead to the easy influx of the toxic ions into the cell. On the other hand, the gelling properties of cell wall pectin may modulate the wall extensibility, which is associated with cell elongation and division, and thus can affect root growth (Jarvis 1984; McCann et al. 1994; Thiyagarajah et al. 1996). The extensive reduction of cell wall pectin content may also result in the inhibition of root growth directly.

The supplement of calcium to the growth medium is known to ameliorate depressive effects of salinity in many plant species (Kurth et al. 1986; Bressan et al. 1998; Bernardo et al. 2006). Our result also showed the obvious ameliorative effect of calcium under salinity. In plant, large amount of calcium is located in the cell wall, where it links the pectin components to one another or the other acidic polysaccharides (Demarty et al. 1984). It is suggested that calcium was very efficient in promoting gelling in a pectin solution (Tepfer and Taylor 1981). Moreover, calcium can affect cell growth through regulating cell wall enzymes. Sugawara et al. (1981) showed that the wall bound acid phophatase could be activated by calcium in potato tubers. It is also reported that the addition of calcium contributed to the control of Na-absorption at root surface and reduced sodium binding to the cell walls (Stassart et al. 1981; Maeda et al. 2003). Therefore, in this study, the alleviation of root growth inhibition by calcium application under salinity could be ascribed to two aspects: one, the increased calcium accumulation in the cell wall may lead to more conjunction of cell wall pectin and other acidic polysaccharides and finally result in maintenance of a certain extent of cell wall substances for keeping cell growth under salinity stress; the other, calcium itself also provided benefit by restraining Na^{+} influx into the cell.

Maeda et al. (2003) also showed that salt tolerance had close relation to the residue pectic acid-binding calcium content in the root after salinity treatment, which suggested an important role of cell wall bound calcium in salt tolerance. In addition, the restoration effect of calcium differed between the two cultivars: in Dare, calcium application recovered more pectin content than in Tousan69. This is in accordance with the observation that calcium restored root growth more conspicuously in Dare than in Tousan69 under salinity stress. The ability to maintain high pectin content in the root cell wall may be one of the mechanisms for salt tolerant Dare to keep a high growth rate under salinity, as compared to Tousan69.

In summary, the results of this study showed that sodium inhibited the synthesis of the chemical constituents of cell wall, which may be one of the reasons for salinity depression of root growth, and the change of pectin content revealed a close relation with the regulation of root growth under salinity. Thus, the difference in salt tolerance between the two tested cultivars can partly be explained on the basis of the changes in the cell wall composition in response to salinity. Calcium application alleviated root growth inhibition under salinity, which could be partly ascribed to the restoration of the cell wall composition, particularly the pectin content.

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Theme 3: Enhancing resilience of local agricultural communities in drylands through adaptation strategies

Theme 3d: Crop improvement (breeding and biotechnology)

29. Development of crop varieties resistant to drought and heat stresses in Egypt

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Abstract

The Egyptian's increasing population, shortage in food supply and limited land and water resources directed the activities of the Field Crops Research Institute, towards increasing production per unit area and water and intensifying crop productivity for both old and new lands and rainfed areas. The rainfed coast in north Egypt extends over a length of 500 km and is 10-20 km wide, covering about 168 thousands hectares. Rainfall in this region is extremely low, ranging from 105 to 300 mm. Several drought-tolerant varieties have been developed and planted under rainfed conditions of the northern coast of Egypt. These include the bread wheat (*Triticum aestivum* L.) variety 'Sahel 1', giving a grain yield of 1.19 t/ha under rainfed conditions. In case of barley (*Hordeum vulgare* L.) the drought-tolerant hulled varieties are 'Giza 125', 'Giza 126' and 'Giza 2000', , and hull-less ones are 'Giza 130' and 'Giza131'. Their average grain yield was 1.1 t/ha under < 200 mm rainfall, with an average increase of yield ranging from 12.3 to 25.3% over checks verities. In lentil, the drought-tolerant cultivar 'Sinai 1' is highly adapted to dry conditions in North Sinai; it gave 116% yield increase over 'Giza 9'. In addition, under irrigation conditions, efforts have been made to reduce the frequency of irrigation and hence reduce amount of irrigation water for the most of field crops. Several varieties of faba bean, lentil and soybean have been identified as having low-water requirement under irrigated conditions. Attention has also been given to develop heat-tolerant crop varieties. Most of that work has been done in South Egypt (Quena, Toshkey and East-Owinat) where high temperatures prevail. A total of 25 heat-tolerant crop varieties have been identified and released. These included 3 varieties of bread wheat, 3 durum wheat, 1 barley, 6-single and triple-crosses of maize, 6 lentil and 7soybean.

Introduction

The Egyptian economy has traditionally relied heavily on the agricultural sector for food, fiber and other products. The agricultural sector provides the livelihood for about 55% of the inhabitants and employs about 34% of the total labor force. About 20% of the gross domestic product (GDP) and about 20% of the total exports and foreign exchange earnings come from agriculture. The demand for agriculture products is increasing due to population growth and the need for more export earnings. The national plan is to bring under cultivation a total of 3.4

million acres of newly reclaimed land from the desert by the year 2017. This necessitates more emphasis on agricultural research to identify constraints to productivity and to develop solutions through appropriate technologies, especially in the newly reclaimed areas.

Egypt has four agro-ecological zones, based on soil characteristics and water sources. These are: old lands (Nile valley and Delta), newly reclaimed lands (mainly located on the east and west sides of the Delta but also occurring in various other parts in the country), oases, and rainfed areas (located in north coastal belt in Sinai and Matrouh). The total agricultural land in Egypt is about 3.7 million hectares, which is only 3.4% of the total geographical area of the country. Of the total cultivated area, about 61.4% is the old land in the Nile Valley and Delta, 21.6% is the newly reclaimed desert land, and 17 % is the rain-fed area in northern coast and in the oases. Soils in old lands are silty-clay of good quality, deposited during thousands of years of the Nile flooding. The soils in the newly reclaimed lands are mostly sand, coarse textured, and calcareous or non-calcareous, except in some areas in the northern part of the Delta, where the soil is alluvial.

Egypt's agriculture is almost totally dependent on irrigation because of the paucity of rain. The only area where rainfall is enough for rainfed agriculture is found along the northern coast. Agriculture development is therefore closely linked to the water resources of the Nile River. The amount of available water in Egypt is presented in Table 1. The total water resources now available to Egypt are estimated at 73.8 billion cubic meters (BCM) per annum, including 55.5 BCM from the Nile River. Water scarcity in Egypt is a serious challenge as Egypt will face deficit of 2.5 BCM by the year 2017.

Table 1. Available and currently used water (billion m^3/annum) in Egypt

Source	Available quantity	%	Currently-used Water	%
River Nile	55.5	75.2	51.7	82.6
Underground reservoir	11.3	15.3	5.2	8.3
Reuse of agric. drainage water	5.0	6.80	3.7	5.9
Treated wastewater	1.5	2.03	1.5	2.4
Rainfall	0.5	0.67	0.5	0.8
Total	73.8	100	62.6	100

The main plant species grown in Egypt are filed crops, vegetables and fruits, forest trees (lumber wood trees), and medicinal, aromatic and ornamental plants. The major field crops are maize, rice, cotton in summer and wheat, clover (*berseem*) and faba bean in winter. The Field Crop Research Institute (FCRI) of the Agriculture Research Center (ARC) of the Ministry of Agriculture and Land Reclamation of Egypt is responsible for developing improved varieties of field crops such as the cereals (wheat, rice, barley, maize and sorghum), food legumes (faba bean, lentil, chickpea, fenugreek, lupine and soybean), forage crops (clover *berseem,* alfalfa, forage sorghum, Sudan grass, pearl millet, and teosinte), oil crops (sunflower, sesame, peanut, and canola), fiber crops (flax, kenaf, jute and sesame) and onion. The field crops occupy about 78% of the total cultivated area in Egypt. The productivity of the most of the field crops is high (Table 2). The productivity has shown particular increase during the last few decades, for example the grain yield of wheat increased from 3.5 t/ha in 1982 to 6.5 t/ha in 2009 (by about 685). Similarly, the productivity of all field crops has increased, ranging from 13 to 167% (Table 2). However, due

to the rapid population increase and limited land and water resources, the production of the most of these field crops is not enough to meet the local demand.

Table 2. Average productivity (t/ha) of major field crops in Egypt in 1982 and 2009 and percentage yield increase in 2009 over 1982

Crop	Grain yield t/ha	Yield increase in 2009 over 1982 (%)	
	1982	2009	
Wheat	3.5	6.5	86
Maize	4.4	8.1	84
Rice	5.8	9.6	66
Grain Sorghum	3.7	5.5	49
Barley	2.9	3.8	31
Faba bean	2.1	3.4	62
Lentil	1.1	1.9	73
Chickpea	1.7	2.1	24
Fenugreek	1.8	2.2	22
Lupine	1.6	1.8	13
Soybean	2.6	3.1	19
Clover (berseem)	60	89	48
Alfalfa	74	134	81
Sudan grass	61	94	54
Sesame	1	1.4	40
Peanut	1.8	3.3	83
Flax	6.7	12	76
Onion	12	33	167

The agricultural research strategy in Egypt has taken in consideration the constraints mentioned above and the activities of the FCRI have accordingly been directed towards increasing the production per unit area and water and intensifying cropping in both old and new lands. The main objectives of FCRI are:

1. Develop, release and maintain high-yielding cultivars, strains, and hybrids of wheat, barley, rice, maize, sorghum, food legumes, forage crops, oil crops, fiber crops, and onion.
2. Develop and test the most favorable agricultural production packages, which maximize the realization of the genetic potential of the released cultivars.
3. Produce enough breeder and foundation seed of the newly developed and recommended cultivars to provide seed companies and the Central Administration for Seed Production.
4. Explore various systems of crop intensification and agricultural rotations and extend such activities to newly reclaimed lands and rainfed areas.
5. Provide extension and training programs to transfer new technologies to farmers.
6. Conduct collaboration research with other ARC institutes to resolve major production constraints *e.g.* stresses caused by diseases, insects, weeds, drought, heat, salinity, and others.
7. Strengthen co-operation with various national and international research centers and organizations, as well as international development agencies.

Development of crop varieties resistant to drought

The rainfed coast in northern Egypt extends from Rafah city in the east to Salloum city in the west. It is 500 km long and 10-20 km wide, covering about 168 thousands hectares. Rainfall in this region is extremely low, ranging from 200 to 300 mm in Rafah to about 105 mm in Salloum. Because the dry environment, drought tolerant crop varieties are needed a sustainable agriculture.

Drought resistance is the ability of a genotype to produce higher yield when subjected to periodic water deficits (Turner 1979). Two frameworks for the adaptation of plants to drought have been proposed (Turner 2003), namely a drought-resistance framework and a yield-component framework. The drought-resistance framework deals with the specific morphological, physiological and biochemical characteristics that enable plants to adapt to low water availability, while the yield-component framework focuses on yield under water-limited conditions and the components of yield, namely water use and water use efficiency (Turner 2003). For survival and improved yields under rainfed conditions, plants usually possess more than one adaptive mechanism (Khanna-Chopra 1982). Work done at FCRI has adopted both the frameworks.

Barley: The majority of barley (*Hordeum vulgare* L.) production area in Egypt is located in the rainfed region (in both Northwest and Northeast coast of Egypt) where cropping is dependent mainly on rainfall. The cultivated area in this region is about 54 thousand hectares. Bedouin community here produces barley to be used mainly as animal feed. Obtaining drought-tolerant barley cultivars with high levels of diseases and insects tolerance is a major goal of barley breeding program at FCRI.

Several drought-tolerant barley varieties have been released. Early in 1992 and 1993 the cultivars 'Giza 125' and 'Giza 126', six-rowed spring barley, were released (Noaman et al. 1995). Giza 125 out yielded the check variety Giza 123 by 25.3% with average grain yield of 1.1 t/ha under < 200 mm rainfall conditions. Giza 126 has wider adaptability than Giza 125 under different levels of drought stress in rainfed areas. Other drought-tolerant barley cultivars have also been released. Ahmed et al. (2003) released 'Giza 2000', which out yielded Giza 126 by 19.4% under rainfed conditions. This variety was also moderately resistant to leaf rust (*Puccinia hordei*) and resistant to powdery mildew (*Erysipha graminis hordei*) and net blotch (*Drechslera teres*) diseases. Another drought tolerant cultivar, 'Giza 132', was released by Noaman et al. (2006). This cultivar out yielded the check cultivars Giza 126 and Giza 2000 for grain yield by 13.7 and 12.3%, respectively. Besides being higher yielding, it is more stable and less susceptible to major diseases and has higher kernel weight. This cultivar has been recommended for rainfed areas and the newly reclaimed lands in North Egypt.

Efforts have been made also to develop drought-tolerant cultivars of hull-less barley. Two six rowed spring type hull-less cultivars, 'Giza 130' and 'Giza 131' have been developed for rainfed areas (El-Sayed et al. 2004). These cultivars are dual purposes type (used for food and feed) and they out yielded Giza 126 (hulled variety) both in grain and straw production. They showed moderate resistance to leaf rust and powdery mildew and resistance to net blotch and stripe (*Drechslera gramiea*) diseases.

Bread wheat*:* Bread wheat (*Triticum aestivum* L.) is the most important food crop in Egypt. The self sufficiency is about 55%, hence efforts have been made to increase the local production by increasing yield productivity and cultivated area. Development of adapted wheat cultivars to rainfed areas in Egypt contributes in increasing the total wheat area in the country. A new bread wheat variety, 'Sahel 1', adapted to rainfed area in North-West coast of Egypt was released in

1994. Its grain yield in North-West coast was 1.19 t/ha, which exceeded the yield of 14 bread wheat accessions by 16-83%. It gave the highest number of spikes (166 spikes/m^2), kernels/spikes (35) and 1000 kernel weight (38 g). It was also resistant to stem and leaf rust diseases and had reasonable stability under rainfed conditions (Ghanem et al. 1994).

Lentil: Lentil (*Lens culinaris* Medikus) is an important component of the rainfed farming system in West Asia and North Africa and a source of high-quality protein for human. The linear regression technique was successfully used to describe the behavior of lentil genotypes across a range of environments, allowing selection of genotypes for either wet or dry conditions (Hamdi et al. 1992). A new lentil variety named 'Sinai 1' was developed for North Sinai (Hamdi et al. 2002). It showed high adaptability to dry conditions and yielded 116% higher than the Egyptian local cultivar 'Giza 9'. This cultivar matures one month earlier and has good seed quality (Hamdi and EL-Emery 1996). The farmers in Sinai have widely adopted this cultivar. In addition, there are some other lentil genotypes that are promising for rainfed areas (Hamdi et al. 1999). Sources of drought tolerance have also been identified in wild species of the genus *Lens* (Hamdi and Erskine 1996).

Development of crop varieties showing low-water requirements under irrigated conditions

Saving irrigation water is an important goal in agriculture in Egypt. Efforts have been made to reduce the frequency of irrigation and hence reduce amount of irrigation water for the most of field crops, and also to increase the efficiency of irrigation operations and reduce water losses. In addition, earliness in maturity has been incorporated in all the varieties as another strategy to reduce water use.

Faba bean*:* Seventy Egyptian landraces were evaluated in the Nubaria region (a new reclaimed land in North Egypt) under rainfed condition plus one supplemental irrigation as compared to three irrigation regime commonly used by the farmers. The selection based on morphological features, earliness in maturity and high-yielding ability. Their seed yields ranged from 2.134 to 3.454 t/ha, comparing with 1.856 and 3.475 t/ha for the check cultivars 'Giza 461' and 'Nubaria 1', respectively (Mahmoud et al. 1999). Amongst these, the most promising landrace 'Ihnasia 2' is now under the process of release as 'Nubaria 3'.

Lentil: The response of several cultivars to sprinkler-irrigation system compared with furrow-irrigation has been studied at Gemmiza Research Station in the Delta in North Egypt (Hamdi and Abd El-Mohsen 2009). The amount of water given to lentil with furrow-irrigation system was 1779 m^3, while with sprinkler-irrigation system the amount of water was 752 m^3 (210 m^3 + 542 m^3 for sowing irrigation), giving 58% water saving. The water use-efficiency under sprinkler-irrigation system for the cultivars 'Giza 51' and 'Giza 370' was 1.28 and 1.13 kg seeds/m^3 water, respectively, compared to 0.31 kg seeds/m^3 under furrow-irrigation all over the country. Seed yield of Giza 51 (under sprinkler-irrigation system) reached 2.3 t/ha, while the average seed yield of the country (under furrow-irrigation system) is 1.8 t/ha.

Soybean**:** It is grown in summer in Egypt and it requires about 6 irrigations. El-Garhy et al. (2008) succeeded to reduce the frequency of irrigation to only three and get a seed yield close to that obtained under 6 irrigations. Eisa et al. (2002) also found that reducing number of irrigation did not significantly affect seed yield of this crop.

Development of heat-tolerant varieties

Air temperature has been shown to influence the evolution and adaptation of crops worldwide and, with water availability, essentially determines the growing season for most crops. Summerfield et al. (1989) reported that under controlled conditions, progressively warmer temperatures post-flowering restricted vegetative growth, accelerated progress towards reproductive maturity and reduced seed yield. High temperatures associated with strong wind and dry soils are especially damaging. Earlier flowering and maturity can avoid high temperatures in winter-sowing environments but may expose crops to a greater risk of frost damage in some environments and may limit yield potential.

In Egypt, high temperatures are common in the middle and southern governorates (e.g. Aswan, Quena, Sohag, Assiut, El-Wady El-Gadeed, including Toshky and East-Owinat regions and El-Minia). The average maximum temperatures in winter growing season (October-April) range from 25.1 to 37.6 ^{o}C. In summer season (May-September) the temperatures rise up and the range is from 36.9 to 42.7 (Table 3). Efforts have been made by FCRI since long to produce heat-tolerant crop verities in south Egypt. Since 1999, further research activities were established at Toshky (1200 km south of Cairo, 22° 25 N, 31° 5 E and 181 m above sea level) and East-Owinat (1576 km south Cairo, 22° 5 N, 28° 0 E and 128 m above sea level). As a result, some promising cultivars have been identified.

Wheat: Ghanem et al. (1996) produced bread wheat variety 'Sids 1'. Its seed yield significantly exceeded the yield of checks, and it is more adapted to the conditions in South Egypt than other tested verities. Recently, the new promising bread wheat variety 'Sids 12' was released (Mahrous et al. 2009). Its yield evaluation in 61 experiments indicated its superiority with an average grain yield of about 6.6 t/ha. Stability parameters for grain yield revealed that this variety was more stable in Middle and South Egypt, and hence it could be recommended for planting in these regions. Another bread wheat variety, 'Sids 13', has been released also for planting in South Egypt (Moustafa et al. 2010). The average grain yield of this variety is about 7 t/ha. Recommendation has been made to plant this variety in South Egypt.

The new durum wheat cultivar 'Beni Sweef 4' has been selected from an exotic accession (Abdel-Aleem et al. 2008). Another new durum wheat cultivar 'Beni Sweef 5' has been selected from promising accessions received from CIMMYT (Moustafa et al. 2008). The two cultivars evaluated in 44 experiments in both Middle and South Egypt, gave an average grain yield of more than 8.5 t/ha, exceeding significantly the check varieties 'Beni Sweef 1' and ' Beni Sweef 3' and 'Sohag 3'.

***Barley*:** Heat-adapted cultivar 'Giza 124' has been developed to be grown in hot region in South Egypt (Abo-El-Enein et al. 1998). This variety combines high grain yield, early maturity and moderate resistance to leaf rust.

***Maize*:** The research activities on maize were started in Toshkey and East-Owinat regions by Maize Research Program at FCRI early in 2001, where five broad genetic bases (Giza 2, IW-480, Pop Gen w, Pop Gen y, and IY-513) were planted and a total of 619 S_1 from these populations were obtained (Soliman et al. 2004). In addition, three single-crosses (SC-10, SC-11 and SC-123) and three three-way crosses (TWC-311, TWC-314 and TWC-324) have been identified as heat-tolerant (Soliman et al. 2005). The average grain yield of these crosses was high and reached 9.6 t/ha. Recommendation has been made to plant these crosses in hot environment in Toshkey region especially at high population density (about 7 plans/m^2).

Table 3. Average monthly maximum (Max.) and minimum (Min.) air temperature (oC), relative humidity (RH%), rainfall, latitude, longitude and altitude for Aswan (south Egypt) comparing with Alexandria (north Egypt) in 2009

Month	Aswan				Alexandria			
	Max. °C	Min. °C	RH %	Rain mm	Max. °C	Min. °C	RH %	Rain mm
January	25.1	10.6	35	0.0	20.7	10.7	47.7	7.3
February	26.7	12.2	27	0.0	20.0	9.4	59.0	51.8
March	29.0	13.7	25	0.0	21.3	11.4	54.3	2.0
April	37.4	21.2	19	0.0	24.4	15.9	60.0	0.0
May	36.9	22.7	20.7	3.0	26.6	18.9	61.0	0.0
June	42.2	26.5	16.3	0.0	30.9	22.9	62.7	0.0
July	42.7	28.6	20	0.0	30.4	24.5	70.7	0.0
August	41.4	27.6	20.7	0.0	30.1	24.0	72.0	0.0
September	40.5	25.6	23.7	0.0	30.1	22.7	67.3	0.0
October	37.6	23.1	26.3	0.0	29.1	19.5	71.0	2.0
November	29.6	15.8	37.3	0.0	24.1	15.4	66.0	27.9
December	25.6	12.2	40.3	0.0	21.8	21.1	67.0	20.0
Latitude	23° 58` N				31° 12` N			
Longitude	32° 47` E				29° 57` E			
Altitude	200 m				3.4 m			

***Lentil*:** Twenty lentil genotypes were evaluated in three seasons in Abu-Simbel (the research station of Toshkey region) to identify lines adapted to hot conditions (Hamdi et al. 2003). Significant differences occurred among seasons due to the wide variation in maximum and minimum air temperatures and relative humidity, which affected accumulation of plant dry matter and yield performance of genotypes. Three genotypes (FLIP 95-68L, FLIP 86-7L and FLIP 89-71L) out yielded the check cultivar 'Giza 9' by 32.3, 24.6 and 29.8, respectively. These genotypes also had higher seed yield/plant, number of pods and seeds/plant and have been recommended for hot environmental conditions. In another study, 25 lentil genotypes were evaluated under hot conditions in three seasons in Quena (Mataana), Aswan (Kum Ambo) and East-Owinat to select high yielding and heat-tolerant lentil genotype. For comparison, the genotypes were also grown in relatively cooler condition at Giza Research Station, ARC (Cairo). Three genotypes (ILL 4403, JL-1 and Line 2) had the lowest heat susceptibility index and high seed yield; hence they were recommended to be planted under hot conditions. Seed yield was significantly and negatively correlated with heat susceptibility index at Mataana (r = -0.678) and Kum Ambo (r = -0.818), indicating that high seed yield is strongly correlated with heat-tolerance (Hamdi et al. 2008).

Soybean: Twenty three genotypes were evaluated for earliness, drought tolerance and resistance to insects in East-Owinat during eight summer seasons (1999-2006). The following five cultivars were identified as heat-tolerant: 'Giza 21', 'Giza 22', 'Giza 35', 'Giza 111' and 'Crawford'. Their seed yield was high, 3.39, 3.42, 2.88, 2.82 and 2.75 t/ha, respectively. In addition, three new accessions also gave high seed yield; these are H2-L12 (3.006 t/ha), H15-L5 (3.075 t/ha) and H15-L17 (3.016 t/ha). All these promising genotypes are resistant to cotton leaf-worm insect (Hassan et al. 2001 and 2002).

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30. Engineering antioxidants in transgenic potato (*Solanum tuberosum* L.) confers greater tolerance to various environmental stresses

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Abstract

Environmental stresses such as drought, salt and heavy metals are known to accelerate the accumulation of reactive oxygen species (ROS) in plant cells. ROS are capable of unrestricted oxidation of many cellular components and can lead to oxidative destruction of the cells. Low molecular weight antioxidants such as glutathione (GSH) and ascorbate (AsA) are considered of paramount importance in preventing and controlling the dangerous affects of ROS. In order to maintain greater protection against environmental stresses, we developed transgenic potato (*Solanum tuberosum* L.) overexpressing either *Arabidopsis thaliana* glutathione reductase gene (*AtGR1*) or dehydroascorbate reductase (*AtDHAR1*). The GR transgenic potato maintained up to 6.5 folds higher GR activity, 5.8 folds glutathione (GSH) contents and up to 2.2 folds higher glutathione *S*-transferase activity compared to non transformed plants (NT). Interestingly, while the GR transgenic plants exhibited decreased dehydroascorbate reductase (DHAR) activity, the relative reduced ascorbate (AsA) contents were higher while the relative dehydroascorbate (DHA) were lower compared to NT which provide a support to the hypothesis that an active glutathione-independent pathway for DHA reduction might exists *in vivo*. These GR transgenic plants maintained an enhanced tolerance to methylviologen, and cadmium. When subjected to drought stress, the transgenic plants exhibited faster recovery with less visual injury compared to NT. On the other hand, DHAR transgenic potato maintained up 5 folds higher DHAR activity and exhibited greater tolerance to methylviologen, drought and salt stresses. These results suggest that manipulation of either glutathione or ascorbate levels provides reliable strategy for the development of industrial transgenic potato plants with enhanced tolerance to multiple environmental stresses.

1. Introduction

Environmental stresses such as drought and heavy metals are known to accelerate the accumulation of reactive oxygen species (ROS) in plant cells. ROS such as singlet oxygen (O_2^1), superoxide radical ($O_2\cdot$), hydrogen peroxide (H_2O_2) and hydroxyl radical ($OH\cdot$) are capable of unrestricted oxidation of many cellular components and can lead to oxidative destruction of the cell (Asada and Takahashi 1987; Mittler 2002). Detoxification of ROS in plant cells is accomplished by enzymatic and non-enzymatic scavenging systems. Low molecular weight antioxidants such as glutathione (GSH) and ascorbate (AsA) are of paramount importance in preventing and

controlling the dangerous affects of ROS (Noctor and Foyer 1998). Among antioxidative enzymes, monodehydroascorbate reductase (MDAR), dehydroascorbate reductase (DHAR) and glutathione reductase (GR) are particularly important due to their roles in catalyzing redox reactions and maintaining reduced pools of AsA and GSH in the AsA-GSH pathway (Noctor and Foyer 1998).

GSH, the tripeptide γ-glu-cys-gly, is an abundant and ubiquitous non-protein thiol in most plant cells (Noctor and Foyer 1998). The physiological significance of GSH in plant cells includes sulphur metabolism, detoxification of xenobiotic compounds (Potters et al. 2002; Noctor and Foyer 1998), regulation of gene expression and the redox regulation of cell cycle (Noctor et al. 1998). GSH exists interchangeably with the oxidized form GSSG in the AsA-GSH cycle. GR catalyses the NADPH-dependent reduction of GSSG to GSH.

The antioxidant AsA can directly scavenge free radicals (Halliwell and Gutteridge 2000), and is particularly important as an electron donor for detoxification of H_2O_2 via ascorbate peroxidase in plant cells (Noctor and Foyer 1998). Moreover, AsA is a major redox buffer in plants (Pignocchi and Foyer 2003), a cofactor of many enzymes (Smirnoff and Wheeler 2000), a regulator of cell division and growth (Kerk and Feldman 1995), and a molecule used in signal transduction in plants (Noctor et al. 2000).

Potato (*Solanum tuberosum* L.) is the world's number one non-cereal food crop, with total production reaching a record of 325 million tonnes in 2007 (FAOSTAT, http://www.faostat.fao.org). Due to its high productivity, starch and vitamin contents, potato ranks fourth among most important crops grown worldwide in terms of acreage, yield and value (FAOSTAT). Extensive efforts to improve potato have been made with regards to quality and resistance to pathogens. Improving potato with greater protection against abiotic stresses through molecular breeding technologies remains generally limited (Tang et al. 2006). In particular, little research to incorporate genes for antioxidative enzymes into potato plants has been conducted. Enhancement of oxidative stress tolerance has been reported in transgenic potato overexpressing Cu/Zn superoxide dismutase gene (Perl et al. 1993), class II catalase (Yu et al. 1999), both Cu/Zn SOD and ascorbate peroxidase (Tang et al. 2006) and nucleoside diphosphate kinase 2 (Tang et al. 2008).

In this study, we report the generation of transgenic potato overexpressing either *Arabidopsis* cytosolic *AtGR1* or *Arabidopsis* cytosolic *AtDHAR1*. We further characterized the metabolic effects of the overproduction of these enzymes in the GSH and AsA pools and the consequent gain or loss in the stress tolerance to various environmental stresses.

2. Materials and methods

2.1. Plant materials

Potato plants (*Solanum tuberosum* L.) cv. Atlantic (USDA Plant Genetics and Germplasm Institute) were maintained on Murashige and Skoog medium (Murashige and Skoog 1962) containing 2 % sucrose and 0.4% Phytagel (Sigma, St. Louis, USA) in a growth chamber at 22 °C under a 16 h light cycle and 60% RH.

2.2. Construction of plant expression vectors

The full length cDNA of the *Arabidopsis thaliana AtGR1* (At3g24170) and *AtDHAR1*

(At1g19570) were amplified from *Arabidopsis* cDNA library by PCR using gene specific set of primers as shown in Table S1 (cytGRGW-F and cytGRGW-R for *AtGR1* and AtcytDHARGW-F and AtcytDHARGW-R for *AtDHAR1*) and the Primse- STAR® HS DNA Polymerase (Takara, Shiga, Japan). Transformation constructs were obtained with Gateway technology (Invitrogen, Carlsbad CA, USA) by cloning *AtGR1* and *AtDHAR1* independently into pDONRTM/Zeo then shuttling these genes independently into the destination vector pGWB502Ω (Nakagawa et al. 2007). This construct was introduced into *Agrobacterium tumefaciens* strain C58C1 and used for *Agrobacterium*-mediated gene transfer as described by Banerjee et al. (2006).

Table S1

Primer name	Primer sequence (5'-3')
cytGRGW-F	GGCTTCACCATGGCGAGGAAGATGATGCTTGTTGATGGTGA
cytGRGW-R	GAAAGCTGGGTCTCATAGATTTGTCTTAGGTTTGGGTTTGT
GR-RT-F	CATTTCACCCTATTAGCTCTG
GR-RT-R	CTTCGCTGAGACCCACTACAG
AtcytDHARGW-F	GGCTTCACCATGGCTCTAGATATCTGCGTGAAGGTT
AtcytDHARGW-R	GAAAGCTGGGTCACGCATTCACCTTCGATTCCCAA
DHAR-RT-F	ACTGTCCGTTTAGCCAACGTG
DHAR-RT-R	TTCTCAAACGACTCCCTAGA
actin-RT-F	TGGACTCTGGTGATGGTGTC
actin-RT-R	CCTCCAATCCAAACACTGTA

2.3. Genomic PCR and RT-PCR

The presence of *AtGR1* or *AtDHAR1* in the genome of transgenic potato plants was confirmed by PCR using the corresponding gene-specific primers (Table S1) and Go Taq® Green Master Mix (Promega, Madison, USA) according to the manufacturer›s instructions. For RT-PCR, total RNA was isolated from leaf tissues using TriPure Isolation Reagent (Roche, Mannheim, Germany) and treated with RNase-free DNase I , then one µg was used to synthesize a first stand cDNA using Transcriptor First Strand cDNA Synthesis Kit (Roche). PCR was carried using the gene-specific primers (Table S1), while actin was amplified using actin-RT-F and actin-RT-R (Table S1) as described by Tang et al. (2006).

2.4. Western blot analysis

Protein samples (25 µg) from the transgenic potato and non-transformed (NT) plants were used for western blotting as described previously (Eltayeb et al. 2006).

2.5. GR activity staining

Leaf samples (0.1 g) from transgenic potato, NT plants and *Arabidopsis* were frozen in liquid nitrogen and grounded to powder with a pre-cooled mortar and pestle, homogenized in 50 mM potassium phosphate buffer (pH 7.8) containing 1 mM ascorbate and 2% (w/v) polyvinylpolypyrrolidone (PPVP). The homogenate was centrifuged at 15000 rpm at 4 °C for 25 min and the supernatant was used for enzyme activities. Activity staining of GR was carried as described by Foyer et al. (1991). Total protein was determined according to Bradford (1976).

2.6. GR, DHAR and GST activities

All enzyme activities were measured sepctrophotometrically using Ultrospec 2100 *pro* (Biochrom, Cambridge, UK). GR was assayed according to Tanaka et al. (1988). DHAR was assayed as described previously (Eltayeb et al. 2006). GST was assayed as described by Alla et al. (2007).

2.7. AsA, DHA, GSH and GSSG contents

Leaf samples (0.3 g) were homogenized in 2 ml of 5% (w/v) metaphosphoric acid, centrifuged at 15000 rpm at 4 °C for 20 min and aliquots of the supernatant were used for the measurements. Ascorbate and DHA contents were determined following Shigeoka et al. (1987) whereas GSH and GSSG were measured according to Griffith (1980).

2.8. Measurements of ion leakage, chlorophyll contents, and hydrogen peroxide

Ion leakage was measured as the increase in the conductance of the floating solution using a B-173 conductivity meter (Horiba, Kyoto, Japan). Total ion contents were estimated by autoclaving the leaf discs and the conductivity of the resulting solution was determined. Chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), and total chlorophyll (Chl *a*+*b*) were determined according to the methods of Wintermans and De Mots (1965). Hydrogen peroxide (H_2O_2) contents were measured as described by Ella et al. (2003).

2.9. Methylviologen (MV), drought, salt and cadmium stress treatments

We chose plants that were uniform in size, height, and shape for all treatments. MV treatments were carried out by soaking plant leaf discs (12 mm in diameter) in 2 ml of distilled water or 3 µM MV for 12 or 24 hours at 25 °C under continuous light. For the drought, salt and cadmium stress treatments, shoot parts of the potato seedlings (2 cm) from the transgenic and NT were excised and transferred to MS medium supplied with 5% (w/v) polyethylene glycol (drought stress), 50 mM NaCl (salt stress) or 200 µM $CdCl_2$ (cadmium stress) and maintained for 3 weeks under controlled conditions (25 °C, 16 h light, 8 h dark photoperiod). At the end of this period, the total stem elongation and the length of the induced roots were measured.

2.10. Statistical analysis

Data points represent the mean of three replications. Data were analyzed using Student's *t*-test at 95% confidence limit.

3. Results

3.1. Generation of GR or DHAR overexpressing transgenic potato

The cDNA of *A. thaliana* cytosolic AtGR1 or *AtDHAR1* were independently cloned into under pGWB502Ω vector (Nakagawa et al. 2007), mobilized into *Agrobacterium tumefaciens strain* C58C1 and used for *Agrobacterium*-mediated gene transfer of potato plants. Genomic PCR analysis confirmed the presence of *AtGR1* in the genome of the three lines (Fig. 1A) and the presence of *AtDHAR1* in six DHAR transgenic lines (Fig. 1B). RT-PCR analysis confirmed the overexpression of *AtGR1* transgene (Fig. 1C) and *AtDHAR1* (Fig. 1D) in GR or DHAR transgenic plants, respectively. Moreover, activity staining for GR detected a clear band corresponding to the

cytosolic GR activity derived from *AtGR1* transgene in the extracts prepared from GR transgenic plants but not from NT (Fig. 1E). In contrast, western blot analysis detected high levels of DHAR protein (23.4 kDa) derived from the *AtDHAR1* transgene in the extracts prepared from transgenic potato but not from the NT plants (Fig. 1F).

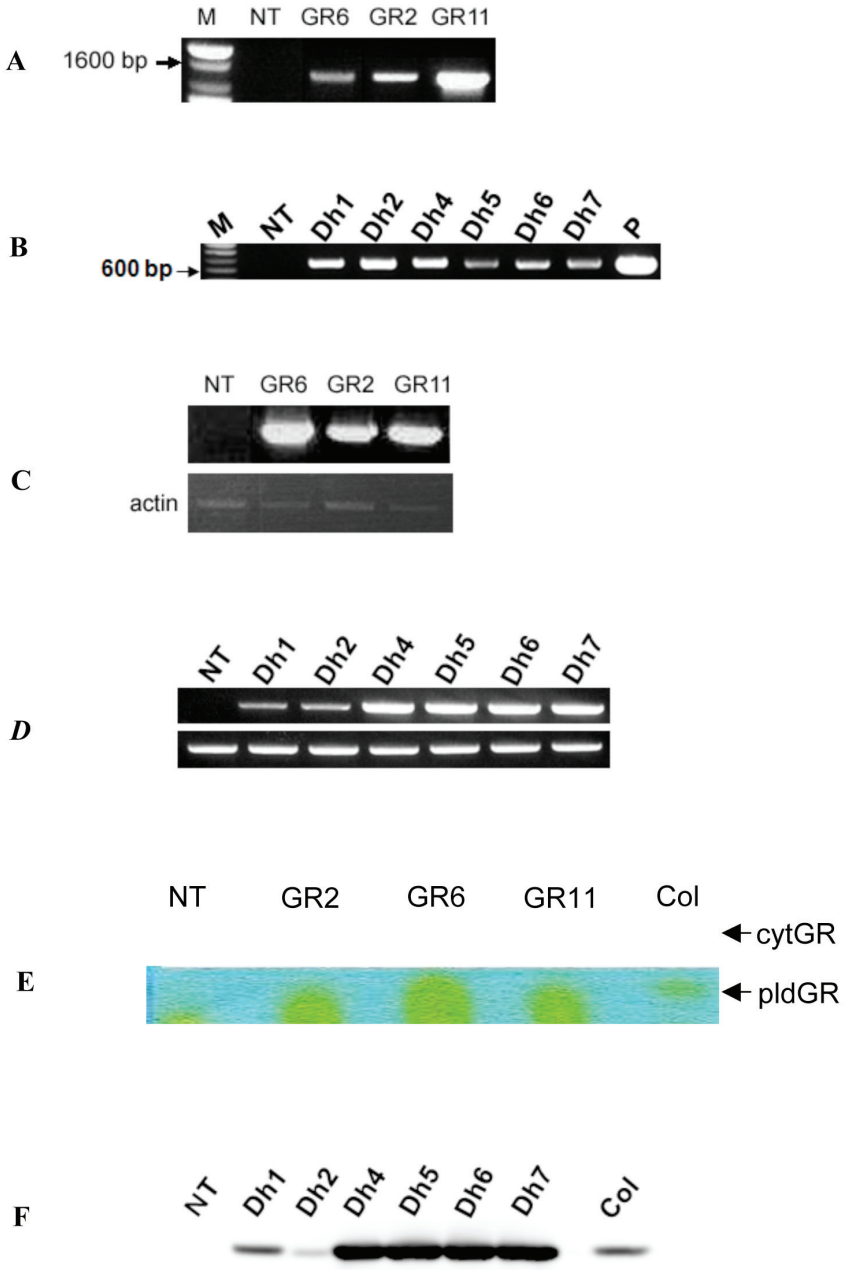

Fig. 1. Molecular analysis of the transformed and wild-type (WT) potato plants. *A and B, detection of the AtGR1 (A) and AtDHAR1 (B) transgenes by means of PCR using genomic DNA isolated from GR or DHAR transgenic potato, respectively, and NT. C and D, expression analysis of AtGR1 (C) and AtDHAR1 (D) by means of RT-PCR using total RNA isolated from GR or DHAR transgenic potato, respectively, and NT. Actin, used as a control to ensure equal loading. (E), GR activity staining using proteins isolated from GR transgenic potato and NT. cytGR, cytosolic GR; pldGR, chloroplastic GR; Col, Arabidopsis plants cv. Columbia. (F) Immunoblotting of the proteins from DHAR transgenic and NT.*

3.2. Biochemical and physiological evaluation of GR transgenic potato

3.2.1 Higher GR activity and GSH contents in GR transgenic potato

Compared to NT plants, GR transgenic potato exhibited up to 6.5 folds higher GR activity (Fig. 2A) and up to 5.8 folds higher contents of GSH (Fig. 2B). The contents of GSH in GR2 and GR11 represented 91.7 and 89.9% of the total glutathione pool contents compared to 74.5% in NT plants (Fig. 2C).

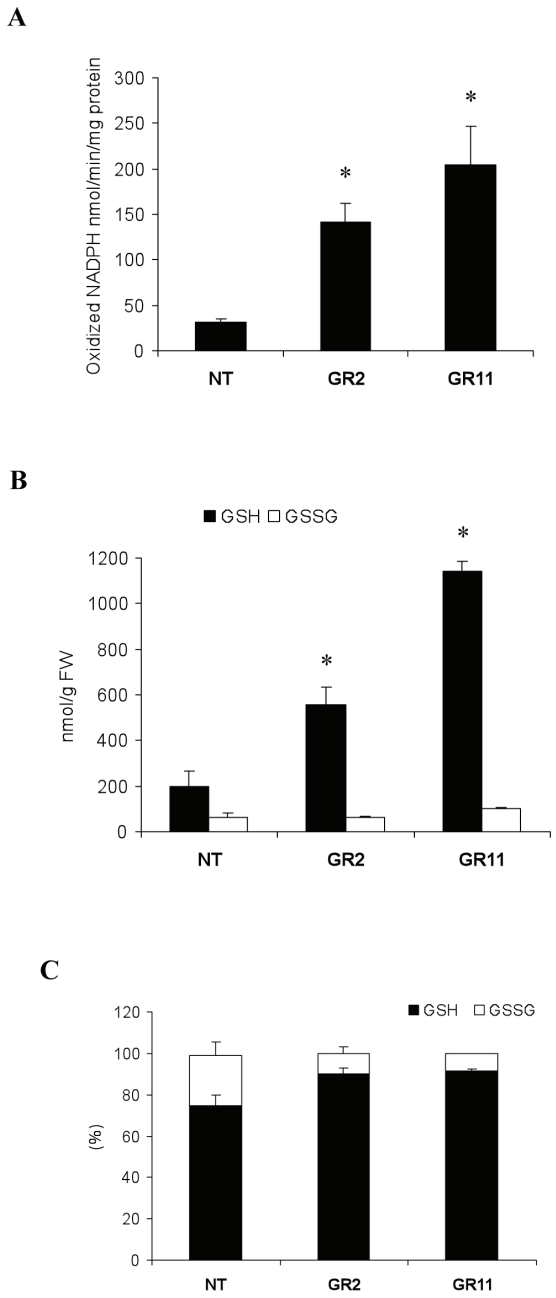

Fig. 2. GR enzyme assay, GSH contents and the relative contents of GSH and GSSG using extracts from GR2 and GR 11 transgenic potato and NT. (A), GR enzyme assay. (B), GSH contents. (C), the relative GSH contents. *, significantly different from the NT plants ($P < 0.05$). Values represent means and SE ($n = 3$).

3.2.2. GST and DHAR activities in GR transgenic potato

Overexpressing GR resulted also in an increased GST activity up to 2.2 folds, respectively (Fig. 3A) compared to NT plants. Significantly lower DHAR activity (Fig. 3B) and less contents of AsA were observed in GR transgenic potato (Fig. 3C). Despite less activity of the DHAR, DHA (proportion of the total pool) contents were surprisingly lower in GR transgenic potato (Fig. 3C). The relative contents of AsA were higher in GR transgenic plants where it represented up to 71.8% of the total ascorbate compared to 53.0 % for NT plants (Fig. 3D).

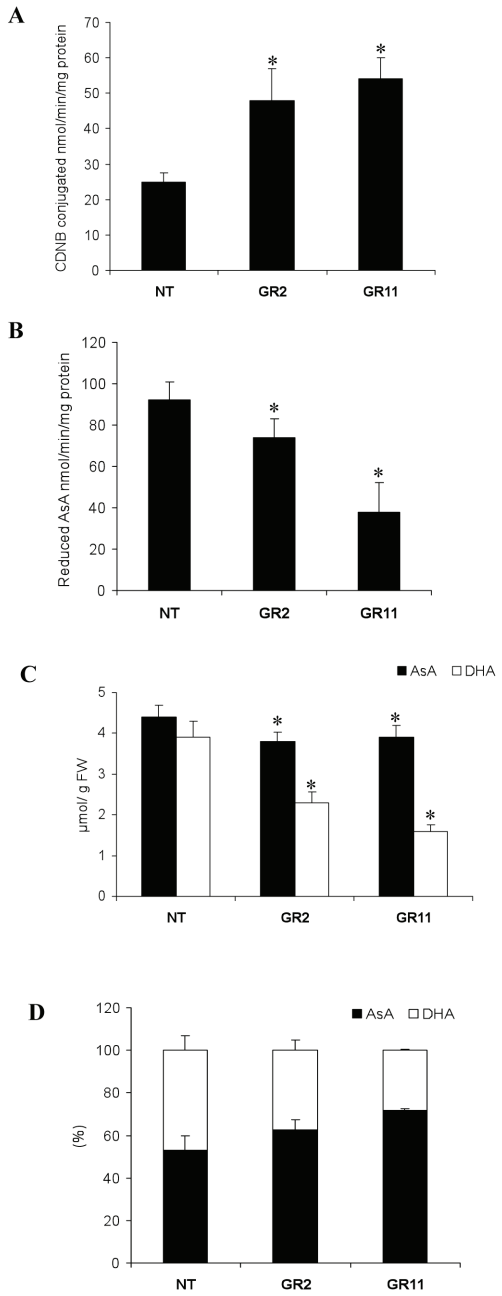

Fig. 3. GST, DHAR enzyme activities, AsA contents and the relative contents of the reduced AsA and oxidized DHA measured in leaf crude extracts from GR transgenic and NT plants. (A), GST enzyme activity. (B), DHAR activity. (C), contents of AsA and DHA. (D), the relative contents of the reduced AsA and oxidized DHA. *, significantly different from the NT plants ($P < 0.05$). Values represent means and SE ($n = 3$).

3.2.3. Performance under drought, MV and cadmium stresses

Treatment with MV causes the generation ROS and participate in the damage to plants (Asada and Takahashi 1987). After either 12 or 24 h of MV treatments, GR trangenics leaked significantly less ions compared to NT plants (Fig. 4A).

GR transgenic potato showed better and rapid recovery from drought stress with less visual injury in the leaves and the stems as compared to NT plants (Fig. 4B). Although under cadmium stress the growth of all plants was severely reduced, GR transgenic potato lines extended significantly longer roots compared to NT plants (Fig. 4C). In contrast, NT maintained slightly better shoot length compared to transgenic potato.

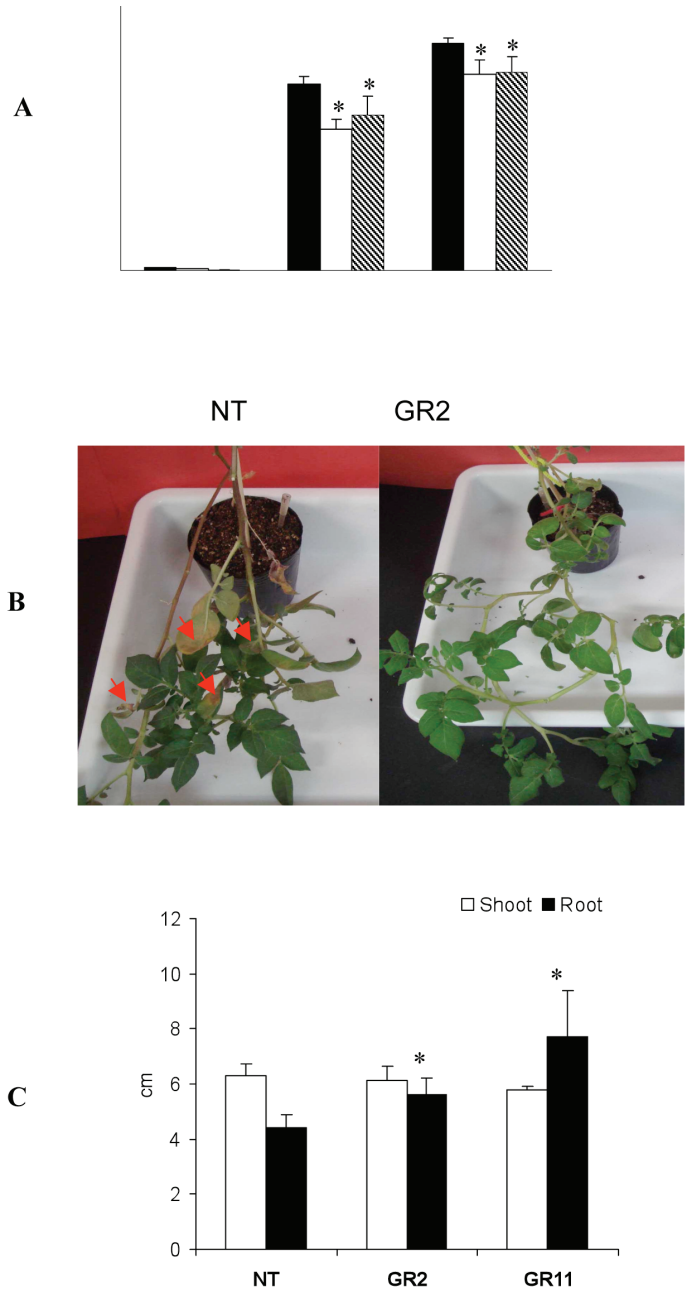

Fig. 4. Stress tolerance evaluation in GR transgenic potato. (A), Ion leakage, measured in leaf discs from GR transgenic and NT subjected 3µM methylviologen for 0, 12 or 24 hours. (B), Visual injury and recovery from drought stress. (C), Root and shoot growth under cadmium stress. *, significantly different from the NT plants (P < 0.05). Values represent means and SE (n = 3).

3.3. Biochemical and physiological evaluation of DHAR transgenic potato

3.3.1 Higher DHAR activity and increased AsA contents in DHAR transgenic potato

DHAR transgenic potato exhibited increased DHAR activity up to 4.5 folds (Fig. 5A) while AsA contents were up to 2.8 folds compared to NT (Fig. 5B). The relative AsA contents were significantly higher in DHAR transgenic plants while the relative DHA was much higher in the NT (Fig. 5C).

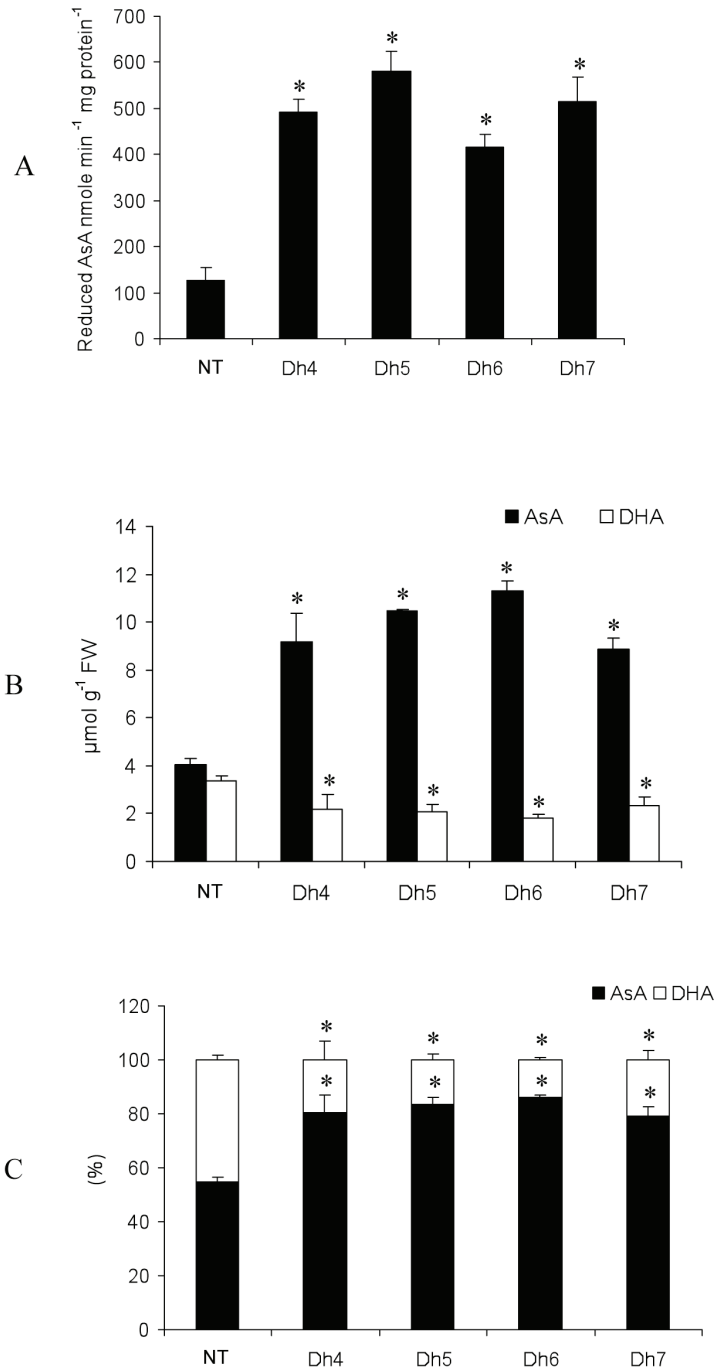

Fig. 5. DHAR enzyme activity, contents and relative contents of AsA and DHA measured in leaf crude extracts from DHAR transgenic and NT. (*A*), DHAR activity. (*B*), contents of AsA and DHA. (*C*), the relative contents of the reduced AsA and oxidized DHA. *, significantly different from the NT plants (*P* < 0.05). Values represent means and SE (*n* = 3).

3.3.2. Ion leakage, H_2O_2 and chlorophyll contents following MV treatment

MV treatment causes the generation of ROS, which damage the plant (Asada and Takahashi 1987). Leaf discs from the transgenic plants exhibited significantly less ion leakage than the NT plants after both 12 and 24 h when treated with 1 or 3 µM MV (Fig. 6A and 6B, respectively). All transgenic plants (except Dh6 at 1 µM MV) maintained significantly higher Chl *a*, Chl *b*, and total chlorophyll (Chl *a*+*b*) contents than in the NT plants after 24 h in both the 1 µM MV treatment (Fig. 7A) and the 3 µM MV treatment (Fig. 7B). Exposure to 3 µM MV for either 12 or 24 h resulted in significantly lower H_2O_2 levels in the transgenic plants than in the NT plants (Fig. 8A). Visible injury on leaf discs treated with 1 µM MV for 24 h was clearly less in the transgenic plants (Fig. 8B).

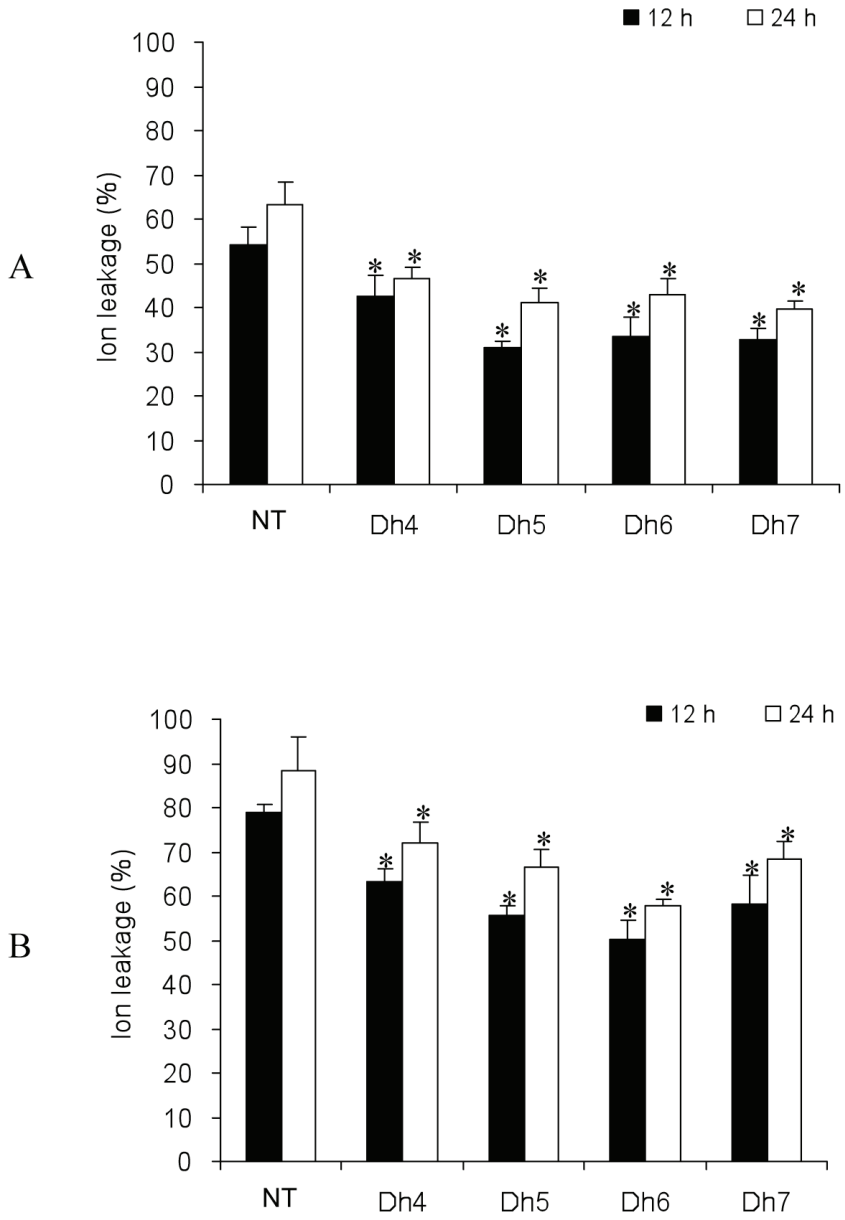

Fig. 6. Ion leakage measured in leaf discs from DHAR transgenic and NT potato. Ion leakage of leaf discs subjected to (A) 1 µM MV or (B) 3 µM MV for 12 or 24 h. Dh4, Dh5, Dh6, and Dh7, transgenic lines; *, significantly different from the NT plants (P < 0.05). Values represent means and SE (n = 3).

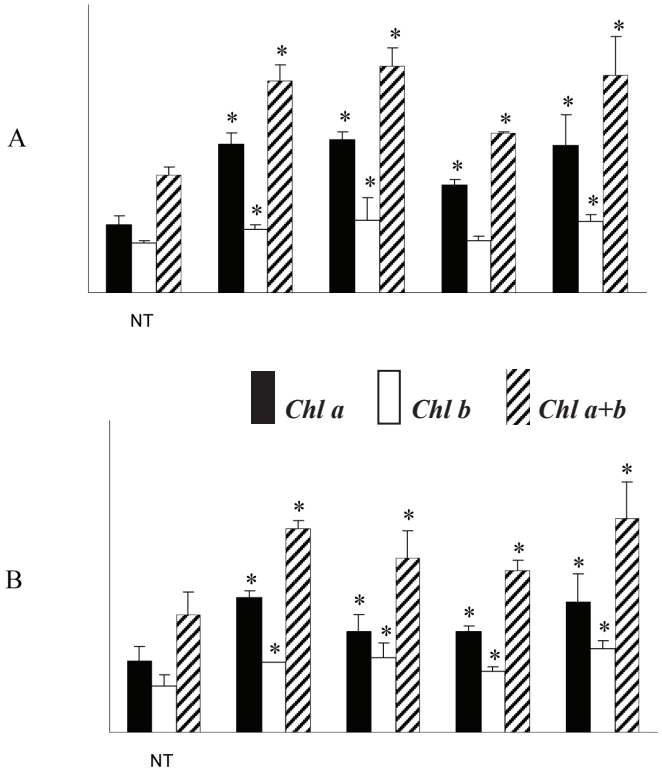

Fig. 7. Chlorophyll contents after MV treatment in DHAR transgenic and NT potato. Chlorophyll content of leaf discs subjected to (A) 1 µM MV or (B) 3 µM MV for 24 h. Dh4, Dh5, Dh6, and Dh7, transgenic lines; *, significantly different from the NT plants (P < 0.05). Values represent means and SE (n = 3).

3.3.3. Plant growth under drought or salt stress

Shoot parts (2 cm) of the seedlings from NT and transgenic plants were excised and maintained in MS medium supplemented with either 5% (w/v) polyethylene glycol or 50 mM NaCl for 3 weeks. Although no difference was observed in the root length (data not shown), transgenic plants showed significantly longer shoots than the NT plants under both stresses (Fig. 8C).

4. Discussion

4.1. Engineering glutathione transgenic potato

In this study, we achieved up to 6.5 folds higher GR activity in the cytosol of GR transgenic potato (Fig. 2B). Staining activity of the overexpressed cytosolic GR showed remarkable higher activity compared to the activity detected in NT and *Arabidopsis* plants (Fig. 2A) which indicate the stability of the *Arabidopsis* GR in the cytosol of transgenic potato. The GSH contents of the transgenic potato were up to 5.8 folds higher compared to that of the NT plants (Fig 3A), which could be attributed directly to the elevated GR activity and its stability in the transgenic potato lines. Similar GR activities were obtained in transgenic poplar (Foyer et al. 1995) plants transformed with bacterial GR, while GSH contents was not affected in the poplar due to less stability of the bacterial GR in the cytosol (Foyer et al. 1995). Transgenic potato with overexpressed levels of GR showed an increased GST activity up to 2.2 folds compared to NT plants (Fig. 4). These results agreed with Mauch and Dudler (1993) who have demonstrated the induction of wheat GstA1 by addition of GSH.

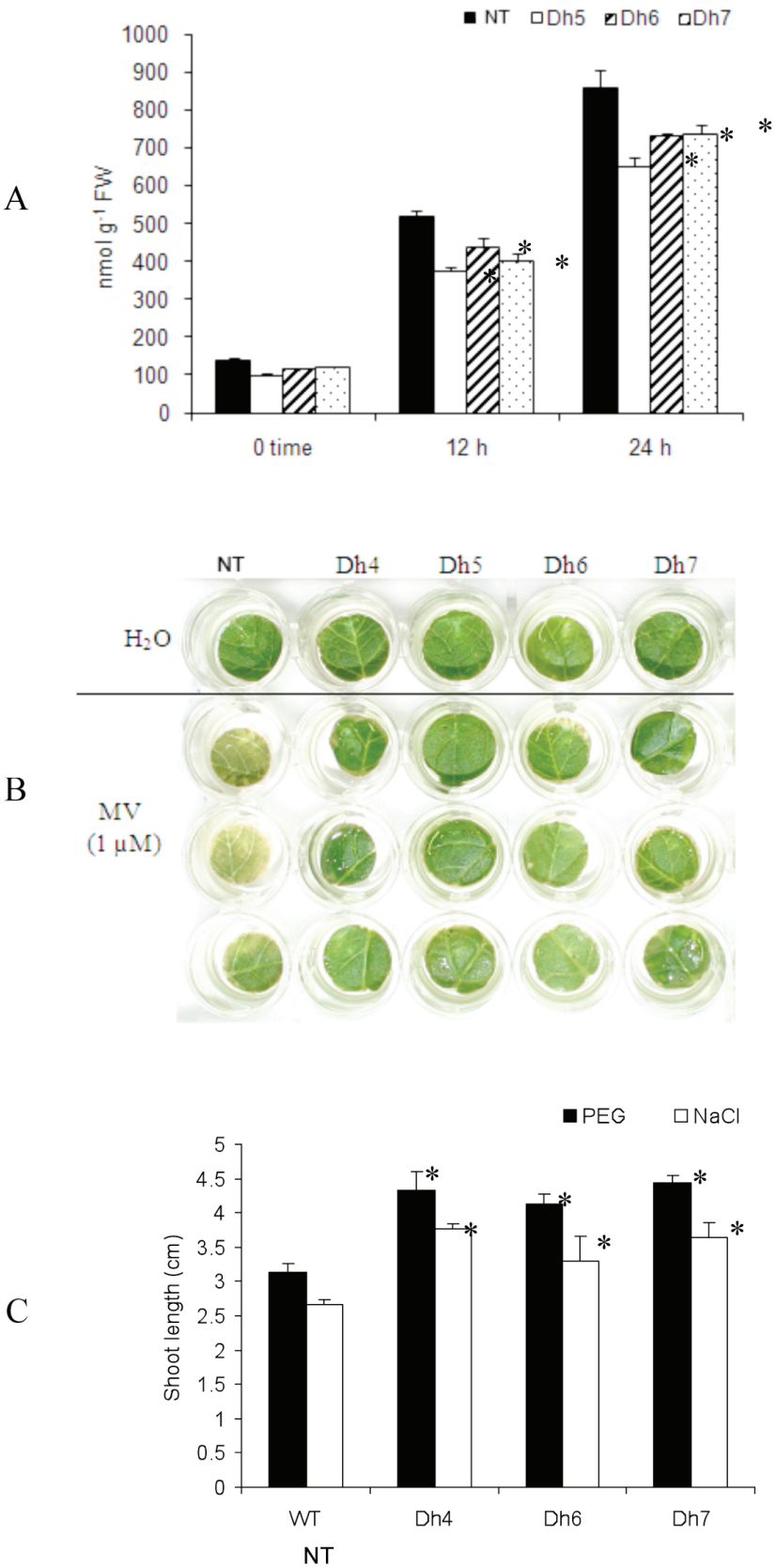

*Fig. 8. Hydrogen peroxide (H_2O_2) contents, visual injury and shoot growth under drought or salt stress in DHAR transgenic potato and NT. (A), H_2O_2 contents in leaf discs after treatment with 3 µM MV for 0, 12, or 24 h. (B), visual injury in leaf discs after treatment with 1 µM MV for 24 h. (C), shoot growth under drought stress induced by polyethylene glycol (PEG) or salt stress induced by NaCl. *, significantly different from the NT plants ($P < 0.05$). Values represent means and SE ($n = 3$).*

At alkaline pH values, GSH rapidly reduces DHA to ascorbate in non-enzymatic reaction and in plant tissue this reaction is catalyzed by DHAR (Noctor et al. 1998). In order to observe the metabolic consequences of GR overexpression, we measured DHAR activity and the contents of the ascorbate pool in GR transgenic plants. Surprisingly, the transgenic potato plants exhibited significantly decreased DHAR activity (Fig. 5A) and total ascorbate contents compared to NT plants (Fig. 5B). While these results appear to be in contradiction with the reports that showed higher ascorbate contents in transgenic plants overexpressing GR (Foyer et al. 1995), they were in line with recent findings that suggest the existence of an active GSH-independent pathway for DHA reduction (Potters et al. 2004). Moreover, different proteins have been proposed to carry out DHA reduction without using GSH in animals (Potters et al. 2002) and plant thioredoxins apparently show DHA reducing activity (Morell et al. 1997; Foyer and Mullineaux 1998).

DHA can be reduced directly by reduced glutathione at alkaline pH values and also by enzymes which catalyse this conversion such as DHAR (Foyer et al 1998). Despite the lower activity of DHAR, DHA contents were lower in the GR transgenic potato (Fig. 5B) which could be attributed to availability of higher GSH levels in the transgenic plants. Higher reduced state of ascorbate was similarly reported in transgenic poplar trees with overexpressed GR from bacteria (Foyer et al. 1995).

4.2. GR transgenic potato maintained greater stress tolerance

To investigate the stress tolerance of the GR transgenic potato, all plants were subjected to MV treatment, drought and cadmium stresses. When challenged by MV, transgenic potato exhibited less ion leakage compared to NT plants (Fig. 6). Detoxification of various herbicides by GSH conjugation has been demonstrated to be a major factor in herbicide tolerance in maize and other plants (Edwards and Owen 1986; Gronwald et al. 1987). The enhanced tolerance to MV could be directly linked to the elevated GR activity and the protective effects of the maintained GSH pool. These results are in general agreement with reports that higher GR activity and GSH protect from oxidative stress derived by MV (Aono et al. 1993, Foyer et al. 1995). Moreover, GSTs are known to function in various cellular processes including their capacity to detoxify herbicides (Hatzios 1989) and protecting cells from oxidative damage by quenching reactive molecules with addition of GSH (McGonigle et al. 2000). Tolerance to MV could also be attributed to higher GST activities in the transgenic potato.

Drought stress accelerates the accumulation of ROS in plant cells. When subjected to drought stress, GR transgenic potato plants recovered better than NT plants in term of less visual injury on the leaves and stems (Fig. 7). Similarly, up regulation of GR was associated with recovery from drought in tolerant cowpea cultivars (Torres-Franklin 2008). In drought tolerant wheat cultivars, expression level and early induction of GST during drought was suggested to play a major role in protection of optimal metabolism of cell (Galle et al. 2009). Therefore, high GST activity might also count positively in inducing faster recovery in the transgenic potato.

Under cadmium stress, the growth reduction reflected by the decrease in the length was clearer in roots than for shoots (Fig. 8). Upon entering cells, Cd might be bound by thiol-containing compounds such as phytochelatin and its precursor, GSH, before being transported to vacuole for storage. Plant GSTs metabolize a wide variety of toxic exogenous compounds (xenobiotic) via GSH conjugation (Mannervik and Daneilson 1988). Accordingly, tolerance to Cd might rely largely on the availability of protective pools of GSH and on GST activity. In this study, roots were significantly protected in GR transgenic potato plants compared to NT (Fig. 8), which we

assume is directly linked to their higher GSH level and GST activity. In rice seedling exposed to cadmium stress, a significant correlation between applied Cd level and GSH content or GST activity was observed, and the ability of Cd detoxification was much higher in roots than in shoots (Chun-hua and Ying 2008

4.3. Engineering vitamin C transgenic potato

Regeneration of AsA in plant cells occurs via two pathways: the Mehler ascorbate peroxidase reaction mainly reduces monodehydroascorbate to AsA, and the Halliwell-Foyer-Asada cycle, which is found in several compartments of plant cells, mainly reduces DHA to AsA (Horemans et al. 2000). To enhance the plant's ability to recycle AsA through efficient regeneration of AsA from DHA, we developed transgenic potato plants that overproduce DHAR in the cytosol by overexpressing *Arabidopsis thaliana* cytosolic *AtDHAR1*. DHAR transgenic potato showed a significant increase in DHAR activity compared with the NT plants (Fig. 2). This indicates that the enhanced DHAR activity in the transgenic potato resulted from the introduced *AtDHAR1* transgene. Similarly, we have previously demonstrated enhanced DHAR activity in transgenic tobacco (*Nicotiana tabacum*) that overexpresses *AtDHAR1* (Eltayeb et al. 2006).

AsA contents increased significantly in DHAR transgenic potato (Fig. 3A) which could be attributed to efficient conversion of DHA into AsA before it is hydrolyzed into 2,3-diketogulonic acid. Cytosolic DHAR is important in reducing DHA that has diffused into the cytosol from other cell compartments (Horemans et al. 2000). NADH or NADPH appears to be absent from the apoplast and cannot drive the reactions of the AsA-GSH cycle; consequently, apoplastic DHA must be returned to the cytosol before it can be reduced to AsA (Pignocchi et al. 2003). Therefore, the significant increase in AsA levels in the leaves of the transgenic plants and their high relative AsA contents (Fig. 3B) can mainly be attributed to the enhanced activity of the cytosolic DHAR in reducing oxidized DHA that has diffused from the apoplast, chloroplasts, and other cell compartments into the cytosol. A similar increase in AsA due to increased expression of DHAR was reported by Eltayeb et al. (2006).

4.4. Elevated ascorbate enhances the stress tolerance in DHAR trangenics

MV is a herbicide that exerts its phytotoxic effect by generating toxic ROS, and especially superoxide anion radicals (Babbs et al. 1989). These toxic ROS cause lipid peroxidation and membrane damage. DHAR transgenic potato plants showed reduced membrane damage resulting from oxidative stress caused by the exposure to MV; they exhibited significantly less ion leakage than the NT (Fig. 4A and 4B). This level of protection against MV could be directly attributed to maintenance of the AsA pool. These results are in general agreement with those of Kwon et al. (2003), who reported enhanced tolerance of MV in transgenic tobacco that overexpressed the human DHAR gene in the chloroplasts, and with those of Pyon et al. (2004), who reported that a paraquat-resistant biotype of *Erigeron canadensis* showed higher contents of the reduced AsA than susceptible biotypes.

Several reports have described the positive effects of overproduction of antioxidative enzymes in maintaining chlorophyll contents despite MV-induced oxidative stress (Aono et al. 1993, 1995). To our knowledge, the effects of cytosolic overproduction of DHAR on chlorophyll contents under MV stress had not yet been investigated when we began our study. We found significantly higher Chl *a*, Chl *b*, and total chlorophyll contents in the DHAR transgenic plants than in the NT plants (Fig. 5A and 5B). These results demonstrate not only the importance of the cytosolic AsA

in protecting the chlorophyll against oxidative damage imposed by MV, but also the importance of efficient cytosolic recycling of AsA to maintain a continuous supply of AsA that could be translocated into other cellular compartments.

Compared to the NT, lower levels of H_2O_2 (Fig. 6) and clearly lower visual symptoms of injury (Fig. 7) in DHAR transgenics were detected. Excess accumulation of toxic H_2O_2 is one of the mechanisms by which plants are damaged by adverse environmental conditions (Hung et al. 2005). H_2O_2 can pass through cell membranes and reach cell locations remote from its site of formation (Foyer et al. 1997). To detoxify H_2O_2 by reduction and maintaining the antioxidative activity of AsA, regeneration of AsA from DHA is necessary (Hossain et al. 1984). Therefore, the lower levels of H_2O_2 (Fig. 6) and the reduction in visible signs of injury in the transgenic plants under MV treatment (Fig. 7) could be attributed mainly to rapid reduction of H_2O_2 as a result of the elevated levels of AsA. Similarly, we have previously demonstrated that tobacco plants that overexpress *AtMDAR1* accumulated lower levels of H_2O_2 in response to salt stress (Eltayeb *et al.* 2007).

DHAR transgenic potato maintained greater shoot extension than NT when subjected to drought or salt stress (Fig. 8). These results agreed with our previous reports that elevation of AsA levels through the overproduction of either DHAR (Eltayeb et al. 2006) or MDAR (Eltayeb et al. 2007) in transgenic tobacco provided enhanced tolerance to salt and drought stresses. Moreover, these results confirm those of Adriano et al. (2005), namely that the amount of AsA available to limit cellular damage caused by ROS was an important attribute linked to drought tolerance, and those of Huang et al. (2005), who reported increased sensitivity to salt stress in an ascorbate-deficient *Arabidopsis* mutant.

5. Conclusion

This work demonstrated that elevation of either GSH or AsA contents through overexpression of their recycling enzymes could significantly provide greater protection against various environmental stresses. This approach provides reliable strategy for the development of industrial transgenic potato plants with enhanced tolerance to multiple environmental stresses.

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31. Identification and expression analysis of salt and drought stress responsive genes from *Leymus mollis*, a coastal wild relative of wheat (*Triticum aestivum*)

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Abstract

The dune grass *Leymus mollis* (Triticeae; Poaceae) is a wild relative of wheat (*Triticum aestivum* L.) and grows mainly along sea coasts and in inland dry areas. *L. mollis* is significantly tolerant to salt and drought stresses, resistant to diseases and adaptive to harsh environmental conditions. Despite its high tolerance to multiple environmental stresses, the genetic bases that control the biochemical and physiological response to salt and drought stresses in *L. mollis* remain largely unexplored. We used suppressive subtraction hybridization (SSH) to identify salt and drought stress responsive genes from *L. mollis*. Fifty nine genes were identified and confirmed to be differentially regulated. Allene oxide cyclase (AOC) and methyljasmonate induced lipoxygenase (LOX) genes were among the highly responsive genes under salt stress, while chloroplast inositol phosphatase (CIP), phosphoethanolamine methyltransferase (PEAMT), ETTIN-like auxin response factor (ARF) and an unknown gene were among the highly regulated genes under drought stress. These genes were also shown to be differentially expressed in response to jasmonic or abscisic acid. Southern blot analysis indicated that *L. mollis* genome has higher number of the isogenes for PEAMT, CIP and ARF compared to that found in the Chinese spring wheat. Since the PEAMT is involved in the biosynthesis of the glycine betaine (GB), we analyzed the contents of GB in *L. mollis* under salt stress. An increased accumulation of GB was observed which indicates the important role of PEAMT in salt stress tolerance in *L. mollis*. Identification of these genes provides insights into the mechanism of salinity and drought tolerance in *L. mollis*. Furthermore, these genes represent important genetic resources for wheat improvement.

Introduction

Salt and drought are among the major abiotic stresses which affect plants growth and decrease the productivity of the major crop plants worldwide. Desertification and salinization are rapidly increasing on a global scale reducing the average yields for most major crop plants. Exposure to drought or salt stress triggers many common reactions in plants. Both stresses lead to cellular dehydration which causes osmotic stress and removal of water from the cytoplasm into the extracellular space resulting in a reduction of the cytosolic and vacuolar volumes (Bartels and Sunkar 2005). Salt tolerance in plants is a complex trait, which involves multiple genes participating in a myriad of processes such as morphological adaptation, osmotic adjustment, ion homeostasis, cell signaling and gene expression, activities and synthesis of many transcription

factors, oxidative stress mitigation, molecular trafficking and cell stability (Bartels and Sunkar 2005; Sahu and Shaw (2009).

Plants sense and respond to drought stress at the molecular and cellular levels as well as at the physiological and biochemical levels, thus enabling them to survive. Drought tolerance has been shown to be a highly complex trait, regulated by the expression of multiple genes that may be induced during drought stress. The products of the stress-inducible genes can be broadly classified into two groups (Reddy et al. 2008). The gene products of the first group directly protect cells against stress (e.g. chaperons, LEA proteins, osmoprotectants, detoxifying enzymes, free radical scavengers and various proteases); the second group includes transcription factors, secondary messengers, phosphatases and kinases such as mitogen-activated kinases, calcium dependent protein kinases and SOS kinases that regulate the expression of other genes in response to drought stress.

The advancements in the biotechnology and molecular biology facilitate the isolation and identification of stress responsive sequences and uncover various genes which can mitigate the effect of the stress. Through gene transformation technologies, these genes can be easily incorporated into crop plants for improving the stress tolerance.

Wheat (*Triticum aestivum* L.) is one of the most widely grown crops in the world. Different strategies have been used to enhance its tolerance to environmental stresses such as crossing it with wild relative species that carry genes for environmental stress tolerance. *Leymus mollis* is a wild relative of wheat and it grows mainly along sea coasts and in inland dry areas. It is an important genetic resource for wheat breeding as it carries genes for salt tolerance and disease resistance (Kishii et al. 2003). In spite of the potential importance of the genus *Leymus*, the genomic relationships among its species are still largely unknown (Kishii et al. 2003). Gagne and Houle (2002) studied the differences in the tolerance of the two species of leymus seedlings to some stresses. Their results showed that tolerance to sand burial, salt spray and soil salinity was higher in *L. mollis* than *Honckenya peploides*. Rachel and Marcel (2000) demonstrated that growth of *L. mollis* appears to be enhanced slightly by submergence for 7 days in sea-water. Despite the high tolerance to multiple environmental stresses in *L. mollis*, the genetic bases that control the biochemical and physiological response to salt and drought stresses remain largely unexplored. Being highly tolerant, *L. mollis* represents an excellent choice to screen for stress tolerance genes and to study their expression patterns with regards to each stress. In this study, we attempted to identify and characterize the expression patterns of salt and drought stress responsive genes from *L. mollis.*

Materials and methods

***Plant material*:** Seedlings of *L. mollis* growing along Japan sea coast were collected from Hamamura beach (Tottori, Japan). Seedlings were washed thoroughly and kept at room temperature with roots soaked in distilled water for 3 days. The seedlings were transferred to 10 L plastic containers for hydroponic culture in a growth chamber under natural light conditions at 25-28 °C and 60–70% relative humidity for 2 weeks. The hydroponic culture consisted of continuously aerated ¼ strength Hoagland nutrient solution (pH 5.6). Hoagland solution was renewed every 2 days and the pH was adjusted each other day with 1 M KOH or HCl.

Stress treatments: *L. mollis* seedlings that are uniform in shape and size were chosen for all treatments. Salt, drought, jasmonic or abscisic acid treatments were carried by maintaining the plants in ¼ strength Hoagland solution supplied with 400 mM NaCl, 15% polyethylene glycol

(PEG), 10^{-5} M jasmonic acid (JA) or 10^{-5} M abscisic acid (ABA), respectively. Control plants were maintained in nutrient solution without any stress. Leaf sample were collected according to day's time course for salt and drought or hours time course for JA and ABA treatments. Samples were immediately frozen in liquid nitrogen and stored at -80°C until used.

***Suppressive subtraction hybridization*:** Total RNA was isolated from leaf tissues of control, salt or drought stress treated plants using TriPure Reagent (Invitrogen, Carlsbad CA, USA) and the mRNA was purified from the total RNA using Oligotex™-dT 30 super kit (Roche, Mannheim, Germany) according to manufacturer's instructions. Suppressive subtraction hybridization (SSH) according to Diatchenko et al. (1996) was performed using CLONTECH PCR-select™ cDNA subtraction kit (Clontech, CA, USA). mRNA from control plants was used to synthesize SSH driver cDNA, whereas mRNA from salt or drought treatments was used to synthesize SSH testers cDNAs for salt or drought subtraction, respectively. Secondary PCR products enriched with the differentially expressed cDNAs were sub-cloned into pCR 2.1-TOPO vector (TOPO TA Cloning®, Invitrogen). Plasmids were isolated from positive colonies using Miniprep kit (PE Applied Biosystems, CA, USA) and inserts were confirmed by PCR using M13F and M13R universal primers.

Differential screening of the expressed sequences: The PCR-Select Differential Screening Kit (Clontech) was used to further confirm the differential expression of positive clones according to manufacturer's instructions with slight modifications. Selected cDNAs amplified from the positive clones were used to prepare two identical copies of nylon-membranes (Hybond™-N^+, Amersham, UK). Forward and reverse subtracted probes were prepared using PCR DIG Probe Synthesis Kit (Roche) and hybridized to the membranes according to Sambrook et al. (1989). Detection of hybridized DIG labeled probe was conducted using DIG Luminescent Detection Kit (Roche) and the hybridization signals were visualized using the LAS-4000 Mini (Fujifilm, Tokyo, Japan).

***Sequence analysis*:** Plasmid inserts from only forward subtractions were considered for sequencing and further analysis. Sequencing was performed using Big Dye Terminator Cycle Sequencing kit (Applied Biosystems). Sequences were analyzed using Genetyx Ver 10.0.3 (Genetyx, Tokyo, Japan). DNA homology searches against the GenBank database were performed with the Basic Local Alignment Search Tools (BLAST, http://www.ncbi.nlm.nih.gov).

***Northern blot analysis*:** Northern blot analysis was conducted to confirm the expression pattern of some selected differentially expressed sequences. Total RNA (30 µg) was denatured in 1% formaldehyde agrose gel and transferred to nylon membrane (Hybond™-N^+, Amersham, UK). Probes were prepared using PCR DIG Probe Synthesis Kit (Roche). Hybridization, detection and visualization of signals were carried as described in the previous section.

***Reverse transcriptase polymerase chain reaction (RT-PCR)*:** Total RNA was treated with RNase-free DNase I (Takara, Shiga, Japan) to remove any contamination with genomic DNA. One µg of the total RNA was used to synthesize first-strand cDNA using the Transcriptor First Strand cDNA Synthesis Kit (Roche). One µl of first strand cDNA reaction was subjected to a PCR using the candidate genes specific primers and actin as internal (Table S1) as described previously (Eltayeb et al 2010).

***Southern blot analysis*:** Genomic DNA was isolated using ISOPLANT II kit (Nippon gene, Co., Ltd., Japan) from leaves of the Japanese wheat variety 'N61', 'Chinese spring Cs81', *L. mollis*, *L. racemosus*, F1 of the cross between *L. mollis* x *L. racemosus* and from *Psathylostachys*

huashanica. Genomic DNA (20 µg) was digested with *Eco*RI and *Hind*III. DNA electrophoresis, transfer and hybridization were carried according to Sambrook et al. (1989). Probe preparation, detection and visualizing hybridization signals were carried as described for northern blot analysis.

***Glycine betaine determination*:** Leave tissues (0.5 g) from control or salt-stress treated plants were homogenized with 4 ml of 90% ethanol, centrifuged at 14, 000 rpm for 10 min and then 0.1 ml portions of the supernatant were vacuum dried. An esterification was carried for the dried extracts using a 0.05 ml of a buffer composed of 100 mM potassium bicarbonate:100 mM potassium dihydrogen phosphate and acetonitrile (1:1:4 v/v) and used for glycine betaine determination by capillary electrophoresis (CE) according to Zhang et al. (2002). CE analysis was conducted using a CE device (Photal CAPI-3300, Otsuka Electronics, Osaka, Japan) equipped with fused silica capillary of 75 µm i.d. and a total length of 80 cm (effective length of 68 cm). Samples and relative standards were injected hydrostatically (25 mm, 60 s). The applied potential was 20 kV, and the peaks of the glycine betaine esters were monitored at 262 nm.

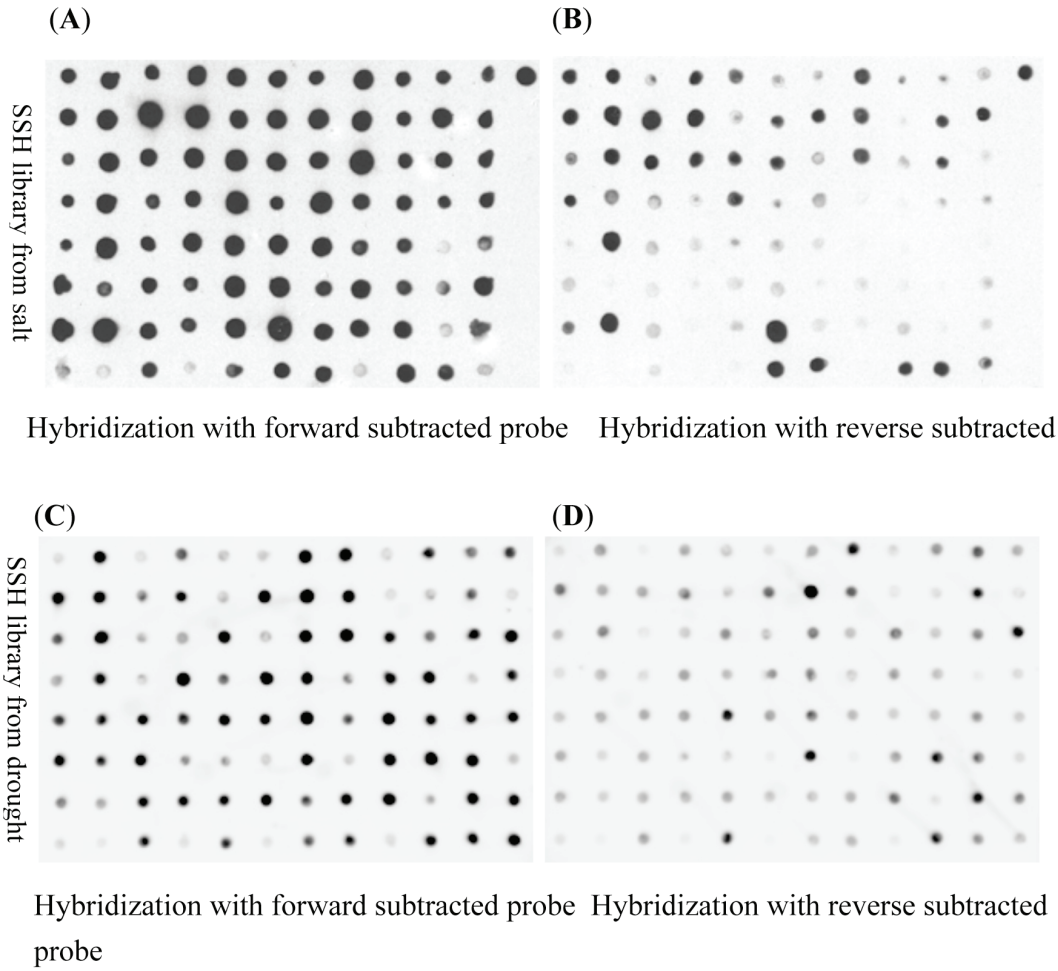

Fig. 1. Differential screening of subtracted clones from the forward subtracted cDNA libraries. *cDNAs from each subtraction were amplified by PCR from positive clones and dot blotted into nylon membranes then hybridized with labeled cDNA probes as described in material and methods. A and B, are the results of the differential screening of the clones from salt subtraction. C and D, are the differential screening of the clones from drought subtraction. Membrane A and C were hybridized with the forward subtracted probe from salt or drought subtraction, respectively. Membrane B and D were hybridized with the reverse subtracted probe from salt or drought subtraction, respectively.*

Results

The SSH according to Diatchenko et al. (1996) was performed to identify genes that are differentially expressed under salt or drought stress but not expressed under normal conditions. The subtracted PCR products were cloned into TOPO TA cloning vector and inserts were amplified by PCR from positive clones. A total of 89 clones were randomly picked for the salt subtraction, whereas 96 random clones were picked for the drought subtraction. Since the subtracted sequences might still contain some cDNAs that are common to the tester and driver samples, differential screening for the cDNA library using forward-subtracted probe and reverse-subtracted probe was performed. Differential screening results showed that several cDNAs were clearly up-regulated to salt (Fig. 1A and 1B) or drought (Fig. 1C and 1D).

***Sequences analysis and homology search*:** Only differentially expressed sequences due to salt or drought stress (forward subtracted SSH cDNAs) were considered for sequencing. A total of 59 differentially expressed sequences were subjected to sequencing. Sequence similarities and homology results for 28 selected sequences expressed under salt stress are shown in Table 1, while sequences which are found to be differentially expressed due to drought stress are shown in Table 2.

***Table 1: Salt stress responsive genes identified from* L. mollis**

Clone no.	**Size**	**Putative identity**	**Origin of the matching sequence**		
			Organism	Accession no.	E.value
1- Salt- H01	551	UDP-glycosyltransferase	*A. strigosa*	ACD03255.1	0.011
2- Salt- H07	350	Cell wall-associated hydrolase	*M. marina*	ZP_01689674.1	2e-6
3- Salt- G01	381	Xyloglucan xyloglucosyl transferase	*H. vulgare*	ABY79073.1	9e-21
4- Salt- G02	135	Beta glucanase	*T.aestivum*	Z22874.1	2e-31
5- Salt- C02	344	Annexin-like protein	*O. sativa*	NP_001105728.1	6e-20
6- Salt- E01	271	Aquaporin	*T. turgidum*	EU182655.1	2e-28
7- Salt- F05	400	Amylo-alpha-1,6-glucosidase	*M. pora sp*	ZP_04609345.1	0.60
8- Salt- C06	599	Chloroplast pyrophosphatase	*H.vulgare*	AJ581660.1	2e-89
9- Salt- E05	476	Serine hydroxymethyltransferase	*T. monococcum*	DQ862827.1	7e-82
10- Salt- G08	243	Alanine dehydrogenase	*Ruminococcus*	ZP_06718033.1	2.3
11- Salt- D02	769	4-alpha-glucanotransferase	*Streptomyces sp*	ZP_06280202.1	1
12- Salt- B11	461	Ornithine decarboxylase	*Vibrio cholerae*	ZP_01980450.1	3.8
13- Salt- B02	592	Methyljasmonate-inducible lipoxygenase 2	*H.vulgare*	U56406.1	3e-75
14- Salt- B04	522	Allene oxide cyclase	*H. vulgare*	AJ308488.1	0
15- Salt-H05	361	DGK1 (Diacylglycerol kinase)	*Oryza sativa*	AAS07206.1	70
16- Salt- F03	230	Xylanase inhibitor protein	*T.aestivum*	AB302973.1	8e-33
17- Salt- F06	315	Harpin inducing protein	*O. sativa*	AF039532.1	5e-31
18- Salt- B05	407	Eukaryotic translation initiation factor	*T. aestivum*	DQ167203	5e-30
19- Salt- D03	-334	Senescence-associated protein [(stress re	*Br. malayi*	BAB33421.1	1e-39
20-Salt- E02	880	Basic leucine	*A. thaliana*	AJ010858.1	0.0
21- Salt- F01	647	Putative fructose 1-,6- biphosphate aldolase	*T. aestivum*	CAD12665.1	2e-58
22- Salt- C01	441	Transaldolase	*O. sativa*	ABR25370.1	8e-52
23- Salt- F04	261	Ribulose-1,5-carboxylase/oxygenase	*H. europaeus*	AAN27981.2	1e-38
24- Salt- D04	431	NADPH quinone oxidoreductase	*Z. mays*	NP_001148702.1	1e-51
25- Salt- G05	274	FAD dependent oxidoreductase	*T. crunogena*	YP_392137.1	5
26- Salt- G06	226	Thioredoxin	*T. aestivum*	ACH61777.1	4e-8
27- Salt- B02	377	Storage protein activator	*T. aestivum*	FM242576.1	6e-107
28- Salt- C03	765	Glycine decarboxylase	*X Tritordeum*	AF024589.1	0.0

Table 2*: Drought stress responsive genes identified from* L. mollis

Clone no.	Size	Putative identity	Origin of the matching sequence		
			Organism	Accession no.	E.value
1- Dr- D05-	454	HVA1 gene-	*H.vulgare*	X78205.1	3e-105
2- Dr- G03	765	Dehydrin 2 gene	*H.vulgare*	X15289.1	9e-115
3- Dr- C07	268	Surface glycoprotein	*T. a brucei*	AAA30252.1	8.7
4- Dr- H01	351	Actin-depolymerizing factor 6	*Z. mays*	NP_001148357.1	2e-49
5- Dr- G03	472	Putative ABC transporter	*O. sativa*	BAD33355.1	3e-26
6- Dr- A02	339	PsaN for photosystem I subunit N	*H.vulgare*	X66428	2e-125
7- Dr- B01	192	Chlorophyl a-b binding protein	*Z. mays*	P10708.1	1e-23
8- Dr- F01	496	4-hydroxyphenylpyruvate (HPP)	*Z. mays*	NP_001150258.1	2e-38
9- Dr- D02	592	Phosphoethanolamine methyltransferase	*T. aestivum*	AY065971.1	4e-155
10- Dr- G01	602	Chloroplast inositol phosphatase	*T. aestivum*	AY736122.1	9e-139
11- Dr- D03	777	Metacaspase type II (MCAII)	*T. aestivum*	GU130248.1	0
12- Dr- G06	566	Pyrophosphatase/phosphodiesterase	*H.vulgare*	CAE46394.1	3e-45
13- Dr- E09	233	Plastid acetyl-CoA carboxylase	*T. aestivum*	EU660899.1	7e-21
14- Dr-A10	763	Metallopanstimulin	*S. ratti*	AJ001134.1	1e-11
15- Dr-A03	409	ETTIN-like auxin response factor	*T. aestivum*	AY376130	8e-150
17- Dr- D06	419	Putative carbonic anhydraSe	*T. aestivum*	ADD65763.1	1e-50
18- Dr-D03	334	Senescence-associated protein	*B. malayi*	BAB33421.1	1e-39
19- Dr- H03	310	Putative senescence-associated protein	*P. sativum*	BAB33421.1	1e-42
20- Dr- C01	479	Ribulose-1,5-bisphosphate carboxylase	*T. aestivum*	AB042069.1	1e-148
22- Dr- A01	270	NAD dependent epimerase/dehydratase,	*R. communis*	XP_002512541.1	1e-07
23- Dr- F02	470	Ferredoxin-NADP(H) oxidoreductase	*T. aestivum*	CAD30025.1	1e-76
24- Dr-A07	375	A genome HMW glutenin A gene locus	*T. turgidum*	AY494981.1	1e-8
28- Dr- A05	540	Unknown	*O. sativa*	EAZ02208.1	3e-19
29- Dr- B02	399	Unknown	*A. tauschii*	AF446141.1	2e-112
30- Dr- H06	436	Unknown	*H. sapiens*	AAH29790.1	1e-28
31- Dr- C02	780	Unknown	*Z. mays*	ACL54019.1	1e-74

***Differentially expressed genes under salt stress*:** Among the genes that were highly expressed under salt or drought are the allene oxide cyclase (AOC), methyljasmonate inducible lipoxygenase (LOX), xylanase inhibitor (XIP) and xyloglucan xyloglucosyl transferase (XET). The nucleotide sequences of AOC showed high identity to AOC of *Hordeum vulgare* (95%), while the LOX gene showed high identity to methyljasmonate-inducible lipoxygenase from *H. vulgare* (87%). These genes showed highly up-regulation under salt stress (Fig. 2A) as well as under drought stress (Fig. 2B) except XET which was down regulated under drought. Moreover, AOC and LOX exhibited up regulation in response to JA (Fig. 4A) and ABA treatment (Fig. 4B), while XIP was down regulated under both treatments (Fig. 4A and 4B).

Differentially expressed genes under drought stress: Chloroplast inositol phosphatase (CIP), auxin response factor (ARF) and phosphoethanolamine methyltransferase (PEAMT) were among the highly up-regulated genes under drought stress. CIP, which is involved in phospholipid signaling, showed high similarity to *T. aestivum* CIP (98%). *L. mollis* ARF showed high similarity to *T. aestivum* auxin response factor (91%). PEAMT, which is involved in biosynthesis of glycine betaine, showed high similarity to that of the *T. aestivum* (93%).

Analysis by RT-PCR confirmed that *L. mollis* CIP, ARF and PEAMT are highly up-regulated under both drought stress (Fig. 3A) and salt stress (Fig. 3B). When subjected to JA treatment, CIP and ARF showed up-regulation in response to JA while PEAMT was down regulated (Fig. 4A). In contrast, ARF and PEAMT were up-regulated while CIP was down-regulated when subjected to ABA treatment (Fig. 4B).

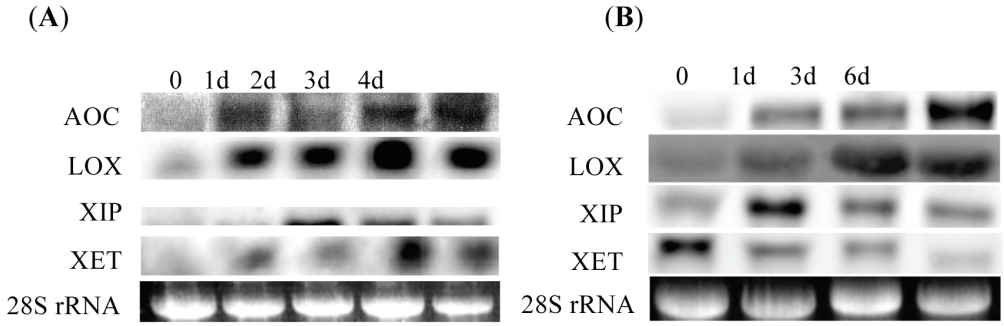

Fig. 2. Expression analysis of selected subtracted cDNAs from salt subtraction under salt or drought stress. *Total RNA isolated from control or salt stress treated plants was used to carry northern blotting as described in materials and methods. A, expression analysis under salt stress. B, expression analysis under drought stress. Day's time course is indicated with letter d. AOC, allene oxide cyclase; LOX, methyljasmonate induced lipoxygenase; XIP, xylanase inhibitor protein; XET, xyloglucan xyloglucosyl transferase.*

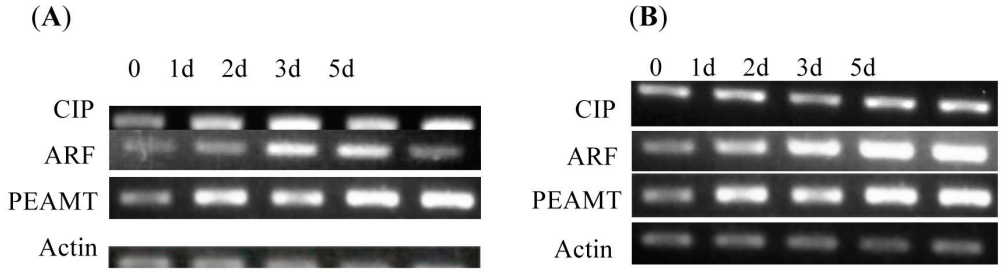

Fig. 3. Expression analysis of selected subtracted cDNAs from drought subtraction under salt or drought stress. *Total RNA isolated from control or salt stress treated plants was used to carry RT-PCR analysis as described in materials and methods. A, expression analysis under salt stress. B, expression analysis under drought stress. Day's time course is indicated with letter d. CIP, Chloroplast inositol phosphatase; ARF, auxin response factor; PEAMT, Phosphoethanolamine methyltransferase.*

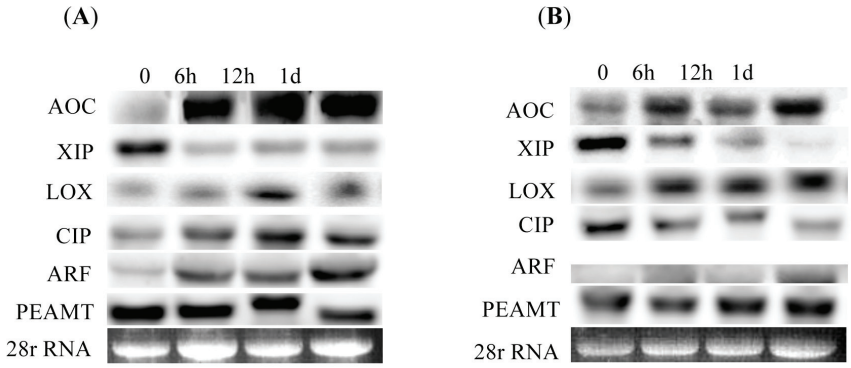

Fig. 4 Northern blot analysis of some selected genes from salt and drought stress forward cDNA library from* L. mollis *in response to JA and ABA treatments. *Total RNA isolated from control, JA treated or ABA treated plants and used to carry northern blotting as described in materials and methods. A, expression under JA treatment. B, expression under ABA treatment. Day's time course is indicated with letter d. AOC, allene oxide cyclase; XIP, xylanase inhibitor protein; LOX, methyljasmonate induced lipoxygenase; CIP, Chloroplast inositol phosphatase; ARF, auxin response factor; PEAMT, Phosphoethanolamine methyltransferase.*

***Glycine betaine contents under salt stress*:** To validate the result of the forward subtractive hybridization at physiological level, we analyzed the contents of the glycine betaine accumulated in the tissues of *L. mollis* under salt stress . Interestingly, as shown in Fig. 5, the contents of glycine betaine increased dramatically under salt stress compared to control plants. Higher glycine betaine contents of up to 1.9 and 2.8 folds were observed after two and four days of salt stress, respectively, compared to control treatment.

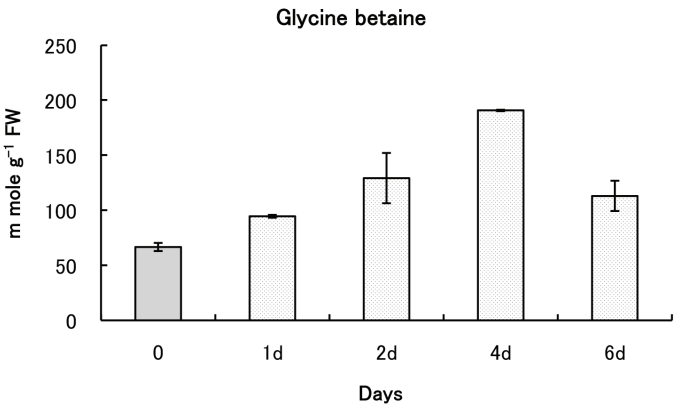

***Fig. 5. Glycine betaine accumulation in response to salt stress in* L. mollis.** *Leave tissues from control and salt stress treated plants were used to determine the glycine betaine contents capillary electrophoresis as described in the materials and methods. Day's time course indicated with letter d. The vertical bars represent the SE of the mean from triplicate determinations.*

***Estimation of the copy number of CIP, ARF and PEAM genes*:** Only three genes were chosen to carry southern blot. Southern hybridization was performed using genomic DNAs from wheat and its wild relatives using cDNA fragments for CIP, ARF and PEAMT gene as probes. Nine bands corresponding to ARF were detected in *L. mollis* compared to only seven detected in Chinese spring Cs81 and N61 wheat cultivars (Fig. 6A). Similarly, higher number of bands corresponds to PEAMT (Fig. 6B) and CIP (Fig. 6C) were detected in *L. mollis* compared to Chinese spring Cs81 and N61 wheat variety.

Discussion

SSH is one of the advanced techniques being largely used to identify stress responsive genes. Attempts have been made to identify salt stress regulated genes using SSH from rice (Sahi et al. 2003), tomato (Ouyang et al. 2007) and natural halophytes (Sahu and Shaw 2009) or drought stress responsive genes from soybean nodules (Clement et al. 2008) and maize (Li et al. 2007). No report exists on salt or drought responsive genes from *L. mollis*, which is likely to give important information on the genes relevant to salt and drought tolerance. In order to enrich and identify differentially expressed sequences, common sequences that might be expressed equally under salt, drought or control conditions were eliminated by a conformational differential screening approach (Fig.1A and 1B for salt subtraction and Fig. 1C and 1D for drought subtraction).

An association between tolerance to salt and drought stress has been observed in this study based on the expression of some selected sequences. Jasmonate inducible LOX and AOC were observed among the differentially expressed genes identified from salt stress. Both genes are involved in the biosynthesis pathway of the jasmonic acid. Jasmonates are compounds of wide

distribution in the plant kingdom and play crucial roles in responses to mechanical and insect wounding and pathogen infection. The defense response involving JA is a two-step process, first perception of the external stress induces JA biosynthesis and then, JA production results in signal transduction leading to the expression of a large number of defense-related genes (Turner et al. 2002). Most of the enzymes involved in the so-called octadecanoid pathway leading to JA biosynthesis have now been identified by a combination of biochemical and genetic approaches (Stenzel et al. 2003). The first step of the JA pathway directs the conversion of α-linolenic acid to 12-oxo-phytodienoic acid (OPDA) by the sequential action of the enzymes LOX, allene oxide synthase and AOC. Northern blot analysis showed an increase in expression pattern for both of LOX and AOC under salt (Fig. 2A) and drought stress (Fig. 2B), and JA treatment (Fig. 4A).

The induction of AOC and LOX identified in this study are in general agreements with several reports demonstrating the involvement of/and induction of those genes under drought or salt stress (Stenzel et al. 2003).

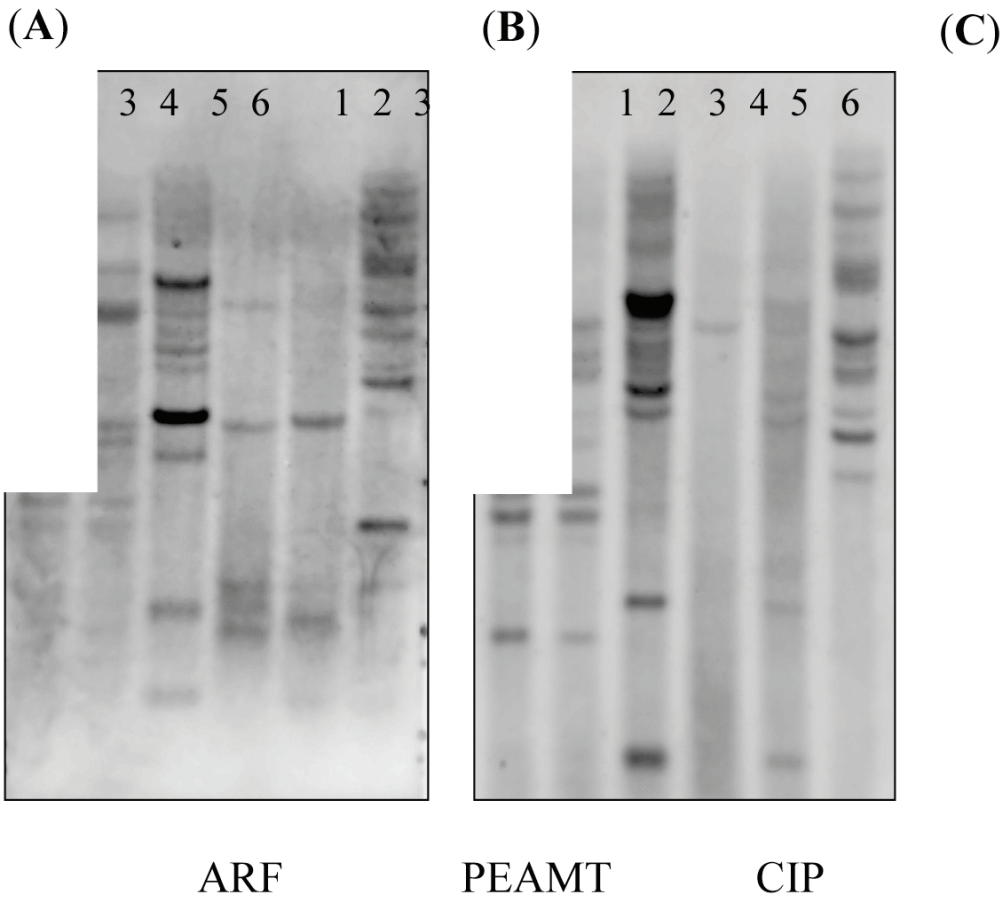

***Fig. 6.* Southern blot analysis for some selected genes identified to be up-regluated in response to both salt and drought stress.** *20 µg of genomic DNA isolated from plants leaves, digested with EcoRI and HindIII and used to carry southern blot analysis as described in the materials and methods. A, sothern analysis results for ARF, B represents the results for PEAMT and C show the results for CIP. Lane 1, wheat variety N61; lane 2, chinese spring; lane 3,* L. mollis*; lane 4,* L. racemosus*; lane 5, F1 of the cross between* L. mollis x L. racemosus*; lane 6,* Psathylostachys huashanica.

High salinity has significant impacts on plant cell wall metabolism by changing cell wall elasticity and composition (Mustard and Renaulta 2004). XET gene, which is involved in cell wall metabolism, was up regulated under salt (Fig. 2A) and down regulated under drought stress (Fig. 2B) which suggest a possible role for this gene in responding to salt stress. Other genes such as XIP and harpin induced protein, which are involved in plant defense mechanisms against phytopathogens, were identified in this study. Although those two proteins are involved in plant microbe interactions, recent reports by Rodriguez et al. (2008) clarified the role of indophyte symbiosis to confer salt tolerance to *L*. mollis. In our data the XIP was induced under salt and drought (Fig. 2A and 2B). Therefore, we suggest that both XIP and harpin induced protein might also be involved in plant stress tolerance mechanism via habitat-adapted symbiosis through regulation of some signaling pathway or activation of salt or drought tolerance genes.

Among the drought responsive genes obtained through the drought subtraction work in this study, ARF, CIP and PEAMT were identified. These genes were found to be highly up-regulated in response to drought (Fig. 3A), as well as salt stress (Fig. 3B).

The predominant view of ARFs is that they bind to auxin response elements (AuxREs) in the promoters of auxin-regulated genes, and mediate auxin signaling by activating or repressing gene transcription (Schruff et al. 2005). We suggest this transcription factors might play an important role in the activation of drought responsive genes and is highly modulated by drought or salt stress in *L. mollis*.

The major phospholipid-derived signaling molecules, which are considered in the context of osmotic stress, include inositol 1,4,5-triphosphate (IP3), diacylglycerol (DAG) and phosphatidic acid (PA) (Bartels and Sunkar 2005). The role of IP3 in the defense response has been demonstrated by Legendre et al. (1993) who documented a rapid increase in IP3 in soybean suspension cells in response to elicitor. The signal induced by IP3 is terminated through the sequential dephosphorylation of IP3 to free inositol. This hydrolysis is catalyzed by a group of specific inositol phosphatases (Berdy et al. 2001). The CIP gene from *L .mollis* showed rapid induction under drought (Fig. 3A) and salt stress (Fig. 3B). This up-regulated expression indicates that CIP may play important role in mediating signaling events in response to drought and salt stress in *L. mollis*.

PEAMT, which is involved the synthesis of glycine betaine, was induced by both drought (Fig. 3A) and salt stress (Fig. 3B). In all biological systems, including most animals, plants and microorganisms, glycine betaine is a major osmolyte which appears to be a critical determinant of stress tolerance and is synthesized by many plants in response to a biotic stresses (Tony and Murata 2002).The activity of PEAMT has been reported to greatly enhance glycine betaine accumulation (Sahu and Shaw 2009). Many studies have reported identification of PEAMT from different plant species and demonstrated that the betaine accumulation is correlated with tolerance of plants to osmotic stress (Tabuchi et al. 2005). The induction pattern of PEAMT expression in *L. mollis* under salt stress was accompanied with clear increase in the contents of glycine betaine (Fig. 5). Betaine may protect the cells from stresses by maintaining osmotic balance and by stabilizing proteins, enzymes and membranes. These results indicate the important role of PEAMT under drought and salt stress in *L. mollis.*

Southern blot analysis indicated that *L. mollis* has a higher copy number of ARF (Fig. 6A), CIP (Fig. 6B) and PEAMT (Fig. 6C) which might represent isogenes or different isoforms in its genome resulting through the evolution of *L. mollis*.

Conclusion

In conclusion this study represents the first attempts to identify and analyze the expression patterns of *L. mollis* stress responsive genes under salt or drought stress. Identification of *L. mollis* genes which are very responsive to both salt and drought stress indicates the importance of the genetic cross-talk mechanism in response to salt and drought stress. Furthermore, identification of these genes represents important genetic resources for improvement of cereal crops such as wheat and other useful crops.

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32. Collection, characterization and identification of drought, salinity and heat tolerant *Sinorhizobium* nodulating alfalfa for adaptation to climate change

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Abstract

The gram-negative bacteria *Sinorhizobium meliloti* and *S. medicae* are able to interact with roots of alfalfa to form nitrogen-fixing nodules and survive as a free living saprophytic bacterium in the soil. The host, alfalfa is the most important forage legume crop in the arid and semi-arid areas of Morocco and North Africa. In these areas, alfalfa is grown in marginal soils and frequently subjected to drought, extremes of temperature and high or low soil pH, soil salinity and heavy metals, which affect biological nitrogen fixing ability of rhizobia and productivity of the host. In this study, we examined physiological diversity of the sampled isolates from marginal soils of arid and semi-arid regions of Morocco for tolerance to the above stresses, molecular genotypic diversity at Repetitive Extragenic Palindromic DNA regions of *Sinorhizobium* nodulating alfalfa, and biological nitrogen fixing efficiency of some of the tolerant isolates. The study revealed that out of the 157 sampled isolates, 136 isolates were identified as *S. meliloti* and the rest as *S. medicae*. Further phenotyping of these alfalfa rhizobia for tolerance to the environmental stresses revealed a large degree of variation: 55.41%, 82.16%, 57.96% and 3.18% of the total isolates were tolerant to NaCl (>513mM), water stress (-1.5 MPa), high temperature (40ºC) and low pH (3.5), respectively. Sixty-seven isolates of *S. meliloti* and thirteen isolates of *S. medicae* 80 that were tolerant to salinity were also tolerant to water stress. Most of the isolates of the two species showed tolerance to heavy metals (Cd, Mn and Zn). The phenotypic clusters observed by the cluster analysis clearly showed adaptations of the *S. meliloti* and *S. medicae* strains to the multiple stresses. Genotyping with rep-PCR revealed higher genetic diversity within these phenotypic clusters and classified all the 157 isolates into 148 genotypes. Some of the tolerant strains were also efficient in biological nitrogen fixation. Therefore, these tolerant strains have a great potential for exploitation in salt and drought affected areas for BNF in alfalfa and also for adaptation to climate change.

Introduction

Currently, arid and semi-arid land areas are increasing globally due to global warming and climate change. As a result, the proportion of crops growing under water deficit conditions is increasing. This phenomenon is constraining crop production in such areas. In many cases, the fields are being abandoned due to erosion and desertification. Although plants have their own mechanisms to cope with water deficit conditions, they become more tolerant to drought when associated with different soil microorganisms (Shisanya 2002). Among these soil microorganisms, the most abundant and effective are rhizobia (Shisanya 2002), which fix atmospheric nitrogen in root nodules of leguminous plants, thereby improving fertility of soil. Therefore, rhizobia are of economic importance in low-input sustainable agriculture and land reclamation in arid and semi-

arid regions. In these areas, many stresses such as drought, extreme soil pH, high temperature and salinity affect the growth and survival of legume crops and their nitrogen fixing rhizobia, thereby affecting nitrogen fixation and productivity of crops (Zahran 1999). The effect of these stresses is expected to be aggravated due to climate change. Therefore, there is a need to develop tolerant legume crops and their symbiotic rhizobia, which can over come those stresses and enhance productivity in marginal environments and permit adaptation to climate change.

Alfalfa (*Medicago sativa* L.) is a deep-rooted, perennial legume capable of producing high yields of good-quality forage. It is grown extensively in arid and semi-arid regions of Morocco and other countries in North Africa. The gram-negative bacteria *Sinorhizobium meliloti* and *S. medicae* are able to interact with roots of alfalfa to form nitrogen-fixing nodules (Elboutahiri et al. 2010). With an aim to isolate drought, salt and heat tolerant rhizobia for inoculation of alfalfa for growing under dry land conditions, we collected rhizobia from drought and salt affected regions of southern Morocco, where alfalfa is being grown, and characterized phenotypic and genotypic diversity of the sampled isolates for tolerance to water and salinity stresses, extremes of temperature and pH, heavy metals and antibiotics *in vitro.* The results of the work done so far are summarized in this paper.

Collection of *Sinorhizobia*

One of the most severe problems facing the agriculture in the dry areas is the degradation of soil quality due to drought and salinity (Vriezen et al. 2007). These two harsh environmental conditions can have a dramatic impact on the endogenous soil bacteria (Fierer et al. 2003). Therefore, the selection of tolerant strains which can withstand the negative impact of saline and desiccated soils can be of great use to improve nitrogen fixation and productivity in arid and semiarid areas. In this context, the 157 isolates used in this study were isolated either from nodules and soils samples collected from 23 locations in drought and salt affected areas of southern Morocco (Figure 1).

The collected soil samples were analyzed for electrical conductivity (EC), pH, and metal content using standard procedures. In the sampled locations, the soil salinity varied between 3.52 dS/m to 10.5 dS/m and the soil pH ranged from 7.23 to 8.53). The soil was moderate to high in the content of Mn and Zn, for Cd, all the soils samples were above the normal level. These regions are also characterized by high temperature (35°C to 50°C), and low mean rainfall (75 mm to 260 mm) (Elboutahiri et al. 2010).

Physiological characterization

The physiological tests to study the tolerance to NaCl (0-10% w/v); water stress (-0.25 to -1.5MPa); and wide range of temperature (28°C to 44°C) and pH (3.5 to 9.5); and intrinsic resistance to antibiotics (chloramphenicol; spectinomycin; streptomycin; and tetracycline); and to heavy metals ($CdCl_2.2H_2O$; $MnCl_2$; $ZnCl_2$; and $HgCl_2$) were done using the methods described previously (Gao et al. 1994; Elboutahiri et al. 2010). The results are summarized in Figure 2.

For salt tolerance, the results showed distinct response. The isolates were classified in three groups according to their salt tolerance: tolerant (100-500 mM NaCl); good tolerance (500-700 mM NaCl); and extremely tolerant (800-1700 mM NaCl), indicating that the rhizobia nodulating alfalfa are more tolerant compared to other rhizobia species (Struffi et al. 1998; Zahran 1999). Salinity imposes both ionic and osmotic stresses. Indeed, the imposition of any stress on rhizobia

results in adaptive responses, which lead to changes in the regular metabolic processes that are then reflected in protein profiles.

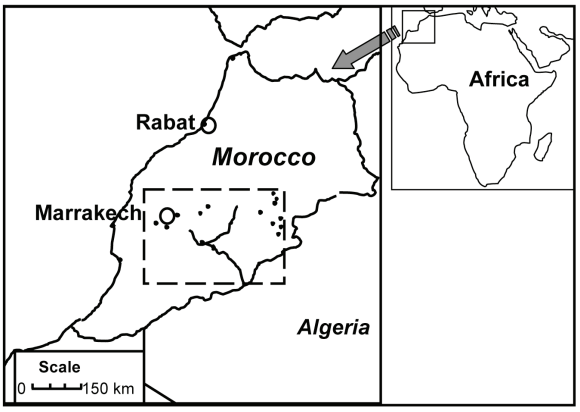

Figure 1. A map showing sampling regions (inner dotted box).

With regard to water stress, 82.16% of the isolates grew at a water potential of -1.5 MPa. The tolerant rhizobia to osmotic stress accumulate the osmolytes, and changes their morphology and dehydration of cells (Buss and Bottomley 1989). Eighty isolates that grew under salinity stress also grew under water stress. Abolhasani et al. (2010) showed that strains tolerating salinity were highly resistant to water stress conditions, and also there was a significant positive correlation between the salt tolerance and the adaptation of rhizobia strains in drought conditions.

For the most rhizobia, optimum temperature range for growth of culture is 28-31°C, and many cannot grow at 37°C (Graham 1992). At 32 and 36°C, respectively, 96.81 and 87.26% of the isolates grew well. At 40°C, 57.96% of the isolates grew and these highly heat tolerant isolates came from hot and dry regions of southern Morocco.

There was a varied response of the isolates to pH. All the isolates tested grew in alkaline pH (pH 9 and 9.5). At very low pH (pH 3.5), only 3.18% of isolates grew normally. Our study therefore confirmed that the alfalfa rhizobia are acid-sensitive.

The sampled isolates showed good tolerance to heavy metals such as Mn, Zn and Cd. The highest number of isolates grew well in 5 µg/ml Cd (92.99%), followed by 300 µg/ml Mn (90.44%) and 200 µg/ml Zn (85.35%); and the growth of almost all isolates was inhibited by Hg (0.69%). Our study showed that *S. meliloti* and *S. medicae* were more tolerant to the heavy metals than the other rhizobia species (Angel et al. 1993).

The evaluation of intrinsic resistance to antibiotics showed that most tested isolates (>85%) had high resistance to streptomycin, tetracycline, chloramphenicol and spectinomycin. However, the degree of resistance to antibiotics was higher than in other species of rhizobia (Wei et al. 2003), indicating that *S. meliloti* and *S. medicae* had higher levels of tolerance to these antibiotics.
Isolates with different phenotypes were observed within a sampling location. The cluster analysis based on phenotypic data further revealed that these isolates represented phenotypically diverse populations. The 157 isolates formed 11 clusters (Figure 3):

- Cluster P-1 consisted of three isolates with different areas of origin. All isolates grew at 40°C, in the medium supplemented with 5% NaCl (855 mM), were resistant to water stress (-1.5 MPa), and sensitive to heavy metals, streptomycin and tetracycline.

- Cluster P-2 consisted of 8 isolates from seven different areas. These isolates had a diversity of salt tolerance. All isolates grew in neutral-alkaline pH; and showed good growth at water stress of -1.5 MPa.
- Cluster P-3 consisted of only two isolates, which were very sensitive to salinity, but resistant to water stress.
- Cluster P-4 consisted of nine isolates from seven different areas. All isolates grew at 40°C, were highly resistant to salinity (8-10%, i.e. 1368-1711 mM of NaCl) and to water stress (-1.5 MPa).
- Cluster P-5 consisted of 17 isolates that were sensitive to salinity stress, had a wide range of diversity for water tolerance, and were resistant to heavy metals and antibiotics.
- Cluster P-6 consisted of 32 isolates. All grew at 40°C, were resistant to heavy metals, and sensitive to streptomycin. They also grew at pH 4.5-9.5 and in medium supplemented with 1-4% NaCl. These isolates had a wide range of water stress tolerance.
- Cluster P-7 consisted of 25 isolates. All grew in medium supplemented with 6% NaCl, at water stress level of -1.5 MPa and were resistant to heavy metals and antibiotics.
- Cluster P-8 consisted of 43 isolates that were resistant to heavy metals and to antibiotics. They grew at 32-40°C, 3-4% NaCl, and had good tolerance to water stress.
- Cluster P-9 consisted of four isolates, which were sensitive to Zn and resistant to antibiotics. They could grow at neutral to alkaline pH, were tolerant to water stress and to 5% NaCl.
- Cluster P-10 consisted of four isolates. All grew at 40°C, were tolerant to salinity and water stress and were sensitive to heavy metals and streptomycin.
- Cluster P-11 consisted of nine isolates that grew in medium supplemented with 3% NaCl, and had a wide range of tolerance to temperature, water stress and heavy metals. All isolates were sensitive to tetracycline.

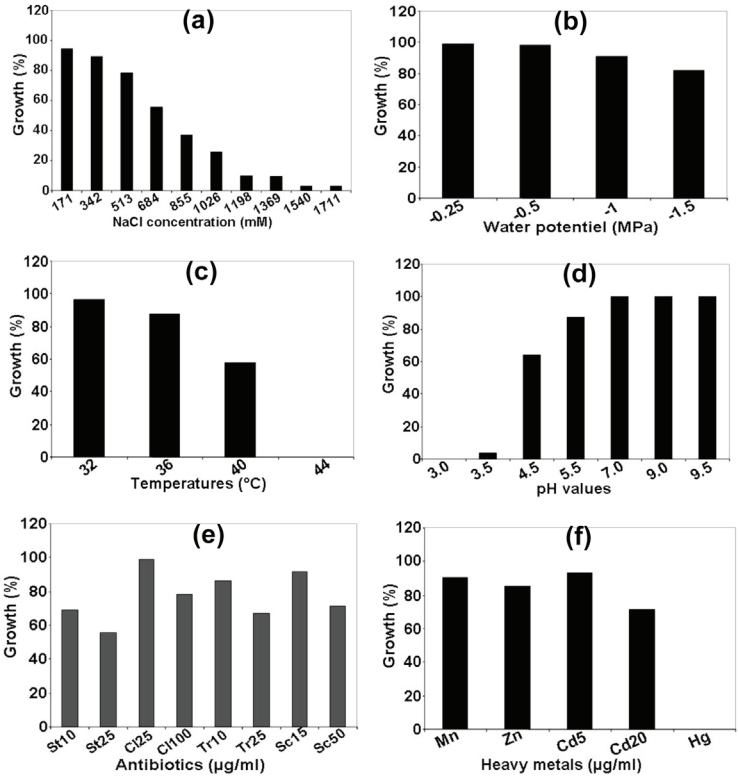

Figure 2. Growth of isolates under salinity (a), water stress (b), high temperature (c), under different pH (d); their resistance to antibiotics (Elboutahiri et al. 2010) St: Streptomycin; Cl: Chloramphenicol; Tr: Tetracycline; Sc: Spectinomycin and concentrations: 10, 15, 25, 50 and 100 µg/ml (e), and heavy metals (Mn 300 µg/ml; Zn, 200 µg/ml; Hg, 20 µg/ml and Cd 5 and 20 µg/ml) (f).

Each cluster showed tolerance to the multiple environmental stresses which are common in marginal soils of arid and semi-arid regions. This kind of phenotypic diversity observed in the rhizobia populations could offer selective advantages in survival and adaptation to those difficult environments.

Genotypic characterization

Genotypic diversity of the rhizobia is present (de Bruijn 1992; Silva et al. 2007), but little is known about such diversity in natural populations of *Sinorhizobium* nodulating alfalfa in the marginal soils of arid and semi-arid regions. Genotyping is essential for identification and classification of strains, estimation of genetic diversity, population structure, evolutionary forces acting on the populations and their interaction with host and environments. With the advent of molecular biological techniques, information concerning genomic organization, variety and diversity of rhizobia has been rapidly accumulating during the last two decades.

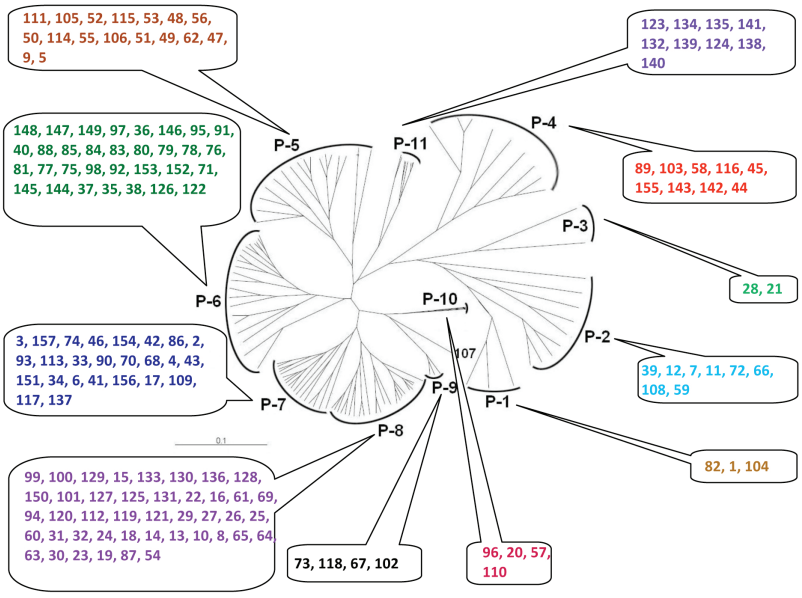

Figure 3. Dendrogram showing relationships among S. meliloti ***and*** S. medicae ***isolates, based on phenotypic variation (Elboutahiri et al. 2010). The UPGMA method was used for the cluster analysis. P-1 to P-11: phenotypic clusters. The numbers indicate*** S. meliloti ***isolate # and the numbers with asterisk (*) indicate*** S. medicae ***isolate #. Details of the individual clusters are presented in the text..***

The investigations initially concentrated on estimating diversity at conserved regions of genomes like 16S rRNA genes using technique called amplified rDNA restriction analysis (ARDRA; Laguerre et al. 1997). Subsequently genomic fingerprinting by PCR amplification with random primers, termed RAPDs (Random Amplified Polymorphic DNA; Williams et al., 1990) gained popularity as a useful technique for comparative genome analysis (Harrison et al., 1992). Later on, PCR amplification with primers specific to the repetitive genetic elements REP (for Repetitive Extragenic Palindromic), ERIC (Enterobacterial Repetitive Intergenic Consensus) and BOX (composed of the box A, B and C subunits), collectively known as rep-PCR, has been used for genomic fingerprinting of Gram-negative bacteria (de Bruijn 1992; Louws et al., 1994; Chen et al., 2000). These repetitive elements, located in the intergenic regions of many bacterial genomes, are considered to be highly conserved (de Bruijn 1992) and as such are useful for elucidating relationships within and between bacterial species including rhizobia (de

Brujin 1992; Elboutahiri et al. 2009). In this study, we used amplified rDNA restriction analysis (ARDRA) technique with *Rsa*I restriction enzyme for distinguishing *S. meliloti* and *S. medicae* species (Laguerre et al. 1997; Silva et al. 2007) and Repetitive Extragenic Palindromic PCR (Rep-PCR) analysis for genetic characterization of isolates (de Bruijn 1992; Kaschuk et al. 2006; Elboutahiri et al. 2009).

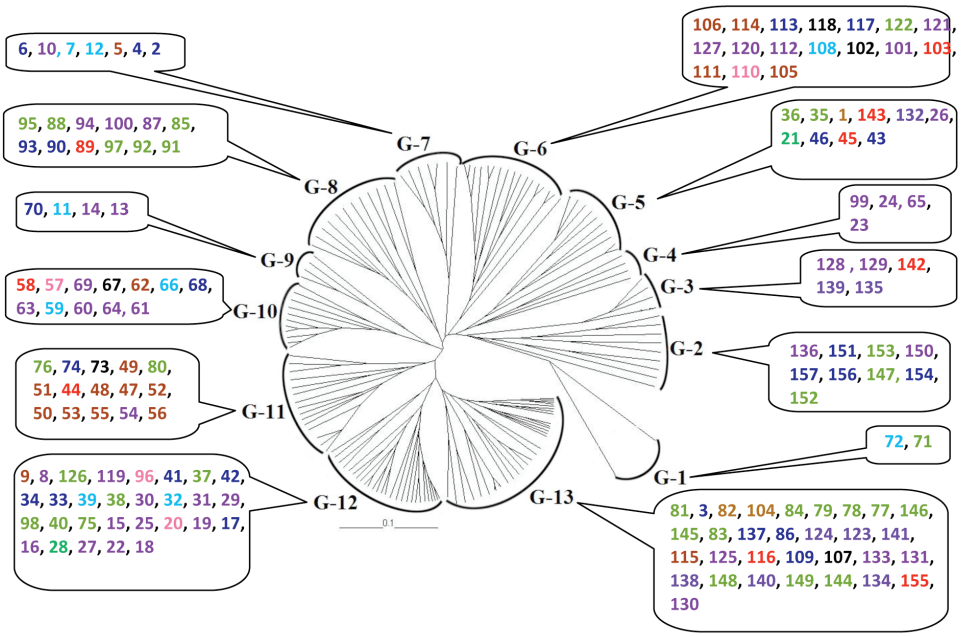

Figure 4. Dendrogram showing genetic relationships among the isolates of S. meliloti ***and*** S. medicae ***(Elboutahiri et al. 2010). The UPGMA method was used for cluster analysis. G-1 to G-13: genotypic clusters. The isolates from the same phenotypic clusters (clusters P-1 to P-11, Figure 3) are denoted by the same colour, as shown in Figure 4. The numbers indicate*** S. meliloti ***isolate # and the numbers with asterisk (*) indicate*** S. medicae ***isolate #.***

Bacterial DNA was extracted by a simple boiling method. For the rhizobia species assignment, the 16S rDNA gene of the isolates was amplified using primers fD1 and rD1 with an annealing temperature of 58°C and restricted with *Rsa*I (ARDRA; Laguerre et al. 1997; Silva et al. 2007). Based on *Rsa*I restriction pattern, the isolates were assigned to either *S. meliloti* or *S. medicate* (Silva et al. 2007), by comparing their pattern with the restriction pattern of the reference strains of *S. meliloti* (USDA, NRRL-45) and *S. medicae* (ABT5). PCR targeting repetitive DNA sequences (rep-PCR) were performed according to de Bruijn (1992) with minor modifications (Elboutahiri et al. 2009). PCR amplified fragments were electrophoresed in an agarose gel (1.5%) and visualized using ethidium bromide staining.

Rep-PCR analysis revealed high intraspecific diversity among the isolates and classified the isolates into 148 genotypes (strains). Among the genotypes, only three were observed 2 times and one was found 3 times and the remaining genotypes were detected only once. The dendrogram constructed based on the genotype profiles provided more information on the specific variability of the strains (Figure 4). At 84% level of similarity, there were 13 definitely separated and delimited clusters of strains. Each cluster was formed by strains from different areas of collection and with different phenotypic traits. In other words, within the same location of collection, the strains architecture was phenotypically and genetically divergent. Eight strains, which are highly tolerant to NaCl (1368-1711 mM NaCl), water stress (-1.5MPa) and high temperature (40°C), were distributed in different genetic clusters, indicating that they are genetically divergent strains.

Biological nitrogen fixation

Studies on BNF of the highly tolerant strains to water, salinity and heat stresses, under saline and drought conditions, imposed in pot culture, revealed that these isolates are also efficient in BNF. These strains are highly useful for BNF under arid conditions and for adaptation to climate change. Further studies on BNF of the highly tolerant strains under field conditions are in progress.

Conclusions

Our study showed that alfalfa in Morocco is nodulated by *S. meliloti* and *S. medicae*. High degree of phenotypic and genotypic diversity is present in *S. meliloi* and *S. medicae* populations of marginal soils affected by salt and drought, in arid and semiarid regions of Morocco. No relationship between genotypic profiles and the phenotypes was observed. Molecular diversity was distributed within the sampling locations. Some of the strains identified as tolerant to salinity, water stresses and high temperature have a great potential for exploitation in drought, salt and heat affected areas for BNF and for adaptation to climate change.

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Theme 5: Blending indigenous/traditional knowledge and heritage with modern science

1. Climate change and local adaptation strategies in the Middle Inner Mongolia, northern China

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Abstract

According to records of 17 meteorological stations located in the study area, climate change of middle Inner Mongolia in northern China was analyzed in this paper. Based on SPOT VGT data, and combined with field investigation, local vegetation change was detected in the last 10 years. The results show that local climate trend has been towards warm-dry conditions during the last 50 years. Air temperature increased by 0.318 ℃$10y^{-1}$ during 1960-2009 and by +0.423 ℃$10y^{-1}$ during 1980-2009, while precipitation decreased by -2.91 mm$10y^{-1}$ and -8.85 mm10 y^{-1} during the respective periods. Yearly cumulative NDVI value and yearly NDVI maximum showed huge fluctuation during the last 10years, especially continuous lower vegetation cover in the western Sonid Steppe Region. With annual mean wind speed decreasing since 1970s, sand-dust storm events decreased till 1990s, but the frequency and intensity of these has increased in the recent decade. Frequent droughts and dust-storms have also seriously affected local pasture and grazing activities, and often resulted in heavy economic loss, especially during the drought period of 1999-2001. To face the drought disasters and strong dust-storms, the local authorities put forward the 'enclosing-transferring' strategy and made great efforts to adapt to the climate change and avoid further environmental deterioration. The efforts included selective emigration, decreasing livestock numbers, fencing grasslands and building forage production bases with efficient irrigation system, and actively adjusting the industrial structure. However, the effects and some potential problems of this adaptation strategy need to be explored further in the longer term for different sub-regions.

Introduction

Climate change is one of the major challenges of our time and adds considerable stress to our societies and to the environment (UNEP 2010). It can affect local or global natural resources such as land, water, diversity and the productivity of agriculture, and even it can bring disasterous consequences, for example, floods, droughts (Jason and Bausch 2006), aeolian desertification and dust-storms (Zhang et al. 1997). Climate change is affecting China, including the Northern China where it is more arid and fragile ecological environment with serious wind erosion (Zibao et al. 2000; Peijuni et al. 2004). Wind erosion is likely to become worse due to increased drought and climate variability associated with climate change (Leys 2009). Climate change and human activities have together accelerated grassland degradation, aeolian desertification and dust-

storms in Northern China (Wang et al. 2006; Liu and Wang 2007). What impacts have been brought about by climate change on local environment and what actions have been taken by the local people for adapting and alleviating climate change? These two problems will be further explored in this paper.

2. Study area

The study area is located in the middle part of the Inner Mongolian Plateau of Northern China, northwest of Beijing. Most of the study area is administrated by Xilingol Meng of Inner Mongolia and it extends between longitudes 110°E and 120°E and latitudes 42°N and 47°N. The average elevation is between 800 and 1400 m above sea level. The Otindag Sandy Land is located in the center of the study area and is a depressed rift valley zone mainly covered by fixed and semi-fixed sand dunes, and increasing shifting dunes in the last 50 years. The east and the south parts of the study area reach the Da Hingganling Mountains and the Yinshan Mountains, respectively. Part of these piedmonts had been reclaimed as farmlands for a long time, even more than 100 years. The north and west part of the study area is undulated grasslands for grazing, extending to the Sino-Mongolia border. Outcrops of granite and metamorphic rock occur in several regions, and some localized areas are covered by basaltic outcrops (Fig. 1).

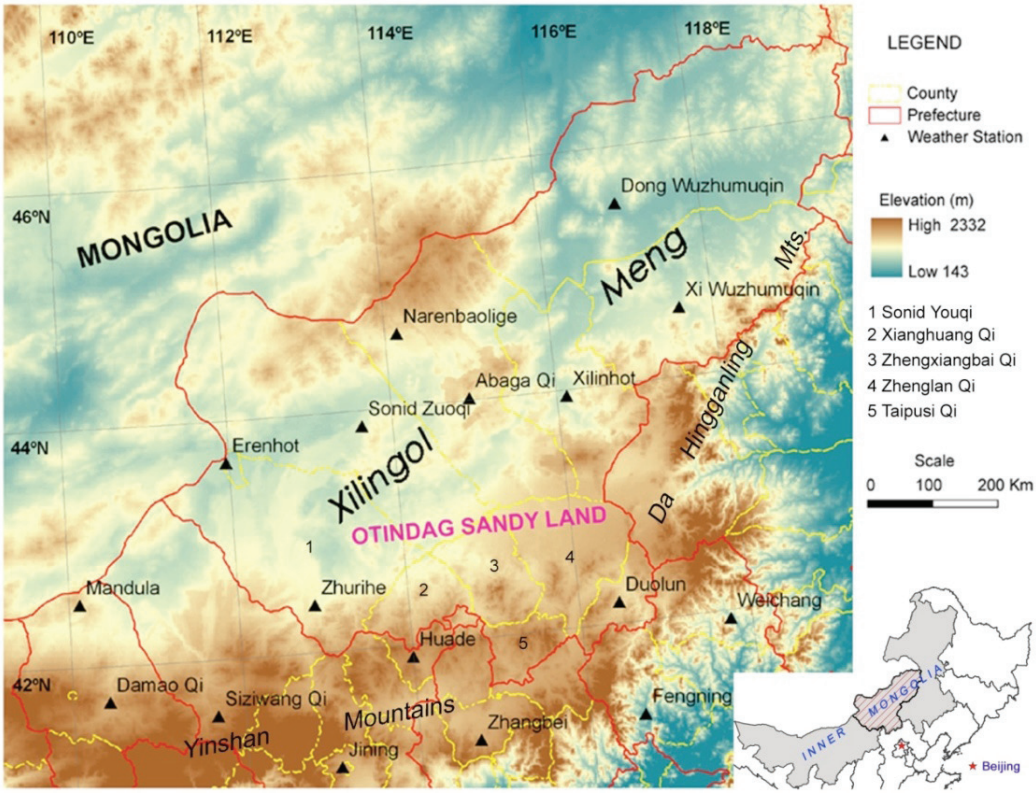

Figure 1. Location map of the study area.

The climate is a continental arid and semi-arid temperate type. Precipitation is concentrated in summer and fall, and the annual average varies from 350 to 400 mm at south-east to 100 to 200 mm at north-west, and 70% of the total occurs during the summer (June–August), mainly influenced by south-east monsoon. The annual mean temperature averages between 0 and 3 ℃. The dominant soil types of the study area include chernozem, chestnut soil, calcic brown soil, and the azonal soil mainly including much mobile sandy soil.

Vegetation here is characterized by sparse wood grassland of eastern Otindag Sandy Land, and meadow grassland in the east, semi-arid typical temperate grassland in the central area, and desert grassland in the west. The representative vegetation of the study area includes sparse woods dominated by *Ulmus pumila, Salix flavida, Caragana microphylla, Artemisia frigida, Stipa baicalensis, Stipa krylovii, Stipa gobica, Stipa glareosa, Aneurolepidium chinensis,* and *Leymus chinensis.*

The study area lies in one of the three strongest wind regions in China. High wind velocities ($\geq$ 17 $m \cdot s^{-1}$) occur 60–80 days $year^{-1}$, with a general increase in this frequency from the southeastern part to the northwestern part. The annual mean wind velocity ranges from 3.5 to 5.0 ms^{-1}, and strong winds are most common in winter and spring, especially in April and May, when the soil's vegetation cover may not have become fully established, thus causing very strong erosion. Farmers and herdsmen in Xilingol Meng directly engaged in agriculture and grazing occupied more than 50% of the total area for a long time, which resulted in heavy pressure on land and accentuated erosion.

3. Data and methods

3.1 Climatic data and sand-dust storm statistics

Dataset of sand-dust storms and climate from Chinese Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/) were downloaded for analysis. The records of sand-dust storm events from 1954 to 2007 in 17 main weather stations were selected and used in this research (Table 1). Other climate data including temperature, precipitation and wind conditions had been updated to December 2009. The climatic conditions in the study area were analyzed using the records of 17 weather stations as mentioned above.

3.2 Vegetation change information

SPOT VGT NDVI data from 1998 to 2008 was used as vegetation information to explore the effect of climate on vegetation. All SPOT VEGETATION 1km 10-day images were downloaded from: http://free.vgt.vito.be. The original VGT-S10 (ten day synthesis) products were composite (maximum-value) products. All the segments of this period were compared to select the maximum ground reflectance values. Because the maximum NDVI value composite (MVC) (Holben 1986) (a maximum daily NDVI value in each 10 days) minimizes atmospheric effects, scan angle effects, cloud contamination and solar zenith angle effects (Hope et al. 2003; Stow et al. 2003), all three 10-day-synthesis products in every month were combined into monthly-NDVI data set for the best vegetation state in those months, adopting the MVC method. The yearly NDVI data set were produced with those monthly NDVI data set from April to October each year using the same method, sequentially, because maximum values were always from April to October every year in Northern China. This also avoided many stochastic errors caused by the lower NDVI value in winter and spring seasons there. So the newly produced yearly NDVI products were the best vegetation state pixel by pixel each year from 1998 to 2008. More detailed information about this data and processing method of SPOT VGT NDVI data can be founded in Liu et al. (2010).

3.3 Socio-economic activities

Human and livestock population, industrial-structure change information, and income of farmers and herdsmen from local statistics departments are used to analyze human activities and the effect

of climate change on the people. Some human activities on the ground were monitored through continuous several-year field investigation and by interviewing local farmers and herdsmen.

Table 1. Location information of main weather stations within and surrounding Xilingol Meng

Station Name	Latitude (degree)	Longitude (degree)	Elevation (m)
Dong Wuzhumuqin	45.52	116.97	838.9
Erenhot	43.65	111.97	964.7
Narenbaolige	44.62	114.15	1181.6
Mandula	42.53	110.13	1225.2
Abaga Qi	44.02	114.95	1126.1
Sonid Zuoqi	43.87	113.63	1036.7
Zhurihe	42.40	112.90	1150.8
Damao Qi	41.70	110.43	1376.6
Siziwang Qi	41.53	111.68	1490.1
Huade	41.90	114.00	1482.7
Zhangbei	41.15	114.70	1393.3
Jining	41.03	113.07	1419.3
Xi Wuzhumuqin	44.58	117.60	1000.6
Xilinhot	43.95	116.12	1003.0
Duolun	42.18	116.47	1245.4
Fengning	41.22	116.63	661.2
Weichang	41.93	117.75	842.8

4. Results

4.1 Climate change

Air temperature rose during the last 50 years, especially since 1987 (Fig. 2). The inter-decadal difference analysis showed that the decadal increase in air temperature grew from +0.318 ℃•10 y^{-1} during 1960-2009 to +0.423 ℃•10 y^{-1} during 1980-2009.

Precipitation change trend in the study area was not clear, but the fluctuation in the rainfall was increasing (Fig. 3). The inter-decadal difference analysis showed that mean precipitation in the study area presented the change characteristics of "dry-wet-dry-wet-dry" from 1960s to 2000s in that order, and the decadal decrease in precipitation grew from -2.91 mm•10 y^{-1} during 1960-2009 to -8.85 mm•10 y^{-1} during 1970-2009. Continuously less precipitation caused serious droughts. For example, the heavy drought events occurred in 1999-2001 and 2005-2007.

4.2 Impact of climate change on vegetation

Data about annual grass growth status during the period of 1960-1985 were obtained from the literature of *Xilingol Meng Chorography* (ECXMC 1996). The Pearson correlation was 0.556 between annual mean regional precipitation and annual grass growth status during the period

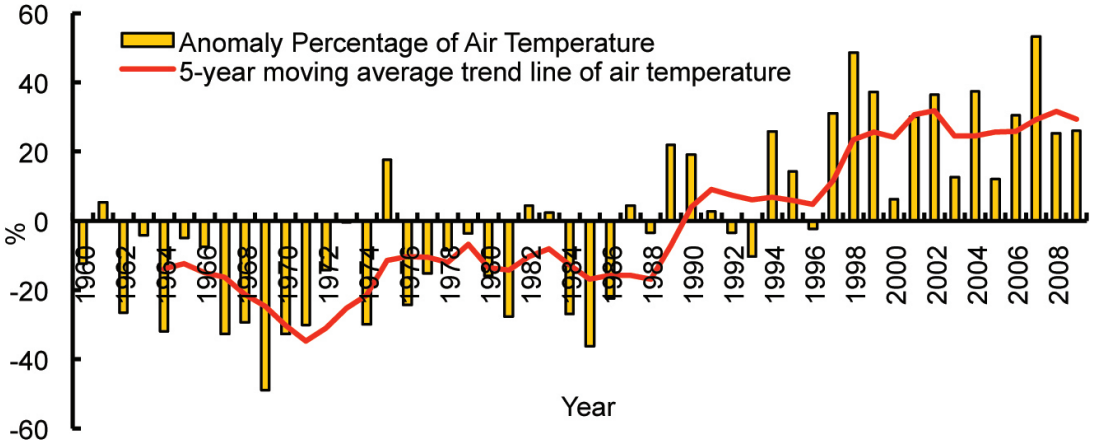

Figure 2. Yearly mean air temperature change in the study area from 1960 to 2009.

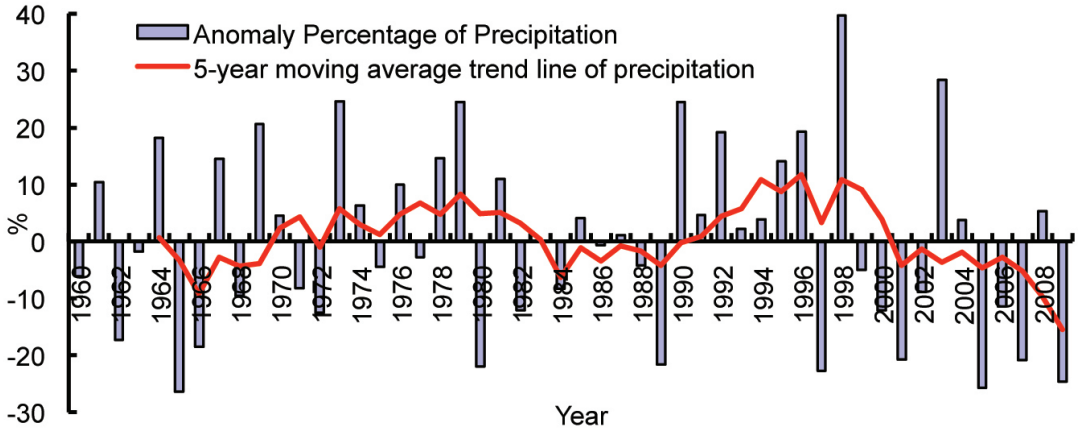

Figure 3. Yearly mean precipitation change in the study area from 1960 to 2009.

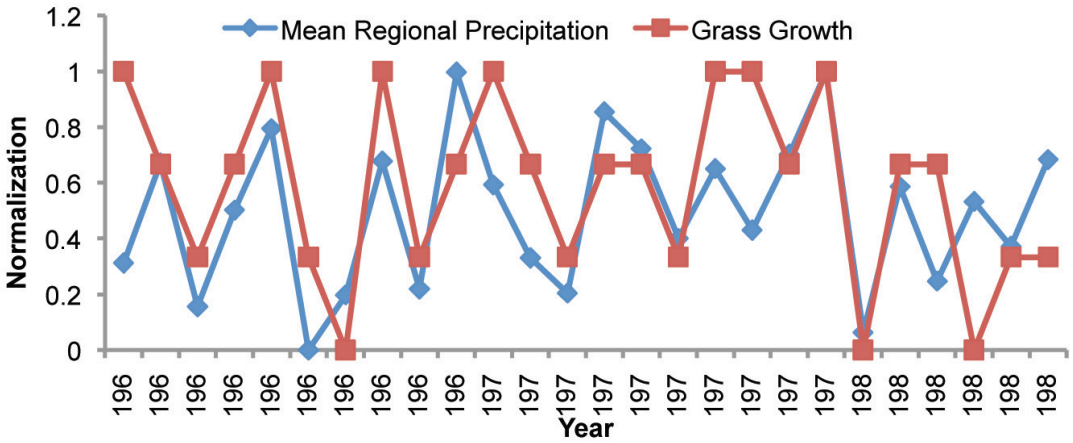

Figure 4. Annual mean regional precipitation and grass growth status of Xilingol Meng from 1960 to 1985.

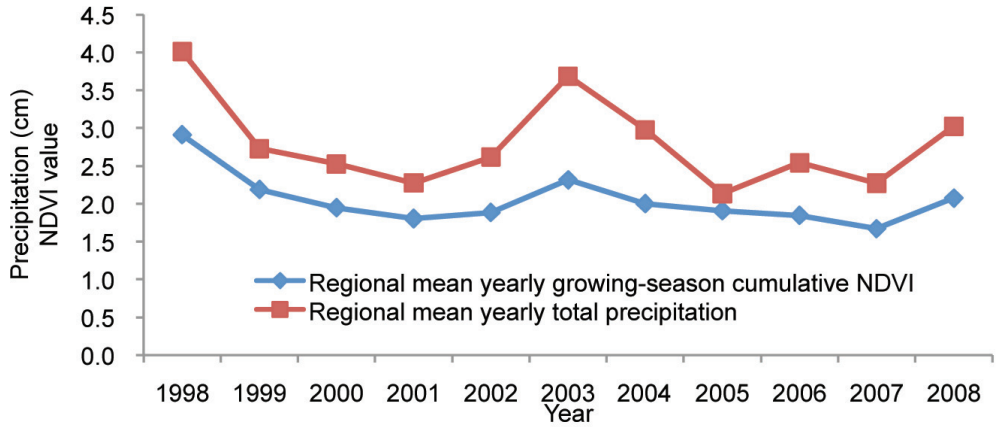

Figure 5. The relation between regional mean yearly growing-season cumulative NDVI and precipitation in the study area

of 1960-1985 (P<0.01) (Fig. 4). According to the correlation analysis between precipitation and yearly growing-season cumulative NDVI value from SPOT VGT data, vegetation was obviously affected by precipitation in the study area (R^2=0.81) (Fig. 5).

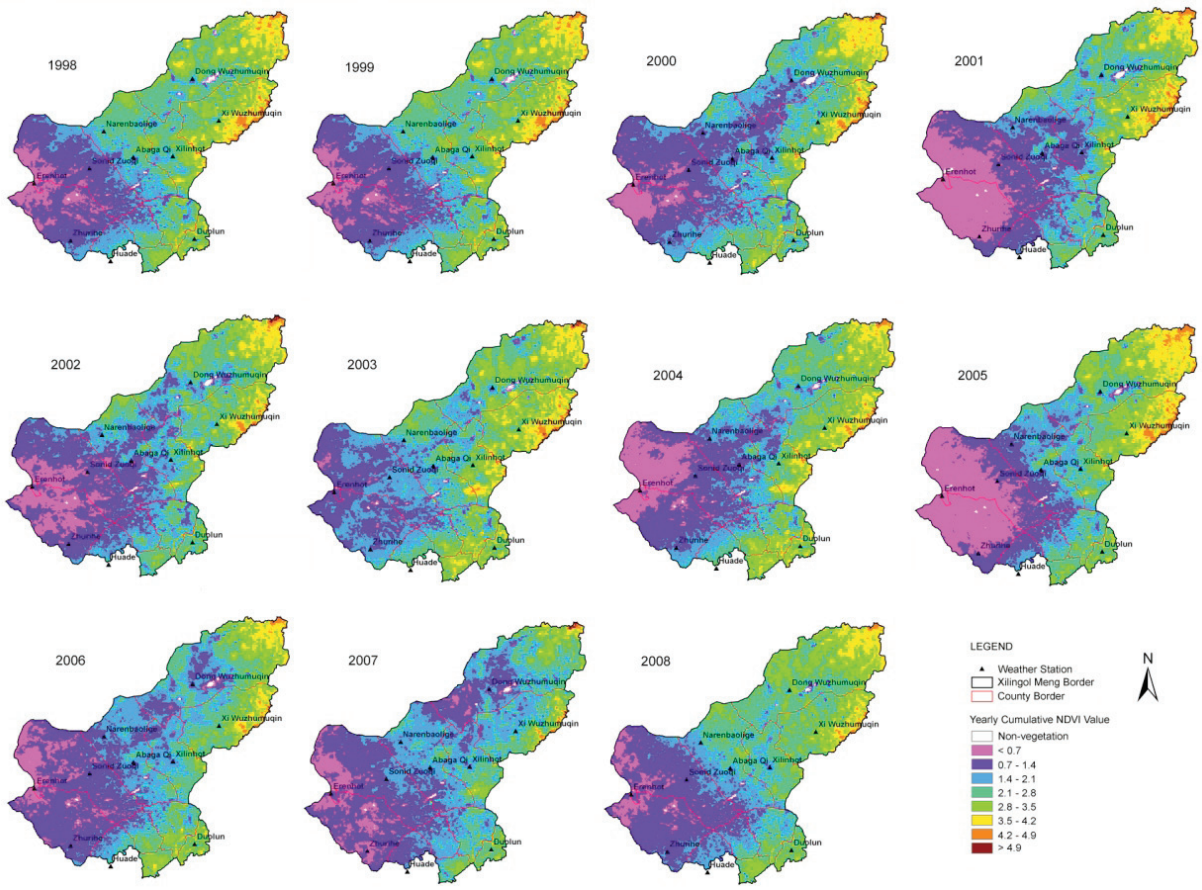

Figure 6. Temporal and spatial distribution of yearly growing-season cumulative NDVI value in Xilingol Meng.

Affected by climate change, with frequent drought events, vegetation in the study area experienced huge fluctuation from 1998 to 2008. Responding to the heavy drought of 1999-2001 and the heavy drought of 2005-2007, extra-low NDVI values appeared in 2001, 2005 and 2007, especially in Sonid Grassland located in the west of Xilingol Meng (Fig. 6). Bigger variation of yearly maximum NDVI occured in the northwest part of Xilingol Meng, including Sonid Youqi, Sonid Zuoqi, the middle of Abaga Qi, the north of Xilinhot and the west of Dong Ujimuqin Qi (Fig. 7-a). Huge variation of yearly growing-season cumulative NDVI occured in the whole Xilingol Meng, especially in the northeast part (Fig. 7-b).

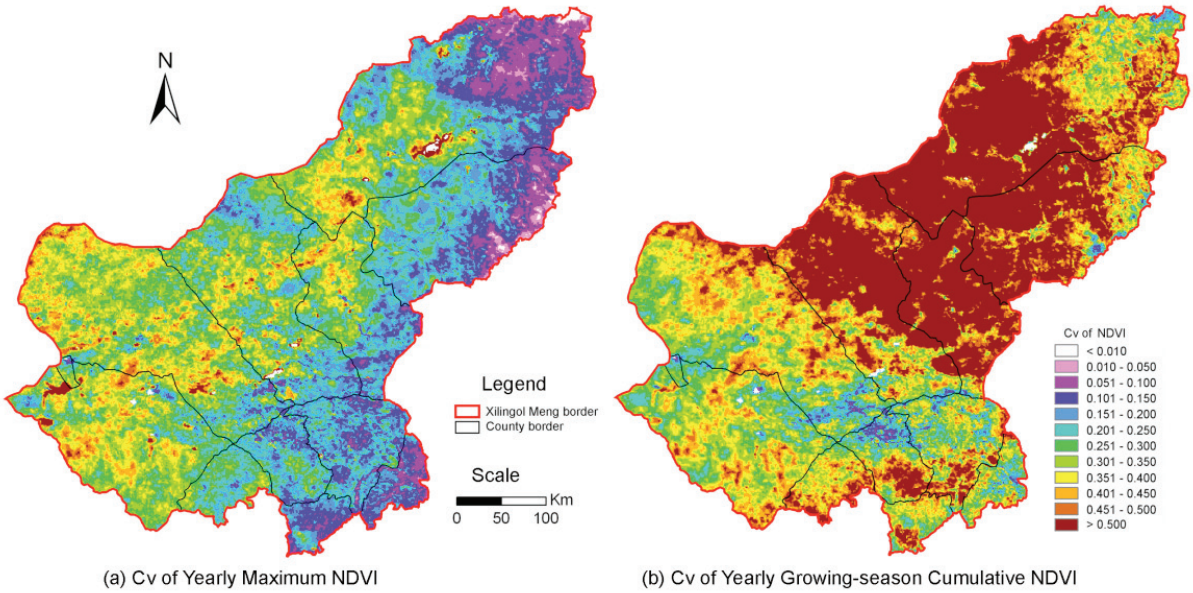

Figure 7. Spatial distribution of Cv (coefficient of variation) of yearly maximum NDVI (a) and yearly growing-season cumulative NDVI (b) in Xilingol Meng.

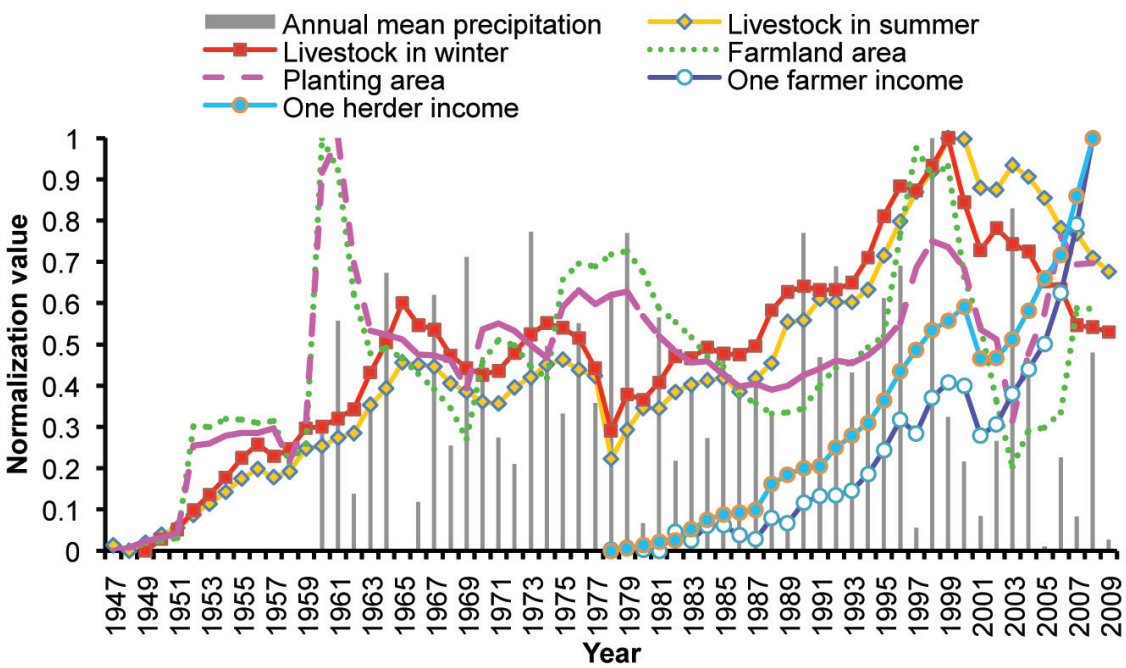

Figure 8. Change of livestock number, farmland area and income of farmer and herder in Xilingol Meng from 1947 to 2009

4.3 Impact of climate change on agriculture and animal husbandry industry

The population in Xilingol Meng increased to 1.010 million people in 2005 from 0.205 million in 1949. The huge rise in population resulted in great demand for food from livestock sector and farmland area. The number of livestock increased to 18.234 million heads in 1999 from 1.643 million heads in 1949. The farmland area increased to 305.56 thousand ha in 1997 from 141.41 thousand ha in 1949, and the highest value of 309.77 thousand ha was reached in 1960 (Fig. 8). However, due to unstable and bigger climate change with various climatic disasters, such as droughts and snow disasters, farmland area and livestock quantities experienced huge fluctuation. Climate change directly affected economic income of local farmers and herders by affecting the productivity of grasslands or farmlands, especially in 1977 with heavy snow disaster and in 1999-2001 with heavy drought. After the consecutive major disaster in the period 1999-2001， the number of poor peasants and herdsmen soared to 242.2 thousand people.

4.4 Climate change and local adaptation strategy

4.4.1 Settlement and building forage base

To avoid the adverse effect of snow disaster, occurring because of climate change, especially after the heavy snow disaster in 1977, local nomadic herdsmen chose to get settled and began to build houses and barns in large numbers for protecting their livestock from cold and hunger (Fig. 9-a). To alleviate drought effect and to adapt to drier climate, local government and residents changed their traditional ideas and practices and chose to utilize underground water resources to produce forage under irrigation conditions (Fig. 9-b). Especially the heavy drought and frequent sand-dust storms during 1999-2001 further promoted this transformation. The effective irrigation area in Xilingol Meng showed continuous rise in recent 10 years (Fig. 10).

a. Herdsmen choosing settlement b. Herdsmen planting corn for silage

Figure 9. Local adaptation strategy facing climate change in Xilingol Meng.

To enhance local adaptation ability to climate change and to rehabilitate and improve local fragile environment, several national projects also were implemented, including the project of ‘Returning Farmland to Woodland or Grassland’, the project of ‘Enclosure and Transferring’, and the project of ‘Wind and Sand Source Area Control’ around Beijing -Tianjin regions, etc. The intensity of bidirectional human activities between the ‘Returning farmland’ project and reclaiming forage base mainly determined the fluctuation of the farmland area: the planted area dropped after 1999 and quickly increased after 2003 (Fig. 8).

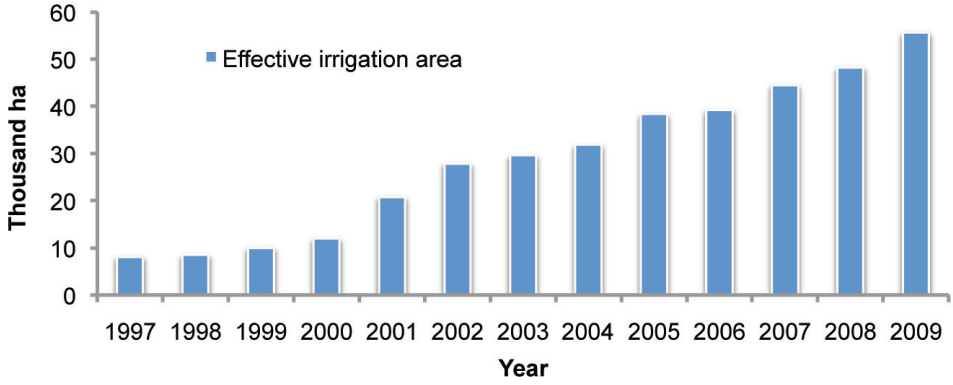

Figure 10. The effective irrigation area in Xilingol Meng in recent 10 years.

4.4.2 Fencing grasslands and reducing the number of livestock

Due to climate change and people's excessive demand for livestock products, the livestock number often exceeded the carrying capacity of grassland for a long time. Once heavy drought event or snow disaster occurred, many heads of livestock would die and this would result in huge economic loss. For example, the heavy snow disaster in 1977 caused the death of 3000 thousand animals; the heavy drought during 1999-2001 resulted in per capita income decrease of farmers and herdsmen of about 500 *yuan*. Facing this situation, local people chose to reduce the size of livestock and increase the rate of off take, under the support and encouragement of the national policy. This was most prominent in the period since 1999 (Fig. 11). Vast areas of grassland were fenced to prevent grazing, or permit seasonal grazing and rotational grazing for enhancing grasslands resilience to climate change.

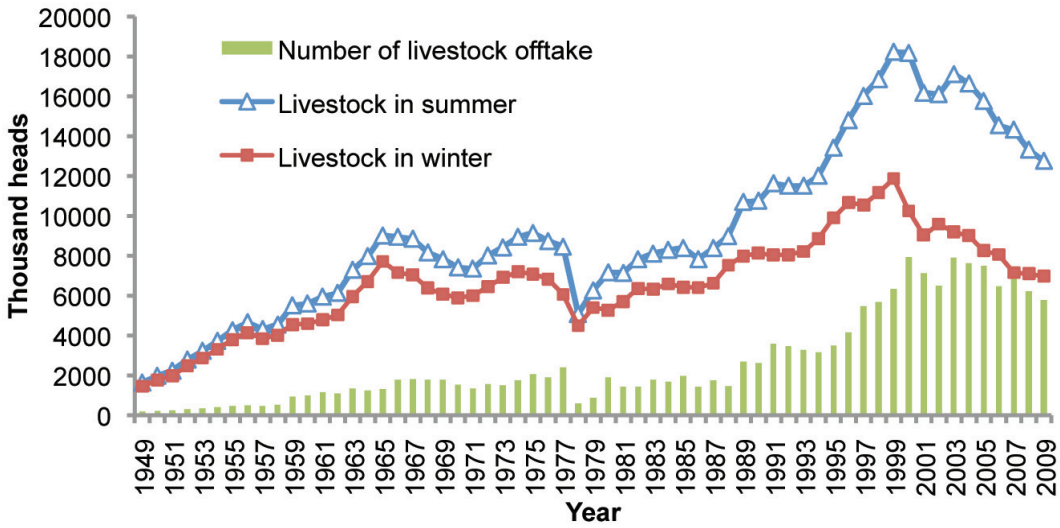

Figure 11. The livestock quantities and livestock offtake in Xilingol Meng in the last 50 years.

4.4.3 Selective emigration and adjusting industry structure

Climate change not only directly affects the primary industry, but also affects humankind. According to the principle of combination of ecology, production and life, and the union of

ecological, economic and social benefits, Xilingol Meng began to actively and steadily implement the large-scale ecological migration since 2002. Local people chose to actively adjust industry structure and to adapt to climate change. Farmers and herders in the most vulnerable regions, where the conditions were extremely deteriorated and were getting worst by climate change, were moved to some towns in the surrounding regions having better production and living conditions, to engage in new productive activities, and to engage in the secondary and the tertiary industry and to promote urbanization, especially in the recent 10 years (Fig. 12). The number of farmers and herdsmen transferred into the city to engage in secondary and tertiary industries reached 176 thousand by 2009. The new path of industrialization and the strategy of industry nurturing agriculture were basically established in the study area since 2000.

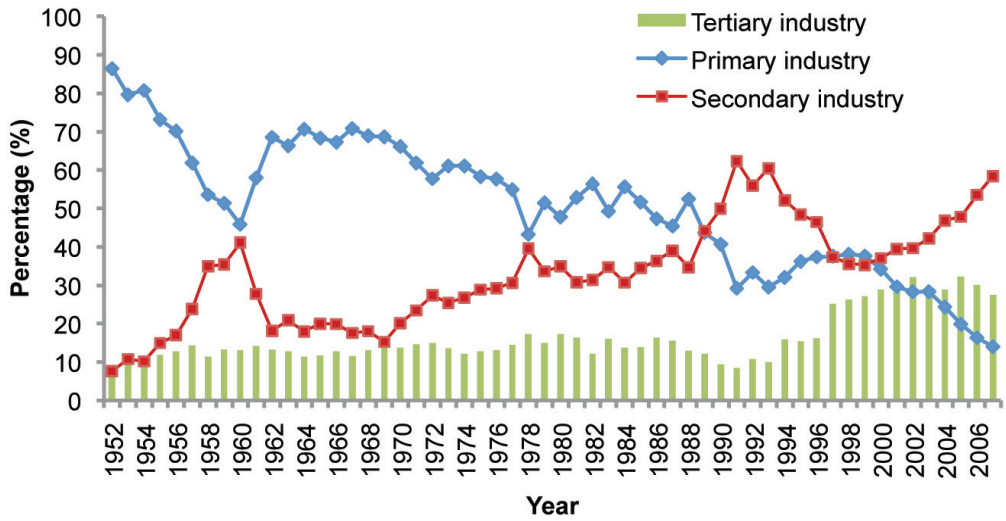

Figure 12. The industry structure in Xilingol Meng in the last 50 years.

5. Discussion and conclusions

The climate tended to become warm and dry in the study area during the last 50 years. The rate of air temperature increase in the study area was much higher than global warming trend of +0.13 $^{o}C \cdot 10\ y^{-1}$ during 1956-2005 (IPCC 2007). The study area had therefore become one of hotspots of global warming.

Local vegetation was significantly affected by climate change, especially the precipitation change. In the northwestern grasslands of China, precipitation has been widely recognized as a critical factor in controlling primary production (Le et al. 2007). Yearly cumulative NDVI value and yearly NDVI maximum showed huge variation in Xilingol Meng area, and there were two lower vegetation periods during the last 10 years. Climate change had important affect on local agriculture and animal husbandry industry, and eco-environment, through directly affecting the vegetation growth. The functioning of the grassland ecosystem or desert ecosystem was badly affected or even destroyed by human activities (Lovich andBainbridge 1999), but the relative contribution of human activities in affecting the response of vegetation to local climate change is not very clear.

Faced by drought disasters with strong dust-storms, the local authorities put forward a strategy of enclosing the grassland and selectively transferring population away from agriculture in the most vulnerable areas to other modes of employment in towns nearby. This was a great effort to

adapt to climate change and to improve the environment that was getting deteriorated because of combined effects of climate change and anthropogenic factors. Fencing grasslands and building forage production bases with irrigation and adjusting industrial structure were successful interventions.

Part of farmlands in the south of the study area were returned to natural vegetation and some trees or grass were planted there for protecting them from wind erosion, while new farmlands were reclaimed for producing feed in some inter-dune lowlands in the Otindag Sandy Land and even some places in Sonid Grassland utilizing underground water resources. These places are easily eroded by wind, where the loose sand material, lack of vegetation cover, and frequent strong wind coincide in spring. Large demand of irrigated forage base poses a big problem in this arid and semi-arid region with worse precipitation or runoff water supply. New wind erosion might get accelerated in these newly reclaimed farmlands due to disuse or improper sand protection.

Local adaptation strategy has made some progress under the support and encouragement of the national policy. Vegetation in Xilingol Meng get improved to certain degree (Yahui and Wei 2008) and farmer and herdsman income also increased after the severe drought (Fig. 8). The sharp increase in the income of farmers and herdsmen since 2001 was mainly because of such factors as increase in yield and price of agricultural products and agricultural wages (due to out-migration for work), increased remittance from outside, and increased non-agricultural income of local farmers and herdsmen benefiting from national policies. These policies played an important role in promoting adjustment in the industrial structure and reducing the size of livestock and farmlands. They included Grain Direct Subsidy Policy, Returning Farmland to Woodland or Grassland Subsidy Policy, Farm Machinery Purchase Subsidy Policy, etc. However, many of these policies need to be further clarified and confirmed. The direct subsidy to farmers was much more than to herdsmen, and this declined herdsmen's enthusiasm in responding to climate change to some extent. Moreover, local farmers and herdsmen are still passive executors; and they did not participate in the decision-making processes. Some of these and related social, cultural and legal problems are required to be seriously considered and solved as soon as possible to improve the resilience of the communities of the study region to the adverse impact of climate change.

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2. Adaptation of mountain villages to glacier loss – pilot research in western Tajikistan

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Abstract

Due to climate change all glaciers in Western Tajikistan are forecasted to melt off within a few decades. The World Bank regards Tajikistan as the most vulnerable country of all East European and former Soviet Union countries mostly due to low adaptive capacity. In 2010 a case study in two mountain villages in Zerafshan region showed high potential to increase adaptive capacity. Although people in both the villages did not refer to climate change when discussing the issue of their livelihoods before, each village developed comprehensive, ambitious and realistic short term and long term action plans to cope with climate change within a participatory research for development framework. The local strategies include (1) means to increase skills on conservation agriculture, irrigation, fruit trees, value chains, water catchments, crop diversification etc. on all relevant levels for both genders, (2) environmental adaptation, (3) economic alternatives and (4) management instruments. In one village, for the first , men and women joined in meetings and worked together. Realizing the risk to their livelihoods and the need for skills on value chains, the villagers showed readiness to improve women education and also women participation in decision making. Interviews later confirmed the commitment to collective action and gender equity. At present mountain villages urgently need awareness and capacity development for adaptation to climate change. The program should directly address the local communities as key players in facing an imminent climate-induced shock: the change from the current situation of plentiful water to severe water scarcity within one generation. There is a need for: (1) best practices for capacity building, collective action and collective management, (2) glacier specialists and experts to identify sites and plan construction of water catchments in adequate numbers, (3) technology packages for agricultural production and diversification on mountain slopes, (4) strengthening market value chains, and (5) measures to prevent loss of biodiversity on high altitudes. As the men folks migrate from mountainous areas due to low income in the agricultural sector, there will be dearth of male labor force for implementing adaptation measures. Making mountain agriculture more profitable will therefore be a prerequisite for successful adaptation program. Otherwise, abandoned mountainous areas will lead to a reduction in agricultural production, loss of biodiversity, and social and political tensions in the areas of resettlement. Research for development therefore should focus on local communities, expand socio-economic research, and develop agriculture-based strategy for dry mountainous areas for the sustainability of the communities living there.

Introduction

Tajikistan is regarded as the most vulnerable country to climate change out of 28 European and Central Asian countries, due to high sensitivity of its people to shocks and limited capacity to

adapt and recover (World Bank 2009). Tajikistan is country with high mountains; more than half of the land is at an altitude of more than 3000 m. Therefore, arable land availability per capita is very low (0.14/ha/capita; www.nationmaster.com). High population growth (from 7 million in 2010 to 11 million in 2050; UNPP 2010) will further reduce the availability of arable land per capita with adverse effect on food production and rural employment. In the rural areas of Tajikistan, poverty is very high; average around 75% (World Bank 2005). Mountain villages currently rely to a great extent on the remittances made by the out migrated people. Nearly one million Tajik migrants are reported to be working in Russia, remitting back money that may amount to nearly 30 to 46% of Tajikistan's GDP (Marat 2009). About 90% of labor migrants are male; this high loss of male labor force could be a great constraint in climate change adaptation in the mountainous region.

The rise in temperature in Central Asia is forecasted to exceed global average rise because of climate change (IPCC 2007). Shrinkage of glacier volume by around 32% is expected by 2050 (WBGU 2007). Albeit few contradictory assumptions (Seversky 2008), all glaciers in West Tajikistan might completely disappear by 2050 due to their small size (WBGU 2007; Tajik Met Service 2003). Stern (2006) and WBGU (2007) regard CA as one of the regions with the highest risk for conflicts due to climate change. Tajikistan is particularly vulnerable in this regard because of its high mountainous terrain.

Climate change affects the mountain villages mostly in three aspects: (1) Loss of water for irrigation due to loss of the glacier functions in delaying snowmelt, regulating water supply and adding melt water during growing period; loss of watering points on pastures; (2) Soil erosion on slopes, causing mudflows and necessitating much more efforts to feed livestock (grazing and forage collection); and (3) Loss of biodiversity (specially the medicinal plants and pollinators).

As glaciers are very small in the western Zerafshan region of Tajikistan, this area was selected for a case study. Two villages were selected as the research sites: one in Aini district (**Darg**, 2300 m) and the other in Gornaya-Macha district (**Imbef**, 2800 m). Both villages are located close to glaciers and have no access to tap water. They were also used to analyze the impact of a tradition of collective action. **Darg** is a member of *The Alliance of Central Asian Mountain Communities* (AGOCA) since 2003; villagers are well acquainted with collective action and collective funding. **Imbef** is not a member of any network, and has no tradition of any collective action except for the construction of a road during the Soviet era.

The purpose of the research was to provide information on the vulnerability of mountain villages to glacier loss and climate change (exposure, sensitivity and adaptive capacity), identify local strategies for adaptation to glacier losses, and develop terms of reference for a broad Research-for-Development (R4D) approach to implement these community-based strategies.

Methodology

Research was based on three assumptions: (1) Without early adaptation measures in high altitude villages decreasing harvest and increasing disasters will cause accelerated male labor migration, which makes adaptation of villages impossible; high migration can cause frictions in areas of immigration; abandoned high altitude villages increase the risk of disasters on more populated lower altitudes. (2) Mountain villages produce highly nutritious food in economic terms; a loss of these products would exacerbate food insecurity and also loss of , particularly on high mountainous rangelands (Körner 2003). (3) Funding for adaptation of small mountainous

villages will be small; therefore, highly effective, low-cost measures for adaptation should be needed.

ICARDA GIS maps and other sources were used for research to get a first overview. The research included two weeks of field work in each village, mainly based on participatory research methods. Social analysis systems (SAS 2) methods (Chevalier and Buckles 2008) were transformed into drawings and symbols to include illiterate participants and to enhance clarity. Additionally participants drew conceptual diagrams, pie and bar diagrams etc. on socio-economic and gender-related aspects.

Invitation to the working groups was mostly done at random, but the local focal point (village development committee VDC member) was instructed to include all age groups and households (**Imbef)**/household types (**Darg**) in each session with both genders. For specific tasks (e.g. medicinal plants; impact of labor migration) villagers with relevant background were invited. The focus of the participatory research was: (1) **socio-economic issues**, estimated income losses of different household types, impact of labor migration, workload etc. and gender; (2) **environmental aspects** related to climate change; (3) **local capacity** to adapt to climate change by identifying sustainable environmental and economic alternatives; and (4) **management issues** like including more stakeholders, role of VDC etc.

Several walks with villagers up to glaciers, pastures, fields, orchards and neighbor villages provided valuable information. Additionally 63 interviews (40 in **Darg**, 23 in **Imbef**) with individual villagers of all age groups, household types, and genders were conducted mainly on financial and migration aspects and villagers' personal readiness to contribute to collective action. In each village, a village meeting was conducted, where villagers presented the research results and the adaptation strategies for 2020 and 2050.

Five household types were identified: livestock production for market (H1, pastoral activity for market), crop production for the market (H2, farming for market), agro-pastoral production for market (H3, pastoral activity and farming for the market), subsistence production (H4, subsistence production), and female headed households (H5, female-headed household. Female-headed household was described as the poorest household.

The research sites (Darg and Imbef)

Darg relies on five glaciers: Chinchewara (identified by villagers in the beginning as the biggest and most important glacier; but in August 2010 it appeared to be only melting snow, frozen ground and a small lake), Luliyon, Mundj, Nihon and Takapar. **Darg** and the neighboring village Kazdon partly use the same glacier-river; since 2009 a conflict on other issues interrupted communication and cooperation to a high extent resulting even in building an own secondary school in Kazdon by collective action. To reduce the risk of escalation into a conflict on water resources the creation of a watershed adaptation committee is indispensable in the face of climate change.

Darg has 3013 inhabitants (including 500 labor migrants; 1265 children below the age of 18 years), 47 ha irrigated land (mainly potato and apricot; also faba bean and alfalfa), 20 ha pastures for grazing and collection of rainfed forage, 2000 sheep, 800 cattle, and 700 goats. The hospital, the secondary school and transport on demand are some additional sources of income. Within a pie diagram villagers identified all five household types: 40% H1, 30% H2, 13% H3, 15% H4 and

2% H5. The H3, H4 and H5 households lack male labor force. Average annual income is 3000 Somoni (4.45 Somoni = 1 US$). Forty households live in food insecurity; two wives of labor migrants are abandoned. Villagers invest up to 50% of their cash income in higher education of the children (subjects: medicine, languages, IT etc.). These children after education can support their families, but they usually do not resettle in the village. The hospital uses local medicinal plants to a high extent. The slopes are highly eroded, mudflows cause significant damage. Due to increase in the number of small rain showers during summer and poor drying techniques women cannot properly dry apricots for storage over the year. So, the production was not economical Women carry the main workload, also concerning fields, orchards and forage collection; they stay with cattle on summer pastures for months. They are part of the decision making at the household level.

Imbef (56 households) relies mainly on Andervash and Roswin glaciers and to a very small extent on the bigger Korvin glacier. Roswin glacier is broken horizontally on top and is melting off fast, but still much bigger than Andervash glacier. One big part of Andervash crashed in summer 2006, and the remaining part is already broken horizontally. Andervash river is the only river for Andervash village (18 households) and due to an approved channel project in the future an additional water resource for Ruvind village (22 households). Ruvind at present relies on a small well only and lacks irrigation water. In Imbef, rivers from Andervash and Roswin glaciers flow into Korvin river, on which the downstream villages Dasht (300 households) and Rundj (60 households) rely.

Imbef has 192 inhabitants (130 are younger than 18 years of age; 1/3 of the male adults are labor migrants), 11 ha irrigated land (mainly potato; faba bean), 2 ha rainfed barley/wheat, 27 ha area for rainfed forage collection, and 14 ha remote summer pastures, 500 sheep, 40 cattle, and 380 goats. Two out of 56 households rely mainly on harvesting medicinal plants on the slopes and selling them to a Chinese Company in Istarafshan and to hospitals in the region. The secondary school (up to 9th grade) and some transport on demand are the only additional sources of income. Within a pie diagram, villagers identified 10% H1, 40% H2, 50% H3 type households. According to villagers in the beginning of the research no household type faces lack of male labor force. Average annual income is 9500 Somoni (1 US $= 4.45 Somoni), but cost of living is high due to high altitude and remoteness. No household lives in food insecurity. Work outside the house is entirely done by men except during harvest time. Women are not involved in decision making and official ceremonies; within this research they participated for the first time in the decision making process.

In both the villages, even the employed inhabitants mainly rely on agriculture because their salaries are low (nurse: 60-70 Somoni; teacher 150-300 Somoni). Both the villages depend completely on pollination services of wild pollinators, but do not care for their habitats and are not aware of climate change risks specifically for pollinators (FAO 2008).

Vulnerability assessment

Exposure to glacier loss and climate change: Though both villages have access to satellite TV, they were not aware of their exposure to glacier melt and climate change. Only the forester in Darg reported that the smallest glacier (Takapar) would melt-off rapidly. In both the villages people stated they would have enough strong glaciers, there would be no problem due to climate change. Some villagers even asserted that glaciers would grow. Villagers did not differentiate between temporary snow cover and glacier. In Imbef, and the neighboring village Andervash,

various influential villagers declared that God would prevent the melt of their glaciers. In both the villages, nobody had checked the glaciers for long. Local knowledge on glacier condition in Imbef was based on a visit some 30 years ago. To go to a glacier requires a vehicle and then at least one day for walking; villagers do not go just for a walk. Villagers who participated in the walk to the glaciers were shocked at the current situation. The VDCs at once appointed a villager to regularly check all glaciers. In Imbef the head of VDC immediately informed neighboring villages and the local Member of Parliament about the critical situation.

In both the villages, participatory working groups drew trends in precipitation and water consumption for different agricultural products in a diagram for the whole year. They realized their dependency on additional water from the river. A map on glacier melt (Tajik Met Service 2003) and the function of three glaciers were discussed (delay of snow-melt down flow from March/April to May/June; balance of yearly and monthly down flow, additional water during growing season). Then the same groups drew a yearly diagram (Fig.1 for Imbef), which showed present amount of water in the rivers starting on low level with slight increase in March/April, steep increase starting in May and peak in August. The second line showed amount and months of water extraction for irrigation. It started in May, had a peak in August and ended in September with potato harvest. Peak of consumption curve was less than half of the availability curve. The third curve was drawn to indicate the estimated amount of water in the river in 2050 in a scenario without glacier and without adaptation measures (i.e. *scenario 0*). This curve showed an increase due to early snow melt already in March, peak of water availability in April. The curve for water availability in *scenario 0*, depending on seasonal precipitation, was much below the demand for irrigation. Realizing this gap, the participants asked and discussed effects of climate change also on slopes, forage, watering points, medicinal plants etc.

Sensitivity to glacier loss and climate change: Based on these maps of water availability and demand, the working groups drew a yearly activity calendar and marked which activities of men and women would become more difficult or impossible in *scenario 0*. Then villagers identified in a drawing the value of all agricultural cash products and all agricultural products for subsistence and then estimated the loss in *scenario 0.*

First villagers identified their sources of cash income and drew the symbol in a size according to importance with black pencil (e.g. Fig. 2). In **Imbef,** they drew a huge potato, followed by meat (about 1/5 of potato size), remittances (even smaller) and salaries (in the case of teachers) (smallest). With blue pencil they ranked the products for own consumption. Thirdly, they discussed and crossed out with red pencil the amount of loss of each product in *scenario 0.* Potato as cash crop was crossed out by 50%. For meat first the men did not see a loss, but when women argued that forage had to be crossed out by 60-70%, the men crossed out 50% of meat as well. Potato for own consumption they crossed out only by 25%, as even with reduced water they would irrigate the potato fields for their own use. Also the other products for own consumption had been significantly crossed out: dairy products (50%), wood (60%), vegetable (50%), meat for own consumption (40%), fruits (60%) and medicinal plants (70%). Only rainfed barley and wheat showed an increase due to increased land for these crops, and remittances, salaries and handicraft were not affected.

The first reaction of men to this scenario was: Then we all have to go to Russia. Women insisted that all families have to develop alternatives within agricultural production, mainly using water more efficiently. In both villages participants were strongly committed that it is the task of the present generation to reduce such risks for their children and grandchildren as soon as possible.

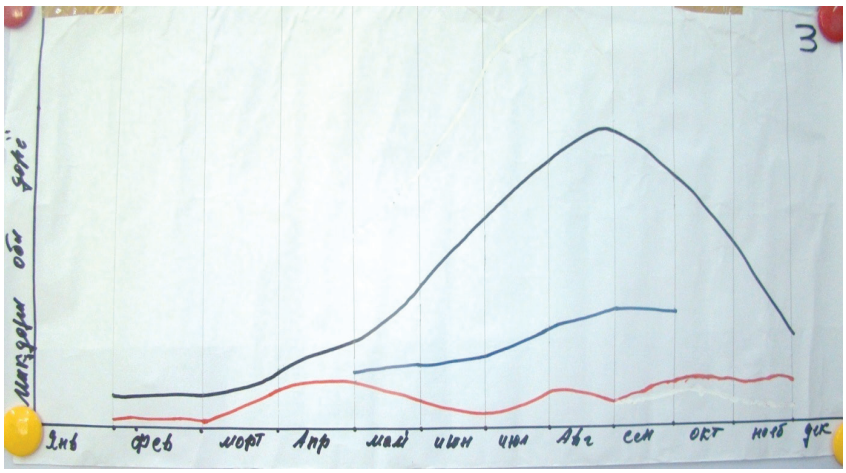

Figure 1. Round the year water availability in the river now (top curve) and in scenario 0 (bottom curve); and water demand for irrigation (central curve) based on group discussions with villagers in Imbef.

Before this research, labor migration was not identified as a problem in both the villages (but was considered as very beneficial), but as sensitivity and adaptation capacity of Tajik mountain villages is highly influenced by lack of male labor force, labor migration was made a topic for group discussion.

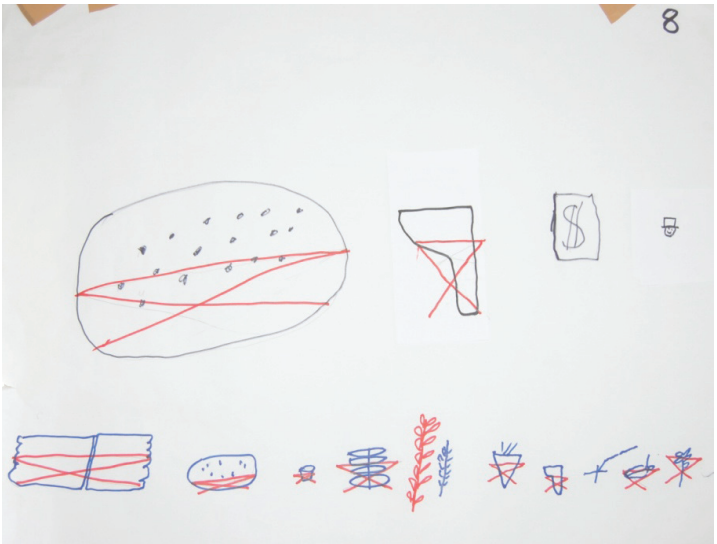

Figure 2. Loss of income and products for own consumption in scenario 0 - Imbef.

In **Imbef**, villagers first stated they had only nine labor migrants out of 192 inhabitants, men would take over all work of labor migrants. But bar diagrams prepared separately by groups of women and men showed very different results; a high share of additional workload was already now on the adult women. According to the participants, this issue was discussed for the first time. In **Darg** H4 production households had up to four labor migrants in one family, H5 households up to three. Until 2000 only heads of household migrated, but later also sons followed as their fathers guaranteed a safe situation for them. Only a few villagers needed remittances for daily expenditures like food. Both villages, specifically **Imbef,** preferred yearly transfer and used remittances for big investments like building a house or weddings. Labor migrants from

Imbef mostly went to Siberia, as there payment is higher. Average income per labor migrant in **Darg** was 200 Dollar per month, in Imbef between 1500 and 4000 Dollar per six months. Both villages realized, during the course of this research, the possibility of using labor migration as an opportunity to gain new skills relevant for agricultural diversification and climate change adaptation.

Within *Timeline* (SAS 2), villagers identified the increase of male and female labor migrants from 1990 to 2010 and the reasons for it. The reasons identified as drivers for labor migration included political events (breakdown of Soviet Union, Civil War, years without salary-or governmental payment for agricultural products) and agricultural problems like a potato pest, less rain, mudflows, brucellosis in livestock and food insecurity. In **Darg** labor migration was common already in the 1990s; labor migration for investments in a better life (new house, etc.) started in 2000. In **Imbef** labor migration started in 2001, because population grew fast and they had to build more houses; later brucellosis and in 2008 avalanches became a main driver; in 2010 also the wish to build a new house.

In both the villages, temporary labor migrants explained that for the hard labor needed for building water catchments or terraces they would migrate for in winter and contribute to collective action in summer. Specifically in **Imbef**, participants stated that labor migrants would make high contribution in cash to adaptation measures. Both the villages did not confirm Glenn's research on abandoned wives of labor migrants (Glenn 2009) because according to the villagers the remittances were transferred regularly by the immigrants to their wives and there were no abandoned wives in **Imbef** and only two in **Darg**.

Adaptive capacity

Adaptive capacity was assessed in consecutive steps identifying first the environmental and economic alternatives and activities, which would increase or decrease water scarcity, erosion on slopes/mudflows and loss of biodiversity (*Force Field*), then the necessary skills, and then the stakeholders (*Stakeholder Rainbow*). Finally, participants drew conceptual diagrams of the village including all alternatives, targets, stakeholders and innovations to be achieved by 2020 and 2050.

Before the drawing for *Force Field* started, in both the , for more than two hours, villagers discussed various options for environmental and economic adaption, partly based on photos taken during the walks to the glaciers. Whereas in **Darg** (tradition of collective action) the participants focused on environmental and economic alternatives in *Force Field,* in **Imbef** (individual farmers) they worked only on economic alternatives. An additional session in **Imbef** identified and compared environmental adaptation measures (*Ecologic Dynamics*).

In **Imbef** men's group and women's group identified different economic alternatives and different rankings in ***Force Field:*** The men's group focused on diversification of livestock: sheep (including wool processing), poultry, starting of rabbit and marmot production, and reduction of cattle. Also oilseeds and barley/wheat (both rainfed) were identified, whereas potato appeared only as a harmful income source, which should be reduced. The women's group ranked wool processing, poultry, rainfed oilseeds, medicinal plants and rainfed wheat/barley very high. They drew middle sized columns for improved irrigation for potato and faba bean and for dairy products, but on the other hand marked cattle as harmful, which stimulated a vivid discussion with the men's group.

For ***Ecologic Dynamics*** men's and women's group ranked seven measures: (1) water catchment, (2) terracing fields, (3) improved irrigation, (4) land leveling, (5) reforestation and making terraces on slopes, (6) sustainable wood harvesting and (7) 'school garden as research site'. Men (in-charge of collecting wood and clearing after mudflows and avalanches) gave highest priority to sustainable wood harvesting and second to stabilizing slopes in the order: 6,5,1,3,2+4,7; women gave highest priority to improved irrigation in the order: 3,1,6,4,2,5,7 for the above seven measures. Specifically, *Force Field, Ecologic Dynamics* and the assessment on workload showed the high importance of involving women even if this is not in line with the local traditions. Men and women identified the highest number of positive side effects for 7 ('school garden as research site') and gave second rank for 1 (water catchment development). They argued that by changing the task of the school garden from production to research site, the youth would become interested in agricultural studies, which at present would be regarded only as the hard labor of fathers and grandfathers. Also, definitely all households would benefit from new knowledge. Some old and very skillful villagers volunteered themselves at once as teachers of effective methods they learnt and practiced since their youth and which are not common anymore. Participants in both villages declared to start the school garden as research site in 2011 and asked for seeds and improved irrigation equipment. 'School garden as research site' should be included in a broader R4D approach, as it is a multi-purpose low-cost measure to increase impact. With a view to identify options, the villagers first reviewed the skills they already had and the skills they needed to acquire in order to adapt to climate change. Both villages focused mainly on the potential of their male youth, who should in future also study subjects like agriculture, engineering for water catchment construction, irrigation and oil processing.

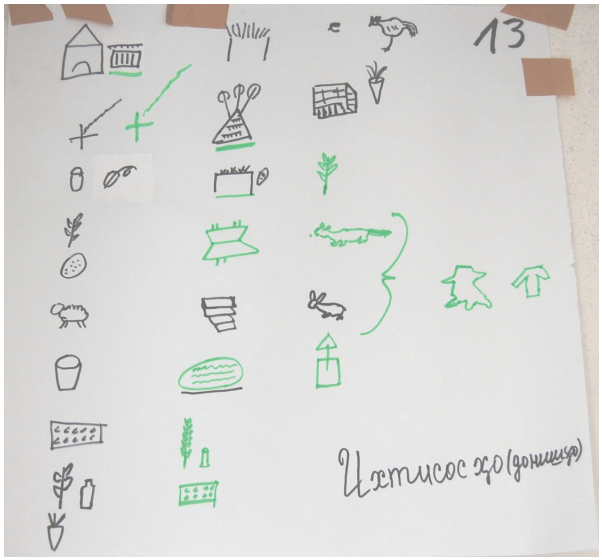

Figure 3. Available skills and demand for additional skills to adapt to climate change – Imbef.

Villagers were very proud on the skills they have and differentiated them very much from those that needed to be acquired by different use of colors forming 5 different groups , for example in **Imbef** (Fig.3): (1) "already sufficient skills": processing fruits and vegetables, growing potato, cattle and small ruminants, making dairy products, vegetable production, sustainable wood harvesting, terracing slopes; they stated that they can improve their skills concerning poultry and greenhouses themselves; (2) valuable skills, which allow to start activities, but later require improvement: to use the school garden as a research site, stabilizing slopes, land leveling; (3) limited local knowledge, high demand for professionalized youth: handicraft, making carpets, oilseeds and oil production; (4) no skills in the village, high demand for experts among youth: improved irrigation, production of marmots (fat for medicinal purposes), rabbit production (for

meat, fur, dresses) and fruit tree nursery; (5) no skills available in the village, high demand for professional among youth, but villagers can contribute by labor and manual skills: building a water catchment.

In **Darg** participants proudly reported on the potential of graduated relatives living in Dushanbe. Asking for experts, trainings and projects was not an issue in **Imbef** and only a few participants in **Darg** intended to fill the gap from outside sources. In both villages participants confirmed their readiness to invest more in education. In **Darg** participants easily decided that some girls should study textile design in Dushanbe to adapt local handicraft skills to the demands of a larger market, whereas in **Imbef**, after a controversial discussion, they identified the option that a married lady might go for studies accompanied by her husband.

Stakeholder Rainbow: For both villages it was difficult to identify stakeholders like research or development organizations, labor migrants, students, the school, experienced old farmers, etc. Both villages first refused to consider the neighboring villages using water from the same glaciers also as stakeholders. In **Imbef** an extremely controversial discussion arose between some middle- aged participants, who refused to share water with any other village, women focusing on improved irrigation and elders insisting on the need to live in peace with neighbors. In the end both villages included neighboring villagers as stakeholders, decided to initiate a watershed development committee and identified the VDC as the coordinating player for climate change adaptation in the village.

In **Imbef** the readiness to cooperate with neighboring villages and to develop a common climate change adaptation plan with all villages of the watershed and all relevant stakeholders was much higher than in **Darg** and even resulted in immediate additional meetings with elders in Andervash, invitation of elders from other villages to the village meeting presenting the adaptation strategy for **Imbef** and a briefing of the local Member of Parliament. **Darg** did not invite Kazdon villagers to the village meeting and also lacked a strong leader like the highly engaged and charismatic head of VDC in **Imbef**. Leadership-training should be part of a R4D-project.

The conceptual diagrams for 2020 and 2050 included clear targets, e.g. in **Darg** one water catchment built by 2020, two slopes stabilized by 2015, diversification of economy and increase of processed products, significant number of graduate agricultural experts among the youth, and 'Darg training center for adaptation of mountain villages to climate change' opened. In **Imbef** targets to be achieved by 2020 included: water catchment together with Andervash built, improved irrigation on 2 ha along Andervash, nursery established, 50% of slopes around the village stabilized, diversification of economy (poultry, rabbit and oil production, planting of medicinal plants), establishment of watershed-development-committee and establishing contacts with more stakeholders.

Discussion and conclusions

The case study showed that Tajik mountain villages are highly exposed and sensitive to glacier melt-off and climate change, but they also have high potential to adapt if timely and adequate research and development support is made available to them. Fast glacier melt and increasing labor migration necessitate urgent action on local capacity building. Increasing income and adaptation must be pursued simultaneously. To cover the full potential of the village, women have to be involved in the initial participatory development of local adaptation strategies even if this was not according to local traditions. To support comprehensive local adaptation processes

in the high altitude areas was highly important to reduce social conflicts, food insecurity, and disasters on more densely populated areas at lower altitudes. It should therefore be a national priority.

Based on the results of this case study, a broader '*research for and with development'* project should cover different mountainous agro-ecosystems to develop an adaptation support strategy for villages, development agencies, NGO and local authorities. Socio-economic and livelihood analysis should be supplemented by research on mountainous land and water conservation, value chain development, and broad capacity development on village and NGO-level. Focus should be on strengthening collective action and mobilizing the full potential of villages. Experienced NGO should be trained in the participatory approach used in this case study for a broad capacity building process; these extension partners should work also on broad takeover of realized and evaluated adaption options. Additionally research on wild pollinators is necessary, as these mountain villages completely rely on wild pollinators, which are highly endangered by agriculture and climate change, but of tremendous importance for adaptation of agro-ecosystems to climate change and for profit-yielding mountain agriculture.

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3. Performance assessment of farmers' management for tertiary level irrigation in arid region – a case study of irrigation improvement in Egypt

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Abstract

Arid and semi-arid regions are characterized by little rainfall and severe water scarcity that is being exacerbated by climate change. A trend for decrease in rainfall is affecting the overall hydrology and water resources in the arera. A typical example is the Nile River Basin where runoff variability in upstream countries is of great importance to the sustainable development of downstream countries such as Egypt. The increase in water demand of upstream countries in the Nile Basin, coupled with the impacts of climate change, can affect the availability of water resources for the downstream countries. Egypt, therefore, faces the challenge of dealing with reduced availability of water resources by applying policies to improve the performance of the water supply system and its development. The Irrigation Improvement Project (IIP) is one of the most important attempts in Egypt to implement more effective on-farm irrigation technologies for modifying traditional irrigation system and saving water by improving the existing delivery system in the Nile Delta over a total area of about 1.05 million ha by 2017. This study aims to evaluate the irrigation system after the improvements brought about by IIP and to determine its impact on water delivery performance on tertiary canal and farmer's practices in the field by comparing with other unimproved system using a set of performance indicators. Results show that the IIP project generally has a positive effect on farmer's practices. The duration of irrigation has been reduced by about 30% - 50% for major crops at different locations in the irrigation system as compared to the unimproved system. In addition, there has been an increase in the production of main crops by about 6% - 20% with the improved system. This can partly be contributed to the formation of water user associations and their successful management and operation of water supply and distribution network.

1. Introduction

Water is becoming increasingly scarce worldwide. Aridity and droughts are the natural causes for scarcity of water, resulting from natural and human factors, which are also causing the climate change (United Nations 1992). Africa is one of the most vulnerable regions in the worlds to climate change and climate variability, a situation aggravated by the interaction of 'multiple stresses', occurring at various levels, and low adaptive capacity. Climate change is likely to aggravate water stress currently faced by some countries in the Nile Basin, while some countries that currently do not experience water stress, such as Egypt, will also soon face the risk of water stress. Possible consequence of climate change for water availability in Egypt is the reduction in

the flow of the Nile River and the intrusion of seawater into coastal aquifers and, in addition, a sea level rise in the Nile Delta.

One of the problems associated with the climate change, to be faced by all the Nile Basin countries, is its impacts on precipitation and flows in the Nile Basin. The precipitation is predicted to decrease slightly over sub-catchment of Blue Nile (-5%) (Eman et al. 2009). Although, the Blue Nile constitutes around 10% of entire Nile Basin area, it contributes about 60% of the total mean annual flow of the basin measured at High Aswan Dam in Egypt. The changes in flow may have a high impact on trans-boundary Nile River basin where there is competition for water between stakeholders from different economic, political, and social backgrounds and the runoff variability in the upstream countries, such as Ethiopia, can affect the downstream countries such as Egypt.

The climate change is also going to affect Egypt adversely because of is the potential impact on the rise in the sea level in the Nile Delta. It was found that a one-meter rise in sea level would destroy weak parts of the sand belt, which is essential for the protection of lagoons and the low-lying reclaimed and other valuable agricultural lands. In addition, intrusion of saltwater will affect freshwater quality and so the health of freshwater fish (UNEP/GRID 2000). Therefore, the government of Egypt is promoting the cultivation of paddy rice in the vulnerable areas in Delta using fresh water. The latter however consumes about 25% of Egypt's quota of water from the Nile flow. Thus, there is a need for sustainable availability of water resources and water saving technologies, particularly in the face of climate change.

The Irrigation Improvement Project (IIP) of Egypt is one of the most important attempts in country to implement more effective on-farm irrigation technologies for saving water. IIP is a national project that aims to rehabilitate as well as improve the exiting delivery system and improve the old irrigation system in the Nile valley, especially in North Delta, over a total area of about 1.05 million ha by the year 2017.. The general objectives of the IIP are to improve the irrigation water management and water distribution among the farmers, to increase crop production. The major components of the IIP are: renovation and improvement of branch canals, including modular discharge regulators at the head of branch canals, cross regulators and downstream water control structures (Fig.1), conversion from rotational to continuous flow; tertiary system level (*Mesqa*) improvement by conversion of low level to raised canals or pipelines and also set-up of water user associations (WUA) among farmers. El-Kashef (1995) stated that the aim of improving the tertiary system is to ensure equity of water delivery among the farmers throughout its length, reduce distribution losses from the system, improve farmers' control over water use, and save land. El-Quosy (1997) discussed the advantages of the replacement of multi-point lift by one point lift at the head of each tertiary level, which would improve the hydraulics of the flow by minimizing its sedimentation and scouring. This study presents the evaluation of irrigation improvement system in old land, its impact on water delivery performance in farmers' fields and saving water in irrigation system. It was carried out to evaluate the performance at the tertiary canal level by comparing with other unimproved system in 2003 and 2004 in Wasat command area in the Nile Delta.

2. Materials and methods

The study area: The Wasat area is sub-catchment area in city Kafr El-Sheikh, which is located on the northern edge of the middle Delta and extends to the limit of the irrigated area bordering Lake Burullus. The command area is fed from the tail reaches of main canal (Meet Yazid), as shown in Fig. 1.

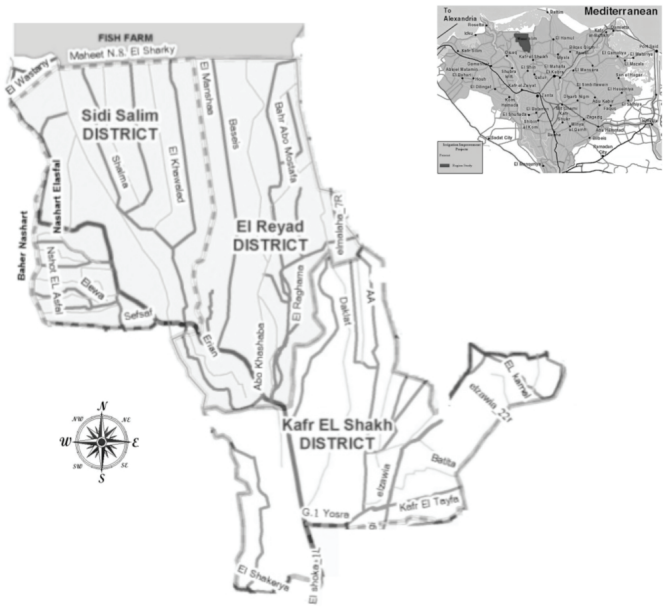

Figure 1. Layout of El-Wasat command area.

This catchment area is famous for its rice production, contributing 40% of the total production in the country. Due to its location at the tail of the feeder irrigation system, El-Wasat command area suffers from inadequate water supplies. This problem is exacerbated by the tendency of farmers to plant more paddy than what the government had allowed. In this study, two branch canals were selected for evaluation: an improved (Daqalt) and an unimproved (Basis) branch canal. Six tertiary canals were selected on each branch canal, located at the head, the middle, and the tail end. Six farmers were selected at each tertiary canal. (Fig. 2).

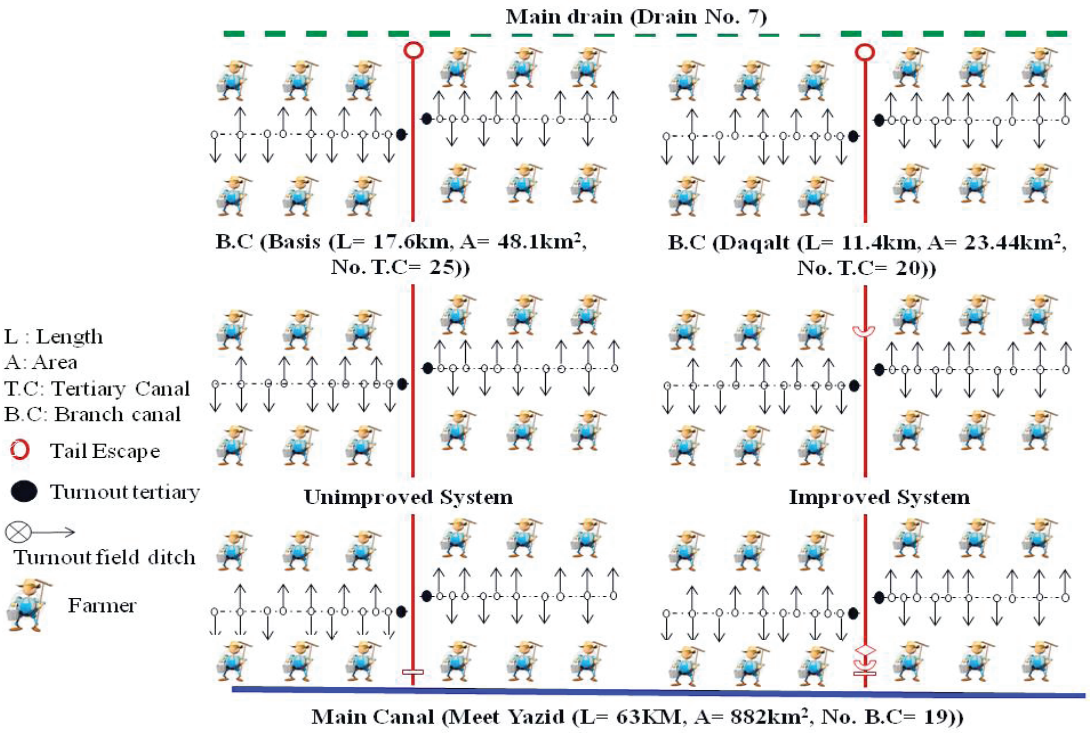

Figure 2. Schematic outline of water delivery canals in study.

***Performance indicators*:** To evaluate the sampled irrigation system the indicators used are: (i) water delivery performance of the tertiary canal, (ii) water delivery performance of the field system, (iii) irrigation hours per unit area among farmers, and (iv) crop yield. Water delivery performance at tertiary canal level was determined according to the indicators of adequacy, efficiency, equity, and dependability. From the computed performance indicator values, performance was classified as "good", "fair", or "poor" according to performance standards given by Molden and Gates (1990).

a. ***Adequacy Indicator***: Distribution of required amount (P_A).
The objective of adequacy states the desire to deliver the required amount of water over the command area served by the system.

$$PA = 1T\ T1RRPA \quad \ldots\ldots\ldots\ldots\ldots(1)$$

where $PA = QDQR$, if PA >1 … PA = 1 OR if PA <1 … PA

b. ***Efficiency Indicator:*** Conservation of water resources (P_F)
The objective of water distribution efficiency embodies the desire to conserve water matching water deliveries with water requirement.

$$PF = 1T\ T1RRPF \quad \ldots\ldots\ldots\ldots (2)$$

where $PF = QRQD$, if PF >1 … PF = 1 OR if PF <1 … PF

c. ***Equity Indicator:*** Distribution of fair amount (P_E)
If equity were interpreted as spatial uniformity of the relative amount of water distributed, then an appropriate measure of performance relative equity would be the average relative spatial variability of the ratio of the amount distributed to the amount required over the time-period of interest.

$$PE = 1T\ TCVRQDQR \quad \ldots\ldots\ldots\ldots(3)$$

d. ***Dependability Indicator:*** Uniform distribution over time (P_D)
An indicator of the degree of dependability of water distribution is the degree of temporal variability in the ratio of amount distributed to amount required that occurs over a region.

$$PD = 1R\ RCVTQDQR \quad \ldots\ldots\ldots(4)$$

where ; a_t : Area of irrigation block; Q_D : Distributed amount; and Q_R : Required amount; = Spatial coefficient of variation of ratio over the region *R*; = Temporal coefficient of variation of ratio over the time *T*;

***Irrigation hours per unit area*:** This indicator is related to evaluation of the event of field irrigation by farmers. Actual hours of the irrigation were recorded, and these data were analysised to assess the average irrigation duration per unit area for common crops during irrigation season. These data were also analysed to determine the incidence of night irrigation, and a comparison was made between head, middle and tail locations of tertiary canal level.

***Farm producation*:** The main benefit predicted from IIP is an increase in agricultural producation and thus the farm income. This project assumed that there would be increases in the yields of the major crops, especially paddy field, concentrated mainly in tail areas as water distribution becomes more equal.

Table of evaluation criteria of each indicator

Measure	Performance Classes		
	Good	Fair	Poor
P_A	0.90 - 1.00	0.80 - 0.89	< 0.80
P_F	0.85 - 1.00	0.70 - 0.84	< 0.70
P_E	0.00 - 0.10	0.11 - 0.25	> 0.25
P_D	0.00 - 0.10	0.11 - 0.20	> 0.20

Data collection: The data on the selected tertiary canals and fields were collected on four main sheets: (i) *Calibration Sheet*: it describes the pump characteristics in lifting point, (ii) *Lifting Point Operation Sheet:* it describes the data of pump operation in lifting point, (iii) *Irrigation Time Sheet*: it describes the data of irrigation time for selected fields in each tertiary canal, and (iv) *Cropping Pattern Sheet*: it describes the data on cropping pattern. Water Management Research Institute (WMRI) of National Water Research Center (NWRC) in Egypt was responsible for collecting the data throughout the irrigation seasons 2003-2004 of this study as per the time schedule shown in Table 1.

The predication method for crop water requirement was used owing to the difficulty of obtaining accurate field measurements. CROPWAT software, prepared by by FAO for windows, is a programe that uses the Penman-Monteith methods (FAO 1992) for calculating reference crop evapotranspiration. These estimates were used in the calculation of the crop water requirements and irrigation scheduling.

Table 1. Field data collection for tertiary canal and farmers practices by NWRC's staff

No.	Sheet	Methodology	Location	Time
1	Calibration Pump	Ultrasonic Flow meter	Lifting point	Seasonally
2	Pump Operation Data	Questionnaire	Lifting point	Daily
3	Field Irrigation Data	Questionnaire	Selected fields	Daily
4	Crop Pattern Data	Irrigation districts	Study region	Seasonally

Results and discussion

Cropping pattern and values of Q_D and Q_R : The major crops in the study area for summer season are rice, cotton, and maize, while for winter season are alfalfa, wheat, and sugar beet. Rice crop is by far the most important for the farmers and for the country as a whole. For farmers, rice is a cash as well as a subsistence crop, whereas for government, it is the highest water-consuming crop in the the Nile Delta. Table 2 shows the precentage of area under different crops for the selected tertiary canal at the head, middle, and tail locations for improved and unimproved branch canals.

Table 2. Irrigated cropping pattern for selected tertiary canal in the irrigation seasons 2003 and 2004. The data show % area under the indicated crop, in each growing season

Crops	Improved system						Unimproved system					
	Head		Middle		Tail		Head		Middle		Tail	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Alfalfa	41.6	40.6	42.2	31.5	60.6	31.1	19.0	19.0	28.8	29.2	27.6	27.6
Wheat	54.6	49.4	36.4	32.1	20.2	34.1	20.9	20.9	38.6	44.6	16.9	16.9
Sugar Beet	3.8	-	21.4	-	19.2	2.3	7.0	7.0	25.2	19.5	52.7	52.7
Cotton	24.2	42.2	29.2	31.3	23.0	25.6	23.0	23.0	28.0	32.2	34.0	34.0
Rice	75.8	47.8	67.5	61.7	63.5	61.8	23.9	23.9	50.4	53.6	47.1	47.1
Maize	-	10.0	3.3	7.0	13.5	12.6	-	-	10.4	8.8	16.1	16.1
Citrus	-	-	-	-	-	-	53.1	53.1	-	-	-	-
Others :summer	-	-	-	-	-	-	-	-	11.2	5.4	2.8	2.8
Others: winter	-	10.0	-	36.4	-	32.5	-	-	7.4	6.7	2.8	2.8

The rice crop occupied about 50% - 70% of cropping pattern in the summer season and next was cotton crop (about 25% - 40%) . In the winter season, the wheat crop occupied about 20% - 50% and alfalfa and sugar beet about 25% to 60% of the cropping pattern. The proportion of main winter crops in improved tertiary canals decreased and changed to other crops in the next season, except at the tail location, while for summer season, the cropping pattern remained more or less stable except at the head location. For the unimproved system, the cropping pattern did not change. This was because there was water control and management through the improved system. It led farmers in head and middle location to reduce the area under major crops.

The calculations of total amount of pumped water and total water requirement (m^3/season) in this study are for the entire tertiary canal for the improved system, while for the unimproved system they are for the entire selected field. For improved system (Fig. 3 a), the water supply was partly stable in summer season and it was higher than in winter season due to larger proportion of total area planted to paddy (more than 50%). The water requirement decreased in the following summer season (and *vice versa* in winter season) due to decrease in area under paddy in the following summer season. For unimproved system (Fig. 3 b), the water supply in the tail location was higher than the other locations due to delivery of the water from the drainage canal through the irrigation season, while the water requirement decreased in the following irrigation season. However, the water requirement was higher than water supply in both the systems due to location of the study area at tail of the irrigation system in the Nile Delta and there was a clear water shortage throughout irrigation seasons.

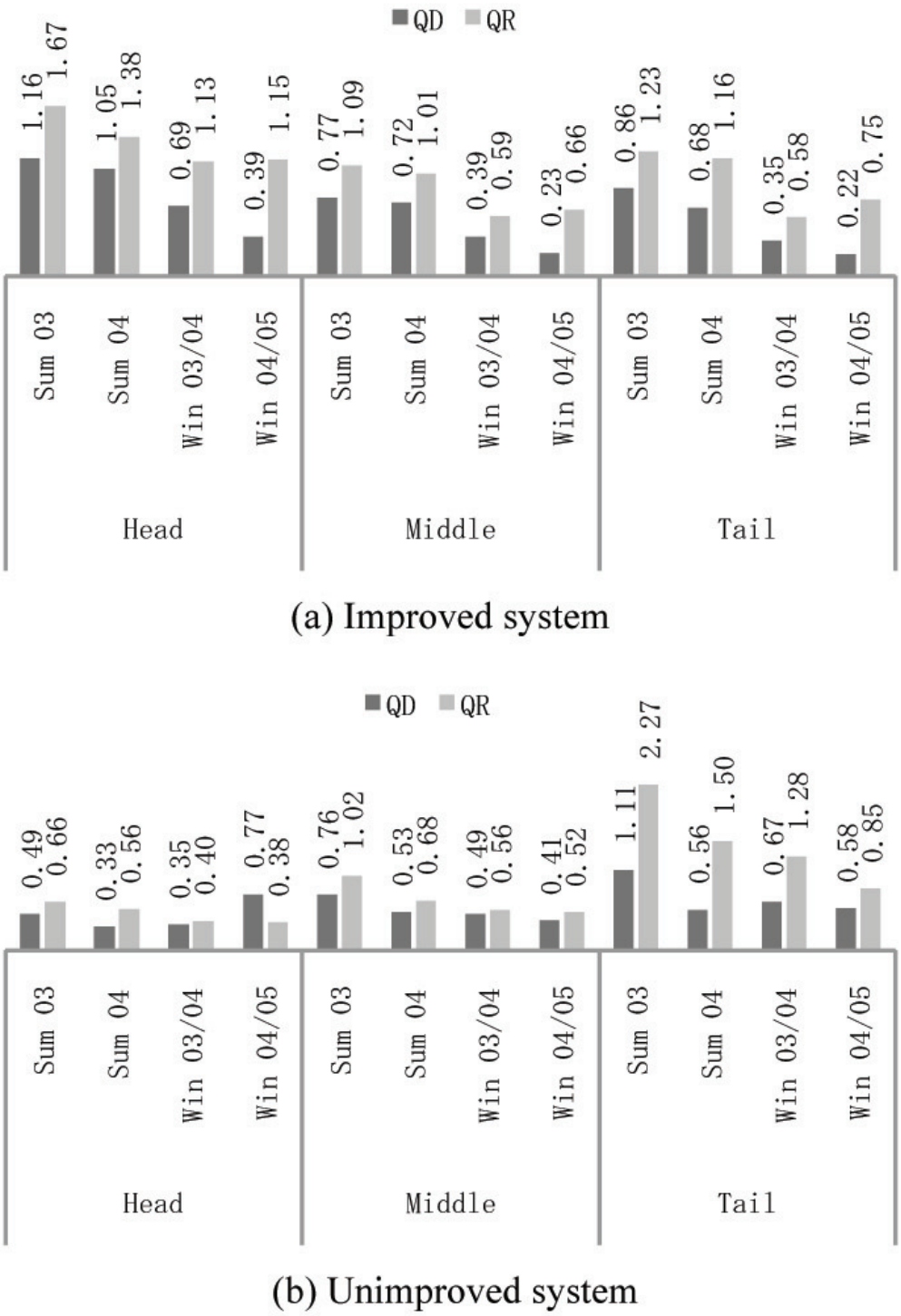

Figure 3. Q_D and Q_R values for tertiary canal through out its location in branch canal.

Water delivery performance of the system: Average indicator values of water delivery performace for fields and tertiary canals are given in Table 3 and 4, for 2003 and 2004 seasons. For fields, average P_A values for improved system were higher than unimproved system in the summer season, while *vice versa* was the case in the winter season. Average P_F values were equal and closed to 0.9 for both systems. Average P_E values were higher in the 2004 irrigation season, which were close to 0.1 and 0.2 for summer and winter seasons, respectively. Average P_D values were poor and did not improve in the following season. According to the performance standard, the water delivery performance of field practices in improved system relative to adequacy and dependability were "poor", while the performance relative to efficiency was "good" and equity

varied between "good" and "fair" in all irrigation seasons. While in the unimproved system, performance relative to adequacy and dependability was "poor", while the performance relative to efficiency was "good" in all irrigation system, while equity was "good" in irrigation season 2003 and "poor" in irrigation season 2004.

Table 3. Water delivery performance at field practices level throughout the tertiary canal locations in both systems in the irrigation seasons 2003 and 2004

Location	Season	Adequacy		Efficiency		Equity		Dependability	
		P_A		P_F		P_E		P_D	
		Imp. .Sys	Unimp. .Sys	Imp. .Sys	Unimp. .Sys	Imp. .Sys	Unimp. .Sys	Imp. .Sys	Unimp. .Sys
Head	Sum 03	0.86	0.65	0.89	0.91	0.09	0.04	0.45	0.80
	Sum 04	0.81	0.59	0.89	0.60	0.08	0.25	0.48	0.75
	Win 03/04	0.82	0.84	0.91	0.96	0.10	0.09	0.67	0.55
	Win 04/05	0.71	0.92	0.95	0.67	0.23	0.29	0.97	0.76
Middle	Sum 03	0.66	0.73	0.97	0.94	0.34	0.14	0.40	0.63
	Sum 04	0.69	0.73	0.92	0.95	0.09	0.09	0.75	0.60
	Win 03/04	0.78	0.77	0.83	0.81	0.50	0.07	0.93	0.99
	Win 04/05	0.78	0.77	0.94	0.93	0.28	0.29	0.74	0.80
Tail	Sum 03	0.61	0.50	0.92	1.00	0.26	0.20	0.69	0.55
	Sum 04	0.72	0.38	0.83	1.00	0.16	0.18	0.88	0.63
	Win 03/04	0.75	0.59	0.99	0.99	0.16	0.20	0.64	0.66
	Win 04/05	0.63	0.75	0.90	0.99	0.22	0.13	0.96	0.76

For tertiary canal, average P_A values for the improved system were higher than for the unimproved system in summer season, while *vice versa* was the case in winter seasons. Average P_F values were equal and closed to 1.0 throughout irrigation seasons for both systems. Average P_E values were improved through the following irrigation season and better than unimproved system, which were lower than 0.1. Average P_D values were poor in all irrigation seasons and not improved in the following season for both systems. According to the performance standard, the water delivery performance of tertiary canal level relative to adequacy and dependability were "poor", while the performance relative to efficiency was "good", and equity was "good" and "poor" for improved system and unimproved system, respectively.

Table 4. Water delivery performance at tertiary canal level in both systems in the irrigation seasons 2003 and 2004

Season	Adequacy		Efficiency		Equity		Dependability	
	P_A		P_F		P_E		P_D	
	Imp. Sys.	Unimp. Sys.	Imp. Sys.	Unimp. Sys.	Imp. Sys.	Unimp. Sys.	Imp. Sys.	Unimp. Sys.
Sum 03	0.70	0.66	1.00	1.00	0.01	0.18	0.27	0.26
Sum 04	0.69	0.58	1.00	1.00	0.11	0.29	0.57	0.43
Win 03/04	0.63	0.76	1.00	1.00	0.04	0.21	0.40	0.42
Win 04/05	0.33	0.82	1.00	0.83	0.08	0.52	0.70	0.43

The water delivery performance for field practice and tertiary canal levels was the same in improved and unimproved systems. However, the improved systems were more consistent for different locations and for irrigation seasons because the performance indicator values were equal through irrigation seasons, although the performance standards were poor. The average values of four performance indicators indicated systemic water delivery problems in the irrigation seasons. The reason for water delivery problems was the absence of crop production planning among the farmers and the capacity of irrigation system was small relative to demand due to tendency of the farmers to plant more paddy than that the government allowed. In addition, this area was located in the tail end of irrigation system in the Nile Delta and faced water shortage through most periods in irrigation seasons.

Irrigation hours per unit area: As shown in Fig. 4, the irrigation hours per unit area for main crops in improved system were lower than in unimproved system among farmers for all tertiary canal locations throughout the irrigation seasons. In the summer seasons, the average irrigation hours of the improved fields was about 60% to 70% of unimproved ones, and 60% to 80% in winter seasons. This is due to irregular irrigation time among the farmers in the improved system and commitment of the operation schedule by water user associations (WUA) through improved tertiary canal, and improved fields by their intake. Fig. 4 also shows cumulative hours of night irrigation for fields in both irrigation systems. The night irrigation during summer seasons was higher than winter seasons due to heavier planting ratio of paddy field. More fields that needed to be night irrigated were located at the tail end location and this was normal because these locations faced water deficit most of the time during irrigation seasons in both systems. The average hours of night irrigation for improved fields were 2.0 and for unimproved fields 3.5.

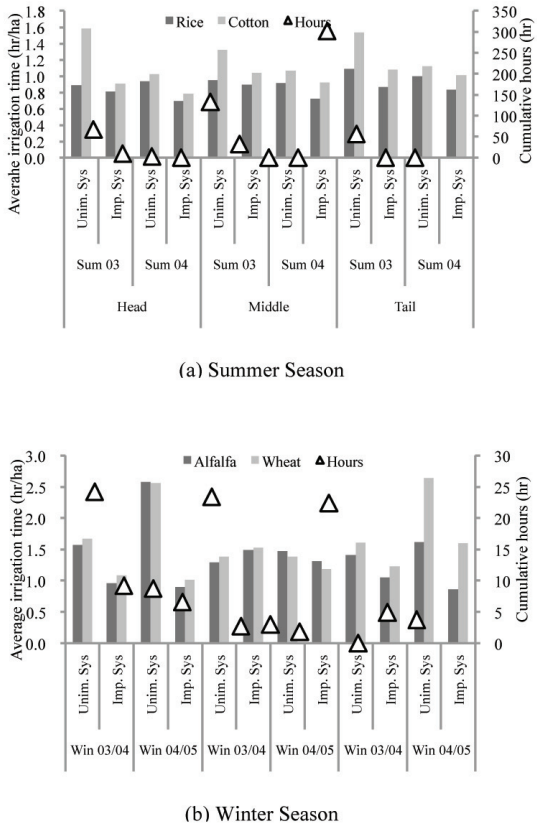

Figure 4. Irrigation hours and night irrigation through locations of tertiary canal through irrigation seasons.

Crop yield: The crops yeild through summer seasons in improved system were higher than in unimproved system, especially of rice crop. The rice crop yield in 2003 was 17 and 9.3 ton/ha and cotton crop was 0.87 and 0.74 ton/ha for improved and unimproved systems, respectively. However, the productivity increase showed a decline in the second summer season; for rice it declined from 50% to 7% and for cotton it declinrd from 11% to 1%. This was due to change in the cropping pattern in improved system by farmers, whereby there was a decrease in paddy area by 30% at the head location. Crop yields in the winter seasons were the same under the improved and unimproved systems.

Conclusion

Based on the evaluation of indicators in this study, it can be concluded that IIP had a positive effect on farmers' practices in their farms. The equity of water distribution among different locations in the improved system was slightly better than that in the unimproved system. The water use efficiency at the improved tertiary level increased in which the irrigation hours and its frequency were less. Farmers' practice of reducing the average irrigation time for major crops at different locations in the improved system gave improved water use efficiency and increased crop production farm income. This was because of the role of WUA and the participation of farmers together in the operation and management of irrigation system at the level of tertiary canals. Therefore, it is essential to expand the responsibility of WUA from tertiary canal level to branch canal and then to main canal level in the future.

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4. Economic benefits of integrating forage shrubs in dryland agricultural systems: an Australian case-study

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Abstract

In face of climate change and other environmental challenges, one strategy for incremental improvement within existing farming systems is the inclusion of perennial forage shrubs. In Australian agricultural systems, this has the potential to deliver multiple benefits: increased whole-farm profitability and improved natural resource management. The profitability of shrubs was investigated using Model of an Integrated Dryland Agricultural System (MIDAS), a bio-economic model of a mixed crop/livestock farming system. The modelling indicated that including forage shrubs had the potential to increase farm profitability by an average of 24% for an optimal 10% of farm area used for shrubs under standard assumptions. The impact of shrubs on whole-farm profit accrues primarily through the provision of a predictable supply of 'out-of-season' feed, thereby reducing supplementary feed costs, and through deferment of use of other feed sources on the farm, allowing a higher stocking rate and improved animal production. The benefits for natural resource management and the environment include improved water use through summer-active, deep-rooted plants, and carbon storage. Forage shrubs also allow for the productive use of marginal soils. Finally, we discuss other, less obvious, benefits of shrubs such as potential benefits on livestock health. The principles revealed by the MIDAS modelling have wide application beyond the region, although these need to be adapted on farm and widely disseminated before potential contribution to Australian agriculture can be realized.

Introduction

Agricultural systems in the Mediterranean-type regions of Australia currently face a broad range of environmental challenges. Finding ways to cope with drought and unseasonable rainfall, soil salinity, soil erosion, soil acidification, herbicide resistance, reduced biodiversity, and pressure to reduce greenhouse gas emissions will likely require adoption of novel technologies and modified farming systems. Agricultural systems will also need to continue to be responsive to changing market trends and consumer demands. Inclusion of perennial species in farming systems seems like a feasible option to help mitigate the extensive impacts of some of these threats (e.g. Bathgate 2006; O'Connell et al. 2006; Byrne et al. 2007; Norman et al. 2007). A change from traditional to sustainable farming systems is required at a time when soil salinity is estimated to affect up to 2.1 million hectares of arable land in Australia, with about half of this in Western Australia alone (Bennett and Price 2007), while in South Australia 6 million hectares of arable land are highly susceptible to wind erosion, and a further 1.2 million hectares are at risk of water erosion (EPA 2008). In addition, nearly 2 million hectares of agricultural land are affected by

soil acidity in that state (EPA 2008). Farmers will also need to continue to be responsive to economic pressures (e.g. decline in the terms of trade for agricultural commodities, increasing inputs costs), government policies (e.g. carbon trading scheme), social changes (e.g. decline of family farm, shortage of labour), as well as changing market trends and consumer demands.

The *Enrich* project is intended to contribute to these various challenges. It aims to develop innovative, profitable and sustainable farming systems in the low-medium rainfall zones (300-650 mm) of southern Australia, based around grazing of novel shrubs and shrub-based systems with potential to improve feed utilisation and animal health (Revell et al. 2008b). In this target zone there are currently few perennial plant options available. This project focuses on a range of mostly Australian native forage shrubs (e.g. *Atriplex* sp., *Acacia saligna, Chenopoium* sp., *Eremophila* sp., *Rhagodia* sp.), which are especially well adapted to the climatic challenges of this land and appear to contain unique bioactive compounds that could be exploited in livestock production (Revell et al. 2008a). They are generally being assessed for their ease of establishment, growth performance, nutritive and anti-nutritive value, and impact on the gut health of livestock. This information is supported by farmer experiences (Toovey and Revell 2008) and by computer modelling through the use of MIDAS (Model of an Integrated Dryland Agricultural System), a bio-economic model of a mixed crop/livestock farming system (Kingwell and Pannell 1987).

This analysis investigates the potential benefits of integrating forage shrubs in a farming system by evaluating shrub biological and management data in a whole-farm economic context using MIDAS. Even though many shrub species have been used successfully for hundreds of years in traditional grazing systems in North Africa (El Aich 1991) and the Middle East (Seligman et al. 1989; ICARDA 2005) and in rangeland production systems elsewhere (Crisp 1978; Bartolome and McCkran 1992; Milton 1994; Watson et al. 1997; Tiver et al. 2006), most previous attempts to use or develop forage shrubs in Australia in managed systems have fallen short of commercial viability. Exceptions include old man saltbush (*Atriplex nummularia*), and tagasaste (*Chamaecytisus proliferus*) that have found niche roles in agricultural landscapes (Dann and Trimmer 1986; Snook 1996; Lefroy et al. 1997; Stokes 2000; Abadi et al. 2005; Bennett and Price 2007; Liddicoat and McFarlane 2007).

The *Enrich* project was built on the assumption that shrubs alone will not provide sufficient edible biomass to support productive livestock systems (Barrett-Lennard et al. 2003). This has directed our research towards the incorporation of shrubs into forage systems for multiple benefits, including a pasture understorey. In addition, the systems under development include a diverse assembly of plants (in space and time) that can collectively provide nutrients and beneficial bioactive compounds for grazing livestock, as well as flexibility in farming systems.

Methods

The MIDAS model

The circumstances under which novel forage shrubs are likely to be profitable and thus potentially adopted into the farming system are being investigated with the help of MIDAS (Kingwell and Pannell 1987). MIDAS was chosen because its complex framework allows for the integration of biological, physical and financial information relevant to whole-farm economics. The model uses linear programming (LP) to select a farm strategy that maximizes an equilibrium farm profit in the medium term. Its detailed representation of the farming system allows us to assess the overall change in profit when a new farming option is included in the system in an optimal way.

Here we use the Central Wheatbelt version of MIDAS (CWM) (Blennerhassett et al. 2002), which represents a typical crop/livestock farming system in a region of south-west Western Australia (Fig. 1). This region has average annual rainfall of 350 mm, of which less than 20% falls outside the relatively short growing season (May to October). The summer maximum daily temperature is over 30 ºC on average. Farms are heterogeneous in terms of soil types, so the model describes eight main land management units (LMU) for the typical 2000 hectare farm. Mixed crop-livestock farms make up the majority of farm businesses. Typically, farms in the region allocate 50-60% of their farm area to crops (and the remainder to pasture production for livestock grazing) although this varies with the mix of soil types present and with farmer preference. Crops grown in the region include wheat, barley, lupins, triticale, canola or rape seed, and a range of pulse crops. Sheep are the dominant livestock and are grazed mainly on annual pasture, which vary widely in composition, some improved by planting of high-quality pasture species (e.g. yellow serradella), some dominated by species that may have been planted for feed purposes decades ago (e.g. subterranean clover or annual ryegrass (*Lolium rigidum*)) and some consisting largely of volunteer weeds. There is also a relatively small area of improved perennial pasture (e.g. lucerne or alfalfa).

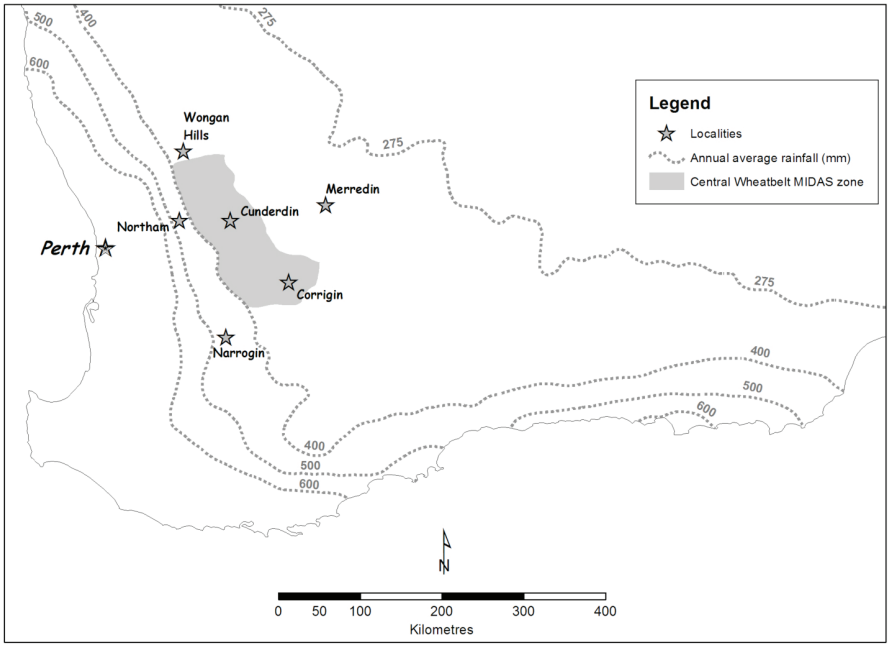

Fig. 1. The central agricultural region (grey shade) of south-western Australia.

Historically, wool production made up the majority of the sheep enterprise, by value of production, but prime lamb production for meat has increased in recent years as a result of improved prices (ABARE 2000-2008). The model also includes an option for oil mallee trees (*Eucalyptus* sp.) a novel enterprise that provides energy, oil and activated carbon, but is not yet firmly established as an economic enterprise in the region. In addition, the CWM accounts for:

- Over 80 crop-pasture rotations and their inter-year biological effects (e.g. plant nutrition and disease effects);
- Ten pasture growing periods within the year;
- Ten major feeding periods within the year;
- A range of supplementary feeding options (pasture, grain, stubble, hay, forage shrubs);

- Over 80 categories of sheep with distinctive characteristics and management options (depending on race, gender, age, bodyweight, reproductive status, feeding regimes, and lambing/shearing/sale times);
- Different energy and volume intake requirements for each sheep category;
- Several grain, stubble and wool quality classes;
- Soil nitrogen balance and fertilization options;
- Deferment of pasture grazing from one time period to the next, allowing for degeneration in terms of both quality and quantity of feed;
- Groundwater recharge;
- Machinery specifications (crop establishment method, machine type, fuel use, contracts, repairs and maintenance);
- Chemical control of diseases, pests and weeds;
- Labour (fixed, casual);
- Finance (credit, debt limit, interest rates, operation costs, depreciation costs, bi-monthly overhead costs, cash return, profit).

MIDAS selects the set of activities that maximize the objective function (usually long-term farm profit), subject to acreage, biological, technical, labour and financial constraints. Model outputs include: rotations for each LMU, enterprise areas for each LMU, sheep stocking rates and flock structure, supplementary feed, fertilizer rates, groundwater recharge volume, expected annual profit, and shadow prices and costs (which indicate second best options).

Being an optimisation model, MIDAS is not amenable to the sort of validation processes advocated for, say, a biological simulation model. However, it has undergone an extensive process of verification, of expert assessment of input parameters, and of comparison with actual farming practice. A very wide range of issues have been analysed using MIDAS since its creation in 1982, including the economic impact of stubble conservation to prevent wind erosion (Bathgate 1989); deep tillage to reduce soil compaction (Abadi Ghadim et al. 1991); greenhouse gas sequestration by tree crops (Petersen et al. 2003) and mitigation of dryland salinity using perennial pastures (Bennett et al. 2004; O'Connell et al. 2006; Bathgate et al. 2007; Norman et al. 2008). In addition to identifying robust messages that can be extended generally to groups of farmers or in the mass media, MIDAS is often used as a tool in defining research priorities and identifying research gaps, in policy advice, in education and training, and as a farming systems database (Pannell 1996).

Including forage shrubs in MIDAS

The CWM was adjusted to include multi-purpose perennial shrubs and is being used to test a range of parameters and scenarios of the new mixed system. Even though the *Enrich* project involves a large number of alternative species, the focus here is on a generic "shrub", in fact representing a shrub mix that provides a range of benefits. Due to the novelty of forage shrubs on Australian farms and lack of specific data, sensitivity analysis is required to explore changes in many of the model's parameters and assumptions that are subject to uncertainty or to change over time and space. A list of approximately 40 shrub, pasture, sheep, environmental and economic parameters and their value ranges used in the sensitivity analyses are shown in the Appendix. Results are presented only for some parameters to which results were most sensitive.

Modelling impacts on animal health

An intention of the *Enrich* project is to capture a range of benefits from secondary plant compounds (SPC) present in many shrub species. A range of animal production benefits are considered likely: higher liveweights and wool growth, a reduced need for antibiotics as a result of parasite inhibition or anthelmintic activity of shrubs, and an increase in the lambing survival rate as a result of improved shade and shelter as well as more permanent and diverse feed on offer supplied by shrubs. The shrubs of interest have relatively high concentrations of crude protein, which should increase digestibility and efficient use of stubble straw. Some of them may also have high levels of other essential nutrients such as vitamin E that can be beneficial for grazing livestock (Barrett-Lennard et al. 2003; Pearce et al. 2005). Conversely, there may be negative effects of toxic compounds in some shrubs (e.g. high levels of alkaloids, tannins or salt in the leaves). Existing evidence about the magnitudes of most of these effects is weak, and is the subject of research within the *Enrich* project. Nevertheless, we have included default values for a range of animal health-related parameters (see Appendix), although the impact of each of these on whole-farm profit is relatively minor.

Modelling groundwater recharge

Dryland farming systems of southern Australia are predominantly based on annual crops and pastures. These use less water than native vegetation did prior to clearing and, as a consequence, naturally saline watertables have risen in many areas, resulting in salinisation of soils and waterways. Inclusion of perennials in the system, with their deeper roots and increased water use, has the potential to reduce the extent of salinity by reducing recharge of groundwater (Ferdowsian et al. 2001; Pannell et al. 2004; John et al. 2005). In the CWM we represented groundwater recharge for shrubs, based on a 20-year average of unpublished data for each LMU. An increase in the farm area under shrubs (or any other perennials such as lucerne and trees) is likely to decrease deep flow and have a positive impact on the sustainability of the farm by reducing future salinity. Here, we use the predicted reduction in groundwater recharge only as an indicator of reduced dryland salinity. The actual reduction in salinity impacts would depend on additional factors such as watertable depth, groundwater salinity concentration, rainfall, topography and local geology (Frost et al. 2001; Pannell et al. 2004; Sanford and Young 2005; Bathgate et al. 2007; Norman et al. 2008).

Modelling greenhouse gas emissions

Australia has recently ratified the Kyoto Protocol, committing the country to the restriction of CO_2-equivalent emissions to 108% of 1990 levels in the first commitment period of 2008-2012 (UNFCCC 1997). Agriculture is responsible for approximately 16% of Australia's total greenhouse gas emissions (AGO 2005a). Table 1 outlines the main sources of emissions that are relevant to established farms that have no potential to clear further native vegetation (AGO 2005a; NGA 2008).

Establishment of woody perennials provides an opportunity to offset some or all of these emissions through sequestration of organic carbon. However, the accreditation of forests and other plantations as carbons sinks under the Kyoto Protocol remains a contentious issue as their contributions are uncertain, difficult to measure and possibly temporary (UNFCCC 2000).

Table 1. On-farm sources of greenhouse gases, global warming potential relative to CO_2 and proportions of total farm emissions.

GHG	On-farm emission source	GWP[1]	% of CO_2-eq farm emissions
Methane (CH_4)	Livestock rumen fermentation	21	42%[2]
Nitrous oxide (N_2O)	Livestock excretions in field	310	
	Nitrogenous fertilization		7%
	Nitrogen-fixing legume crops and pastures		28%
	Crop residues		17%
Carbon dioxide (CO_2)	Fuel use	1	5%
	On-farm electricity use		1%

[1] *Global Warming Potential*

[2] *Includes all livestock emissions (i.e. also N_2O from livestock excretions in field)*

In MIDAS, we modelled carbon sequestration by the non-edible components of the woody shrubs (above- and below-ground) through an annual carbon sequestration value. This is included in an emissions budget for the farm, including a parameter for each gas-emitting activity (converted in CO_2-equivalents); sequestration of 5 to 10 tonne of CO_2/ha/year over at least 10 years is judged to be realistic, based on predictions by AGO (2005b). The model is also used to estimate the impact of an emissions-trading scheme on the optimal level of total emissions (from the farmer's perspective) and on the profitability of forage shrubs.

An additional benefit of shrubs is that they provide a reduction in methane emissions from livestock. In fact, 20% of all native shrub plants investigated in the *Enrich* project have been shown to reduce methane production from microbial fermentation (without markedly affecting other normal fermentation parameters), whilst comparative studies overseas identified less than 5% of plant species investigated with the same potential (Bodas et al. 2007; P.E. Vercoe, UWA 2008 pers. comm.). This offers an additional prospect for shrubs to help reduce agricultural greenhouse gas emissions.

Results and discussion

Initially, results focus on the economic net benefits of including shrub-based grazing systems on the farm from the base-case modelling scenario. Later, results from sensitivity analyses are presented for a range of parameters, starting with an important set of basic economic and production parameters: nutritive value, biomass production, and commodity prices (wheat, wool and prime lamb), as well as carbon sequestration by shrubs. As part of the analysis, results are presented for shrub areas up to 60% of the farm.

Base-case scenario

This section presents an example of standard results from the CWM model. These results are meant to provide a reference for more detailed analyses carried out in the following sections.

Four sets of standard model results are presented in Table 2. The first two sets show an optimal default farm strategy with and without the incorporation of shrubs. The last two scenarios are

similar, but the proportion of poor sandy soils (LMU 1) in the model was increased from 7 to 15%. Where shrubs are allowed into the system, a series of assumptions are made regarding biological characteristics as well as benefits for animal health and natural resource management (NRM) (see Appendix for default parameter values).

Table 2. Key features of the optimal farm plan, with and without shrubs, also for a farm with a higher proportion of poor sandy soils

		Default[1]		+ Poor soils[2]	
	Farm strategy	**No shrubs**	**Shrubs**	**No shrubs**	**Shrubs**
Enterprise	Shrub area (% of farm)	0	7	0	9
	Crop area (% of farm)	55	54	50	51
	Pasture area (% of farm)	45	39	50	40
	Stocking rate (DSM/ha)	6.0	7.0	5.7	6.8
Receipts	Total grain sale and protein payments ($/ha)	140	129	122	123
	Total wool sale ($/ha)	58	68	56	66
	Total sheep sale ($/ha)	44	51	43	50
Costs	Supplementary feed ($/ha)	13	5	12	7
	Crop and pasture inputs ($/ha)	85	78	76	75
	Sheep husbandry and replacements ($/ha)	37	43	36	42
NRM	Groundwater recharge (ml/ha)	20	16	22	18
	Farm emissions (t CO_2-e/yr)	1571	994	1510	774
	CO_2 sequestered (t CO_2-e/yr)	0	700	0	865
	Farm profit ($/ha/yr)	**84**	**102**	**75**	**93**

[1] 7% of poor sandy soils (LMU 1), [2] 15% of poor sandy soils (LMU 1)

As Table 1 shows, the optimal farm plan allocates 7% of the area to shrubs, mainly at the expense of pasture. For a farm with a larger proportion of poor soils, an extra 2% of shrubs is profitable as they are better suited to those conditions than the pasture species represented in MIDAS. Cropping is clearly the most profitable enterprise on this farm, with only 1% change occurring in either case after inclusion of shrubs. The range of benefits from shrubs considered in the model led to a 22% increase in farm profit relative to the strategy with no shrubs. The gain was even more significant (24%) for a farm with a higher proportion of poor soils, despite overall lower profits. The results indicate that the main economic value of shrubs flows from:

1. Deferment of grazing of annual pastures, allowing them to establish well and, as a result, allowing a higher stocking rate (by 1 DSE/ha) and improved animal production (12% of the total benefits of shrubs are due to increased wool sales and 8 to 9% are due to increased sheep sales);
2. Provision of valuable feed after the break of the season (feed gap), reducing the need for costly supplementary feed such as grain and hay during summer and autumn (6 to 9% of all shrub benefits);
3. Profitable use of marginal and poor land, reducing the opportunity cost of growing less crops and pasture in those soils.

Reported savings in crop and pasture input costs as more shrubs grow on the farm are generally off-set by reduced grain sales and protein payments, as well as by higher sheep husbandry and replacement costs. Likewise, an increased sheep carrying capacity is likely to result in higher farm greenhouse gas emissions under the shrub strategies, even though perennial vegetation plays a role in off-setting those emissions. Shrubs also have a positive effect on groundwater recharge (on sandy soils), as will be considered later.

Nutritive value

We looked at the impact of low, standard and high levels of shrub nutritive value (7, 8, 9 MJ ME per kg edible DM) (Figure 2) and biomass production (1, 2, 3 kg DM per plant) on whole-farm profit. These values allow for likely variation among a range of shrub species. Nutritive value is a function of digestible dry matter, protein utilization and metabolizable energy (Norman et al. 2007), and thus a potential indicator of animal performance (e.g. liveweight gain). Furthermore, it is estimated that a diet including green feed from shrubs at certain times of the year (summer and autumn) when annual pastures are senesced could help increase digestibility from 50 to 60-70 per cent (and thereby lower methane emissions from rumen fermentation as a result of modifying livestock digestive processes (Tozer and Wiley, unpublished). For shrubs with a standard nutritive value (8 MJ ME/kg edible DM), profit is maximised with shrubs on 10 per cent of the farm, and remains higher than without shrubs until shrub area reaches 25 per cent (over 50 per cent for high nutritive value). At higher shrub nutritive value, much larger shrub areas (20-25 per cent of the farm) could be established profitably as more and better quality feed supplement becomes available during a greater proportion of the year. Shrub plants with 9 MJ ME/kg edible DM may be a possibility in the near future as research and development work in that area progresses further.

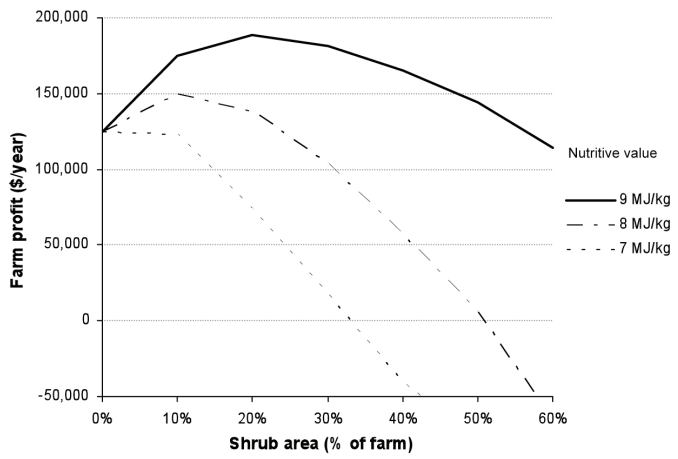

Figure 2. Whole-farm profit for a standard, high and low nutritive value of shrubs.

Commodity prices

The impact of a change in wheat, wool and prime lamb prices on whole-farm profit and optimal strategies was also examined (see Appendix for price ranges), due to uncertainty about future prices and the likelihood that they will fluctuate (Figures 3 to 5). The optimal area of shrubs remained unchanged across the range of price scenarios, indicating that there is some robustness to the finding that allocating approximately 10% of land to shrubs is profit-maximizing. The decline in profit from moving beyond 10% area of shrubs increases as the price of wheat goes up (Figure 3). At low wheat price, profit at 40% shrubs is similar to no shrubs and only slightly

below 10% shrubs. However, at the high wheat price, a strategy with 40% shrubs is substantially inferior to either zero or 10%, due to the higher opportunity cost of reallocating crop land to shrubs. This suggests that it could be valuable to develop cropping systems within shrub alleys, allowing shrubs to be utilized even when there is a reduced demand for feed. The "penalty" for having too many shrubs on the farm changed little as the prices for wool and prime lamb varied (Figures 4 and 5).

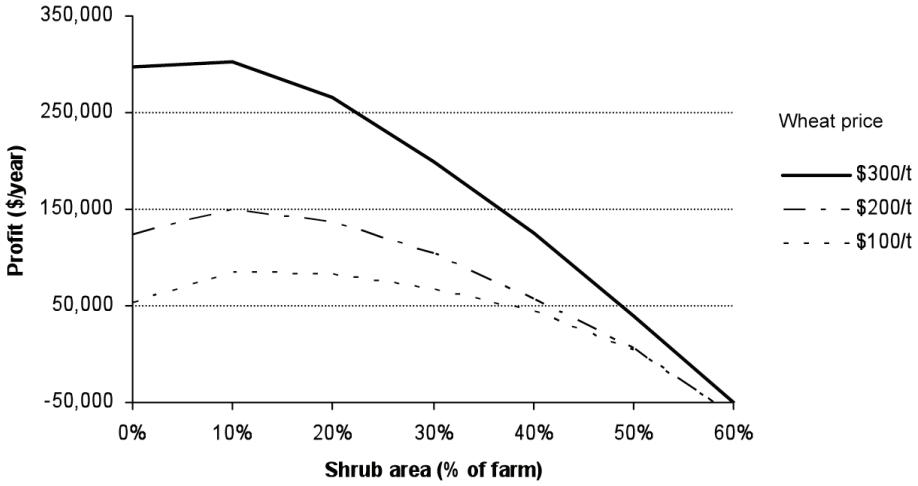

Figure 3. Whole-farm profit for a range of wheat prices (Australian Standard White wheat at 10% protein).

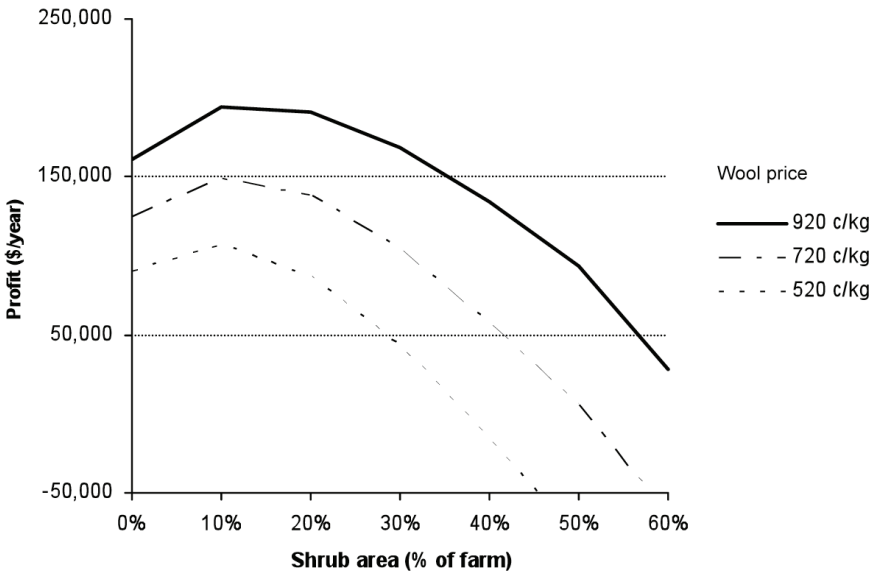

Figure 4. Whole-farm profit for a range of wool prices (Wool Market Indicator).

Groundwater recharge

Results for groundwater recharge are shown in Fig. 6. For the first 10-20% of the farm allocated to shrubs, average recharge across the farm falls disproportionately as the area of shrubs in increased (Figure 5). This reflects that the soil types on which shrubs are most economically attractive are also those on which recharge is highest. If 10% of the farm is sown to perennials (the optimum based solely on short-term financial considerations), average recharge falls by 25%.

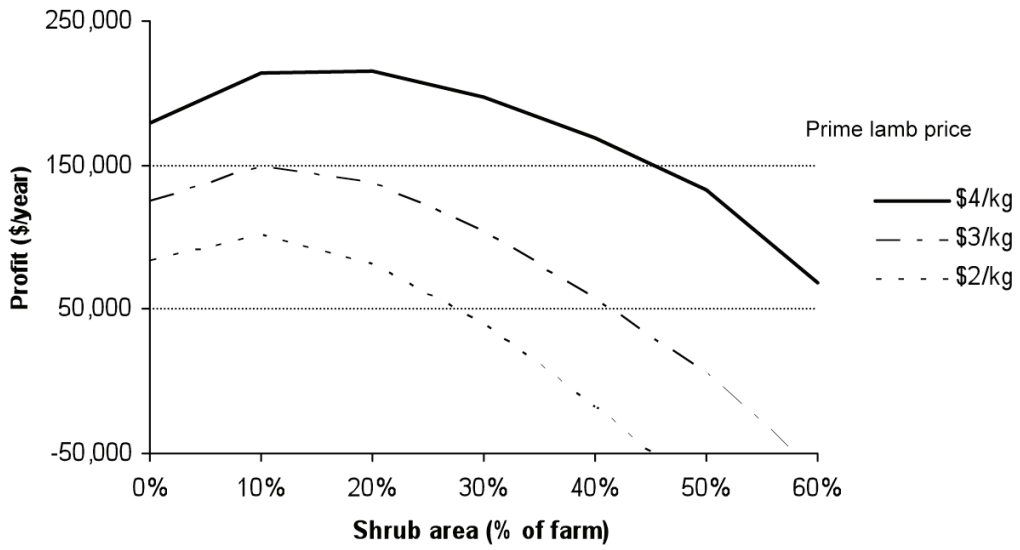

Figure 5. Whole-farm profit for a range of prime lamb prices (dressed weight).

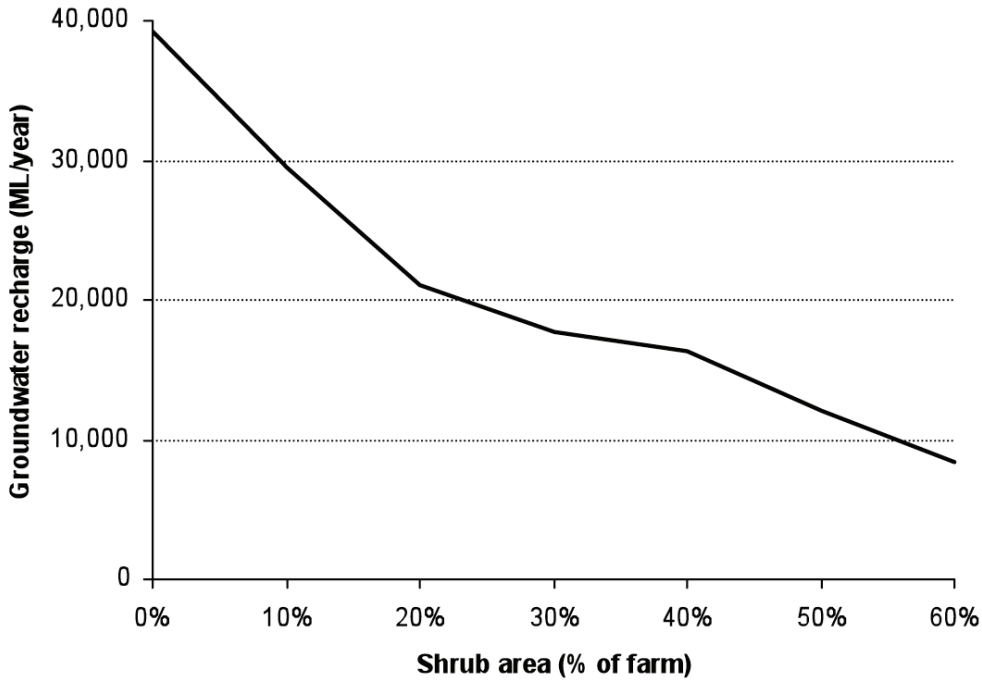

Figure 6. Total groundwater recharge over the whole farm.

Greenhouse gas emissions

The results shown in Figure 7 indicate that shrubs are potentially good carbon sinks, with the sequestration rate having a substantial impact on net emissions. If carbon is sequestered at a high rate of 10 tonne of CO_2-Eq/ha/year, net farm emissions over ten years can be fully offset with only 7% of the farm area allocated to shrubs. At the base-assumption rate of 5 tonne of CO_2/ha/year a neutral emissions status was reached at approximately 16% of the farm in shrubs.

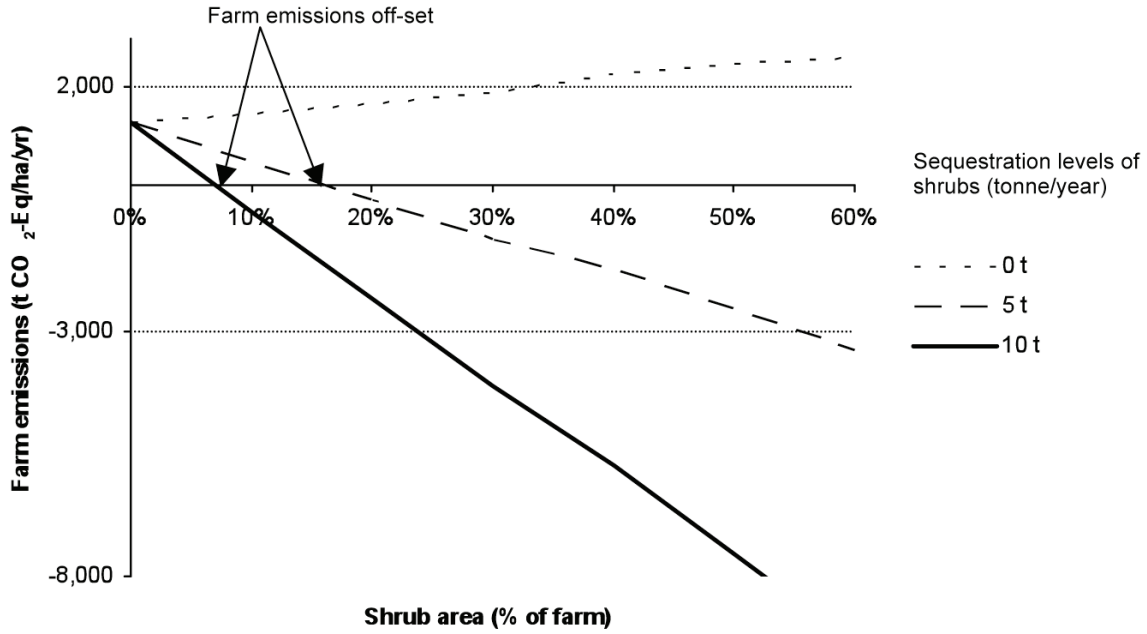

Figure 7. Farm emissions of CO_2-equivalents for a range of carbon sequestration levels over 10 years.

Assuming a price for CO_2 of $25, no significant difference in farm profit was observed across the carbon sequestration levels analyzed for the default parameters, as the annualized payment for carbon sequestration by shrubs represents only a very small contribution to the farm budget. The effect on farm profit and emissions was further investigated for a range of economic parameters such as the price of emissions, price of nitrogenous fertilizer, and fuel price (see Appendix for parameter levels). None of these factors significantly affected profit or the level of emissions generated on this farm, except for the slight impact of a higher fuel price. For the default result, there were nearly 1000 tonne of CO_2-e emitted and 700 tonne of carbon sequestered every year. The optimal area of shrubs stayed around 10% for all cases.

Conclusion

The profitability of including novel shrubs in a typical dryland farm in the mixed farming (crop-livestock) region of Western Australia was evaluated using MIDAS. The results indicate that a perennial forage shrub system can play a substantial role in the region, enhancing economic returns and addressing environmental challenges. For the modelled farm, the analysis estimates an improvement in whole-farm profit by 22% at an optimal area of shrub-pasture sward around 10% of the farm. For a farm with a higher proportion of poor soils, the profit improvement is 24%.

It is notable that this positive result occurs despite a number of other potential benefits being omitted from the economic analysis such as increase in soil fertility and biodiversity, reduction in soil erosion, acidity, and salinity. Conversely, modelling factors such as competition from shrubs (e.g. shading, water) and management interactions across enterprises (e.g. labour allocation) are unlikely to change the main findings, as our modelling and previous studies consistently show that shrubs have an important niche to fill on farms given their provision of feed at a time of year at which feed is generally scarce and their capacity to allow annual pastures to establish

more strongly. Finally, the profitability of shrubs may be less attractive when including factors like reduction in economies of scale created by strip cropping, or indeed not including a carbon trading system that is yet to be implemented in Australia.

This analysis has indicated the scale of impact that forage shrubs may have on whole-farm systems under different scenarios. In so doing, it has helped contextualize research findings in a way that both producers and researchers can relate to, and has therefore strengthened the discussion between practitioners, researchers and funding agencies.

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Appendix

Key parameter values and their sensitivity ranges and data sources for a standard forage shrub system (model default values in bold).

Type	Parameters	Sensitivity value range		
		Min	**Std**	Max
Shrubs	Area of shrub-pasture sward (ha)	0	**200**	1200
	Productive life of shrubs (years)	15	**20**	25
	Shrub density (stems/ha)	1000	**2000**	3000
	Probability of establishment success (%)	80	**90**	100
	Re-establishment period (years)	1	**2**	3
	Nutritive value (MJ ME/kg edible DM)	7	**8**	9
	Biomass production (kg DM/plant)	1	**2**	3
	Crude protein concentration (%)	5	**15**	25
	Vitamin E (mg/kg edible DM)	80	**100**	120
	Salt concentration in the leaves (%)	15	**20**	25
	Anti-nutritional effects on intake (e.g. tannins) (%)	1	**3**	5
Pasture	Understorey pasture density (%)	30	**50**	80
	Pasture (only) growth (%)	80	**100**	-
	Lucerne production (%)	0	**20**	40
Livestock	Liveweight gain (%)	3	**5**	7
	Increase in lambing rate (%)	0	**5**	15
	Reduction in methane production (% of gas from oaten chaff)	0	**30**	60
Environmental	Proportion of sandy poor soils (% LMU 1)		**7**	15
	Carbon sequestration (t of CO_2-e/ha/year)	0	**5**	10
	Carbon sequestration efficiency (%)	80	**100**	-
	Water deep flow (20-year average/LMU) (ml)	0.15	**1.0**	1.4
Economic	Shrub establishment cost ($/stem)	0.2	**0.4**	0.6
	Shrub sward maintenance cost ($/ha/yr)	0	**30**	50
	Sale price of wheat ($/t ASW) [1,4]	100	**200**	300
	Sale price of wool (c/kg clean WMI)[2,4]	520	**720**	920
	Sale price of prime lamb ($/kg DW) [3,4]	2	**3**	4
	Cost of N fertilizer (e.g. urea) ($/t)	400	**500**	600
	Cost of diesel fuel ($/L)	0.6	**1.1**	1.6
	Carbon emissions permit price ($/t of CO_2-e)	0	**25**	50
	Carbon sequestration price ($/t of CO_2-e) [5]	0	**25**	50
	Labour ($/hour)	12	**14**	16
	Discount/real interest rate (%)	5	**8**	10

Sources: *Enrich*-generated data, literature reviews, ABARE, market indicators, WA farm trials by I. Pullbrook, 2008.

[1] Australian Standard White with 10% protein; [2] Western Market Indicator; [3] Dry Weight; [4] Standard default prices for 2002; [5] Annualized over the life of the shrub stand

Theme 6: Socioeconomic, institutional and policy considerations

1. Managing drought in Indian arid zone: Future strategies

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Abstract

Droughts in India are mainly due to failure of rains from south west monsoon. The arid zone of the country is the most vulnerable to drought, with the probable frequency of once in every two years. The drought for the three consecutive years during 1998, 1999 and 2000 is a grim reminder of the likely impacts of climate change on agriculture and society. The earlier approaches to combat drought mainly focused on measures that would generate employment through relief works. The budgetary allocations under various centrally sponsored schemes helped in reducing the severity of impacts of droughts. It is, however, now becoming increasingly important to work out appropriate adaptation strategies on short, medium and long term basis. The important measures may include use of modern tools of information technology to arrive at precise warning systems to forecast drought. Altered agronomy of crops through small changes and cultivation of crops or cultivars more adapted to changed environment will lead to ease the pressures. Practicing resource conserving technologies that enhance efficiency of water and fertilizer use and restrict release of soil carbon in the atmosphere is very important. For drought proofing the region, the medium to long term strategies should aim at creating resilience by measures like securing good quality water, collection and conservation of rain water, joint management of forest and arable lands in forest fringes, promotion of perennial vegetation, improved livestock management and exploitation of under-exploited and under- utilized plant species. As the problem of tackling drought is complex, multi-institutional and multidisciplinary resource building approaches with farmer at the centre stage are needed. Drought prone communities, villages and the areas have to be trained to adopt and sustain the drought proofing methodologies.

Introduction

India is one of the most natural disaster prone countries in the world. Almost 55 million ha of land area (one sixth of the total) of the country is drought prone. The droughts are driven by regional meteorological conditions (Table 1). In the past, India has experienced twenty two large scale droughts - in 1891, 1896, 1899, 1905, 1911, 1915, 1918, 1920, 1941, 1951, 1965, 1966, 1972, 1974, 1979, 1982, 1986, 1987, 1988, 1999, 2000 and 2002 - with increasing frequencies during the periods 1891 to 1920, 1965 to1990 and 1999 to 2009 (Gregory 1989; GOI 2009). Table 2 depicts the frequency of agricultural droughts in four districts in western Rajasthan during 1901 to 2000. Often, the drought persists for 3 to 6 years. An analysis of recent frequency of agricultural drought in 12 districts of western Rajasthan is presented in Table 3. It shows that on an average every alternate year there is drought – severe droughts occurring in Sikar, Pali, Jodhpur, Jaisalmer and Ganganagar districts.

Table 1. Frequency of drought in various regions of India*

Region	Frequency, once in
Assam	15 years
West Bengal, Madhya Pradesh, Konkan, Bihar and Orissa	5 years
Karnataka, Eastern Uttar Pradesh, Viderbha	4 years
Gujarat, East Rajasthan, Western Uttar Pradesh	3 years
Tamil Nadu, Jammu and Kashmir, Telangana	2.5 years
Western Rajasthan	2 years

** deficiency in rainfall 75 % of normal or more); Source: GOI (2009)*

Table 2. Frequency of agricultural drought in selected districts of western Rajasthan in the period from 1901 to 2000

District	Moderate drought (no.)	Severe drought (no.)	Total number of drought events
Barmer	19	30	49
Bikaner	24	23	47
Jaisalmer	26	42	68
Jodhpur	27	16	43

Source: Narain et al. (2000)

Table 3. Frequency of agricultural drought in twelve districts of western Rajasthan in the period from 1999 to 2009

District	Moderate drought (no.)	Severe drought (no.)	Total number of drought events
Barmer	3	2	5
Bikaner	6	2	8
Churu	5	1	6
Ganganagar	1	3	4
Hanumangarh	1	2	3
Jaisalmer	2	3	5
Jhunjhun	3	1	4
Jalore	4	1	5
Jodhpur	4	3	7
Nagaur	3	2	5
Pali	3	3	6
Sikar	0	5	5
Average	**2**	**2**	**5**

The major causes of agricultural droughts in the Indian arid zone are the geographic location of the region that does not get abundant monsoon rainfall, poor quality and excessively deep

groundwater limiting its use for irrigation, absence of perennial rivers and forests, poor water holding capacity of soils, huge withdrawal of limited good quality groundwater resources (Narain et al. 2002). The rise in human population (400% increase) and the heads of livestock (127% increase) during the twentieth century has already put tremendous pressure on land and water resources (Kar et al. 2007).

The droughts put a heavy burden on state exchequer and cause misery to the community in the affected areas. Loss of livestock, wild life and biodiversity, and accelerated land degradation rob the people of their natural and economic resources in this region. The intensity and frequency of extreme weather-related events is likely to increase further because of climate change. In this paper aspects related to management of drought in arid regions of India on a long term basis, with a future outlook of drought proofing of the area, are discussed.

The causes

The summer monsoon accounts for 70–90 per cent of annual rainfall in the country. There is a large temporal and spatial variability in the rainfall. The droughts in India are mainly as a result of failure of rains from southwest monsoon. There appears to be a close association between the El Nino event and weak monsoon (WMO 1994). During the period from 1871 to 1998, 11 of the 21 drought years were El Nino years. During 1901-1990 rainfall was sufficient in all 7 strong El Nino cases.

Most of the studies, however, show that monsoon rainfall does not exhibit any trend and is random in nature. In the coming years, because of climate change, the frequency of droughts and floods are likely to increase. Studies have shown that there is a trend for a slight increase in rainfall in the past 100 years in the north west India (Pant and Hingane 1988), and more so in the irrigated belt of Ganganagar region of Rajasthan, during the past three decades (Rao 1996).

The effects

The storage of water is significantly reduced in drought years on account of scanty and erratic rainfall and thus less availability of surface water flows. As per one estimate, the groundwater table is declining at the rate of 0.2 to 0.4 m per annum in almost three-fourth of the region. Consequently, shallow wells dry up quickly during the drought while the water table in the deep wells becomes deeper (Lal 2001). The quality of groundwater deteriorates and sometimes the concentration of undesirable substances such as fluoride and nitrate increases to levels that are harmful/toxic for human and animal use (Sharma and Singh 2007). Grazing herds of animals quickly remove the scanty grass cover that appears with meagre rainfall, aggravating the problems of soil erosion and desertification (Pant and Hingane 1988).

Widespread crop failures lead to acute shortage of food and fodder. Both human and livestock suffer from malnutrition and consequently become victim of a host of diseases (Roy 2010). As most of the people of this region depend on agriculture and pastoralism for their livelihood, drought leads to decline in income and employment opportunities. Large-scale migration, often with livestock in search of feed and water, is a common feature during prolonged droughts (Bhasin 2002).

The drought years lead to an increase in cultivable wasteland and fallow lands. Because of the drought, the agricultural sector fails to provide employment to the working population and the

raw materials to agro-industries. The people are forced to abandon crop and livestock husbandry, the traditional occupation in these areas, and seek employment in the relief works.

The spread of drought in different parts of Rajasthan and its affect on human and livestock population in recent years is depicted in Table 4. It is evident that a large number of people and livestock are affected on a regular basis.

Table 4. The extent of drought and its effect on human and livestock population in the state of Rajasthan in the recent years

Year	Affected area		Affected population (million)	
	Districts (no.)	Villages (no.)	Human	Livestock
1999	26	23406	26.18	34.56
2000	31	30583	33.04	39.97
2001	18	7964	6.97	6.97
2002	32	40990	44.78	45.16
2003	3	649	0.58	0.76
2004	31	18613	22.76	23.24
2005	22	15778	19.84	17.81
2006	28	10529	13.67	14.20
2007	18	4309	5.61	6.15
2008	12	7402	10.01	10.60
2009	27	33464	42.91	36.46

Source: Government of Rajasthan (2009)

Status of drought management

The central and state governments and non government organizations (NGOs) try to minimize the sufferings of human and livestock through supply of food grains and fodder on subsidised rates and also providing human and livestock health care services. The measures also include provision of drinking water and creation of work opportunities on daily wages for sustaining livelihood of rural poor (KNBB 2005; Roy 2010).

Table 5 depicts various initiatives taken by the government to manage drought since 1970. The impact is however poor, the major causes being (i) lack of integrated planning and implementation – main approach being only sector-wise; (ii) lack of participation of local communities; (iii) non integration of works with developmental planning; (iv) weak or little linkage between technology generation and developmental programmes; (v) non availability of spatial and temporal data for sound planning; (vi) inappropriate government policies – provision of subsidies that accelerate resource degradation.

Drought proofing

As this region is extremely prone to drought, it is essential to prepare plans for drought proofing of the region on a long term and sustainable basis. The integrated development of such drought

prone areas should be based on permanent solutions and not just the relief measures. In fact, after 2002 this concept is being given shape. The international efforts in severely drought/ desertification affected countries, through UN Convention to Combat Desertification (UNCCD), are already benefitting the region to some extent (GOI 2009).

Table 5. Early major initiatives of the Indian government to manage droughts and their impacts

Programme	Description	Impact
Rural Works Programme	Initiated in 1970, it was specifically designed to benefit areas with low and erratic rainfall by creating rural employment through government executed construction of medium or minor irrigation systems; and roads or soil conservation, pasture development and afforestation.	The employment generation took over priority over creation of permanent productive assets which could provide the basis for further development. Little or no productive or developmental impact.
Drought Prone Area Programme (DPAP)	Initiated in 1974, replacing rural works programme, it aimed at achieving integrated area development for mitigating impacts of future droughts by stabilizing production as well as employment in the drought prone areas. Land use practices like farm forestry, horticulture, more productive rain fed agriculture/animal husbandry, soil and water conservation were promoted.	The progress was monitored in qualitative terms like irrigation potential created, areas covered under forestry and pasture development etc. However, emphasis on setting and meeting the financial targets were not conducive for quality in planning, priority setting and implementation.
Desert Development Programme (DDP)	Initiated in 1977-78, it aimed at controlling desertification, restoring the ecological balance, raising the level of production and employment opportunities. Afforestation, conservation and utilization of ground water, agricultural and allied activities were promoted.	Generally, the activities failed to neutralize the adverse impact of the degradation because of the demographic pressures. Only in a few cases reversal of degradation was evident on account of participation of local communities.

The root cause of weak monsoon in India is related to the widespread and persistent atmospheric subsidence which results from the general circulation of atmosphere. Investments are needed for a better understanding and mathematical modelling of the monsoon phenomenon for early forecast of monsoon to enable farmers and state authorities to develop appropriate plans accordingly.

Promotion of suitable land use systems, water harvesting, appropriate soil and water conservation measures, improved agro-techniques for dry land crops, contingency crop planning, use of cost effective irrigation methods, fodder production and conservation schemes, cover of perennial vegetation to stabilize moving sands, arid horticulture, etc. are also very important for improving livelihood opportunities as well as land conservation. Creation of sustainable alternatives for off-farm employment is another way of drought proofing this region.

The frequency and intensity of drought and floods are likely to increase in the future due to the projected climate change (Sinha and De 2003). This will pose a much greater challenge for the society. So such events are to be managed through careful planning and implementation (Table 6).

Table 6. Soil and water conservation measures for arid regions of India

In situ soil conservation measures	Rain water harvesting/management measures
Conservation furrows	Inter plot water harvesting
Mulching	Small field ponds/tanks
Deep ploughing	Revival of traditional water harvesting systems
Inter row water harvesting system	*Khadins*
Small basins	
Contour cultivation	

Desert dwellers understand the value of water; hence, rain water harvesting is traditional in the arid regions. Various techniques of rainwater harvesting have been developed/ refined by research workers such as improved designs of *Nadis*, *Tankas*, *Khadins,* etc. These technologies should be popularized among the people of this region.

Promotion of efficient irrigation technologies like sprinkler and drip system with the aim of improving water use efficiency and saving irrigation water is an important intervention for this region. Cultivation of water intensive crops has to be discouraged in this region. Adoption of improved agronomic practices, based on improved varieties, timely weed control, use of fertilizers along with farm yard manure, *in situ* rainwater harvesting, can ensure good yields even under below normal rainfall.

The flash floods whenever occurring should be utilized for artificial recharge of groundwater. Integrated watershed management, which aims at utilizing the rainfall wherever it falls, should form the base for planning and implementation of the development programmes. The measures like afforestation, pasture development, water storage, livestock management in the watershed areas through well defined schemes will be highly useful in the long run in this region. Greater participation of communities and farm families should be encouraged in executing these schemes. The current trend of putting marginal lands under cultivation is not sustainable. Concerted efforts are required to promote suitable land use systems considering rainfall, soil type and need of the people. Integrated farming systems involving crops, forest and fruit trees and pasture grasses besides the livestock (in various combinations) will minimize the risk of crop failure and provide stability to farm income (Singh 1990).

The perennial vegetation is important for livestock, which is the main source of livelihoods for a large proportion of the people in this region. Management of existing grasslands with *Lasiurus sindicus*, *Cenchrus ciliaris* and *Cenchrus setigerus* and top feed species like *Prosopis cineraria*, *Acacia nilotica*, *Acacia sengal* etc. and promotion of silvipastoral programmes involving growing trees and grass combinations should receive priority attention for inclusion in various schemes under operation in the region. Any excess forage production during the monsoon season should be conserved through suitable schemes (Roy 1993).

Table 7. Treatment of dry roughage to enhance its nutritional value and palatability

Treatment	Procedure
Salt water treatment	Saline water (1-2 kg salt dissolved in 20-25 L water) is sprayed over 100 kg of chaffed dry fodder and used after 7-8 hours.
Urea treatment	Urea solution (1-2 kg of urea dissolved in 20-25 L water) sprayed over 100 kg of chaffed dry fodder and used after 7-8 hours for animals above six months of age.
Urea + Jaggery/Molasses treatment	A mixture of 1-2 kg urea, 1-2 kg salt and 3-5 kg waste jaggery/molasses in 25 L water sprayed over 100 kg quintal of chaffed dry fodder and used after 7-8 hours for animals above six months of age.

Source: Adapted from Patil and Alagundagi (2006)

The drought effects are generally more severe on livestock than on human beings (GOI 2006). However, livestock is most resilient source of livelihood for adapting to drought and other calamities as they can be (i) migrated out; (ii) fed on stored fodder; and (iii) liquidated under most adverse conditions (Mudgal et al. 2003; Misra 2005). The quality of fodder particularly the wheat straw (usually given to cattle during drought) may be improved through urea/molasses treatment, thus ensuring improved returns from the livestock (Table 7).

There are various types of common property resources (CPRs) such as grazing lands, dams, village ponds, etc. in the arid regions. Proper management of these resources by the communities using these resources should be promoted on priority basis for combating drought effectively.

Convergence of resources

The requirement of resources during natural calamities like drought is tremendous. Presently, there are several government sanctioned schemes that can respond to drought crisis quickly (GOI 2009). These are as follows:

Rashtriya Krishi Vikas Yojna (RKVY): RKVY is ₹ 25000 crore (US$ 5000 million) scheme of the Government of India devoted to national agricultural development programmes. The project approval is decentralized at the state level. It includes subsidy for purchase of seeds of crops, other inputs, pumping sets, etc. The drought affected areas may draw money through this scheme for various activities.

Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA): _MGNREGA is ₹ 39000 crore (US$ 7800 million) scheme that provides for meeting high demand for off farm employment due to drought. These resources can be used for de-silting of tanks, ponds, other water bodies, canals, repairing or construction of water conveyance systems, field bunding, contour bunding, digging of trenches even on the fields of small and marginal farmers. Digging of farm ponds is a high priority action for drought adaptations and proofing. Land shaping, levelling fields, making ridges and furrows or beds and furrows to enhance irrigation and water use efficiency are also permitted in the scheme. Labour for spreading organic manure, and for mulching to prevent loss of stored moisture can also be hired under this scheme.

Other miscellaneous schemes: There are several other schemes of the government from which drought managers may draw money. These include (i) micro-irrigation scheme for popularising sprinklers, drippers, fertigation etc.; (ii) Backward Regions Grant Fund (BRGF) generally for civil works, road etc. for implementing drought contingency activities; (iii) Integrated Wasteland Management Programme (IWMP), a ₹ 16000 crore (US$ 3200 million) scheme, for promoting livestock based interventions, activities for landless, *in situ* moisture conservation, rain water harvesting for supplemental irrigation, farming systems etc. in the drought affected regions; (iv) National Food Security Mission (NSFM) for alternative contingency cropping in disaster prone areas; (v) Artificial Ground Water Recharging, a ₹ 1600 crore (US$ 320 million) scheme, for recharging dried wells and ground water, for drought proofing; and (vi) Accelerated Irrigation Benefit Programme (AIBF) for promoting water harvesting by constructing weirs, check dams and conveyance system for alleviating drought stress.

Policy interventions

Although billions of rupees are spent for drought mitigation through various schemes and relief measures in drought years, there is a need to ensure that this expenditure significantly leads to drought adaptation, mitigation/moderation of drought and reduction in vulnerability of the poor in future. This will require paradigm shift in planning and implementation process. The important thrust areas for research and development to combat drought on a sustainable basis are depicted in Table 8.

A highly developed system with strong base at grassroot level and its integration with district, state and national level is required. Disaster preparedness at all levels and committed efforts of official and non official functionaries may lead to sustainable drought management in the region. The common people really need an effective support system through concrete implementable plans.

The policy interventions at government level should facilitate the following so that common people are benefited and drought management is sustainable:

(i) Collective action in agriculture and natural resource management;

(ii) Rehabilitation of degraded lands and diversification of livelihood systems for landless and the vulnerable groups;

(iii) Support to water saving options like drip irrigation and dry land crops;

(iv) Include dry land crops and fodder crops in minimum support price scheme;

(v) Arrange precise forecasting of monsoon under changing climate change;

(vi) Clear definition and enforcement of water rights in watershed communities

(vii) Increase public investment in dry land agriculture – including agricultural research and rural infrastructure

Table 8. Important research and development thrust areas for combating drought in arid regions of India

Area of thrust	Action
Replace vulnerable crops	Crops more vulnerable to drought may be replaced with drought tolerant ones, that are usually fast growing, thrive and yield well and mature early before the depletion of soil moisture. For example, farmers in sorghum growing areas may instead plant earlier maturing pearl millet to escape drought.
Develop and disseminate drought tolerant and climate change ready crop varieties	Investment has to increase on developing more drought and heat tolerant cultivars that can thrive on low soil moisture conditions and have a phenology that matches with the available growing season. Varieties already available of sorghum, pear millet, chick pea, pigeon pea and ground nuts should be promoted in the field areas.
Natural resource management	Efficient management of natural resources is very important in context of arresting land degradation, conserve soil moisture and harvest rain water for supplemental irrigation.
Capacity building (social capital)	The various stakeholders need empowerment through capacity building, knowledge sharing and strategic partnerships.
Institutional mechanisms	Appropriate mechanisms for accessing markets, credit, rural infrastructure and other support services through defined institutions.

Conclusion

Recurrent drought is endemic in the arid zones of India. High human and livestock population in this region is a major driver of degradation of natural resources of land water and agrobiodiversity. Despite the fragile nature of this region there are opportunities of sustainable land management and drought proofing on a long term basis. A shift in planning and implementation process for achieving drought adaptation, mitigation/moderation of drought, and reducing vulnerability is needed. A system with strong base at grass-root level and its integration at the district, state and national levels with in built component of capacity building of stakeholders is expected to provide the common man the drought proofing so much needed in the region.

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2. Grassland conservation in China reviewed from the standpoint of environmental and ecological economics

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Abstract

Inner Mongolia, China, grasslands have been degraded because of overgrazing, mining activities, vehicles running, and the impact of tourism and other human activities. In total, 59% (46.7Mha) of grasslands were degraded (11% - severely, 37% - at medium level and 52% - slightly). The increase in goat rearing to get cashmere fiber has been said to intensify degradation because goats tend to eat up even the grass roots. To conserve the grasslands, Chinese government established grassland law first time in 1985 and revised it in 2002. Revised law intends, among other things, to fix the carrying capacity of the livestock on the grassland. The targets of carrying capacities are to be fixed dependent on the local situations. Although, it is a big progress to establish the targets of livestock number basing on any scientific data, the strict control may be difficult to implement because the herders may not be willing to follow the regulation without any compensation. The carrying capacity figures vary by region, year, season, animal species, productivity of grassland, the degree of outsourcing of feed and other factors. The situation after the implementation of the law are reviewed with special emphasis on the environmental economics and ecological economics.

Introduction

Ito et al. (2006) reported that 59 % of grasslands in Inner Mongolia show degradation. Major causes are (1) land reclamation for agriculture and (2) overgrazing. Countermeasures against them are (1) prohibiting grazing in set areas and (2) improvement of grasslands. Nan (2005) reported that nearly 90 % of the total usable grassland in China has been degraded to various extents.

Arohanbato (2003) reported that shifting to private use system after 1978, stimulated livestock production by putting more heads of animals and increasing the number of profit-yielding goat on the grassland and thus causing grassland degradation. Construction of fence to restrict the unlimited use by herders was necessary. He suggested that for sustainable use of grassland, common use system should be reconsidered. Namulo (2009) reported 5 unsuccessful cases of ecological immigration programs in Searengol league. There was shift of herders from livestock raising on grassland to dairy milk production on newly developed farms and stall feeding of cows. Difficulties came because of lack of experience which resulted in low milk production. Also, relatively low price of milk against high cost of feed resulted in poor economics.

Regulation by law

Chinese Government enacted the "**Grassland Law"** first in 1985 and revised it in 2002. It consisted of 9 Chapters. Those are #1 General Provisions, #2 Ownership of Grasslands, #3 Planning, #4 Development, #5 Use, #6 Protection, #7 Supervision and Inspection, #8 Legal Responsibility, and #9 Supplementary Provisions. (http://faculty.washington.edu/). Shi et al. (2005) explained the significance of this Law. The section on the ownership of grasslands (Chapter #2) sets the frame. Article 33 of the chapter on the use (Chapter #5) restricts the number of livestock not to exceed the carrying capacity figure verified by the competent administrative department.

A partial recovery

The National Grassland Monitoring Report 2009 was published based on the results of grassland monitoring done over 22 provinces including Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilonjiang and Xinjiang. The report said that even though the general situation remained serious (stock carrying capacity showed more than 30 % overburden and damages by rats and insects reached 61 M ha), a partial recovery was achieved after the National Ecosystem Construction programs.

Devolution (participation)

Ngaido and Kirk (2000) recommended totransfer certain part of administrative power to local governments and to groups of people to let them act by themselves and utilize the traditional knowledge. Lack of training and preparedness might be a limitation for implementing this strategy in managing the grasslands.

Economic incentives and the degree of success

Environmental Economics has tried to internalize the external (social) cost. It considers that concrete actions are needed to solve the global environmental issues making any economic incentives as a driving force. They proposed carbon trade under the CDM (Clean Development Mechanisms and other measures. However, the question arises whether the movement to solve environmental issues on the basis of economic incentives would be enough to achieve the goals ? Since Ecological Economics observes the energy and material flow across the whole Earth system, it can be used to provide criterion to judge the degree of success. Recent analysis of 'Ecological Footprint', a trial to compare the capacity of nature and the size of human activities, indicated that the limit was already broken in 1980s (Wackernagel et al. 2002).

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3. Long-term effects of dust storms for nomads in Mongolia

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Abstract

This study aimed to assess long-term effects of dust storm that occurred in May 2008 on the health of nomads in Mongolia. We performed a cross-sectional survey for QOL (quality of life) and subjective symptoms one year later from this dust storm event (May 2009). The study subjects were 45 stricken area inhabitants comprising 22 men and 23 women with a mean (±SD) age of 42.1 (±12.9) years. The data collection method was a face-to-face interview with a questionnaire. QOL was assessed based on four subscales of a 36-item short-form health survey (SF-36). Four subscales are general health (GH), vitality (VT), mental health (MH), and role-physical (RP). The subjective symptoms include eye, nasopharyngeal, and respiratory. To examine the effects of dust storm for nomads, we compared the subjective symptoms and QOL (SF-36) between the subjects who were exposed to the dust storm (victims group) and those who were not exposed to the dust storm (non-victims group. The results of the compared subjective symptoms show that proportion of victims group was higher than non-victims group (nonsignificant). For QOL, the scores of all SF-36 subscales for victims group were lower than non-victims group. Moreover, multiple regression analysis results showed statistically significant correlation between victims group and RP ($\beta=-0.260$, $P<0.1$). In summary, as the long-term effects of dust storm for nomads, the possibility of the QOL decline was indicated.

Introduction

Rapid climate change in Mongolia has escalated the severity of dust storms and is making them a more serious hazard than ever before. In eastern Mongolia, the air temperature exhibits a seasonal increase to 10-20℃ during May to June, and no snow cover is normally observed at this time of the year. Nevertheless, a severe snow-and-sand storm hit eastern Mongolia on May 26 and 27, 2008. Fifty two people lost their lives and three hundred and twenty thousand animals were killed in the two-day dust storm (New Horizons 2009). This study aimed to evaluate long-term effects and vulnerability of the people against the vast backdrop of nature based on this storm.

Methods

Study participants: We performed a cross-sectional survey for QOL (quality of life) and subjective symptoms one year later from this dust storm event (May 2009). The study subjects were 45 stricken area inhabitants living in Khentii Province, Mongolia (Fig 1) comprising 22 men and 23 women with a mean (± SD) age of 42.1 (± 12.9) years, where the highest number of casualties and highest livestock loss were recorded. The study participant includes the person who is age more than 20 years old to 65 years old in each household. The data collection method used in this survey was a face-to-face interview with a questionnaire. The investigators first informed the participants of the purpose of the survey and obtained a statement of voluntary participation from the person being interviewed.

Fig 1. Study area in Mongolia

Quality of life (QOL0 assessment: QOL was assessed based on a 36-item short-form health survey (SF-36). The original questionnaire has 36 items comprising eight subscales. But to keep the questionnaire in this study simple, only four subscales, general health (GH), vitality (VT), mental health (MH), and role-physical (RP), were investigated. The scoring of each subscale was performed according to a scoring protocol (Fukuhara and Suzukamo 2004). Raw scores were converted into numerical scores ranging from 0 to 100. The higher the values, the better was the outcome.

Subjective symptoms: The symptoms concerning the eye included itching, hyperemia, and lacrimation. The symptoms concerning the nasopharyngeal included sneezing, nasal discharge, and congestion. The respiratory symptoms included cough, sputum, breathlessness, chest discomfort, and chest pain.

Statistical analyses: To examine the effects we compared the subjective symptoms and QOL (SF-36) between the subjects who were exposed to the dust storm (victims group) and those who were not exposed to the dust storm (non-victims group). Moreover, a multiple logistic regression and multiple regression analysis were used to adjust the other variables (age and gender). $P < 0.05$ was considered significant. All tesst and calculations were done with the statistical software package SPSS 13.0.

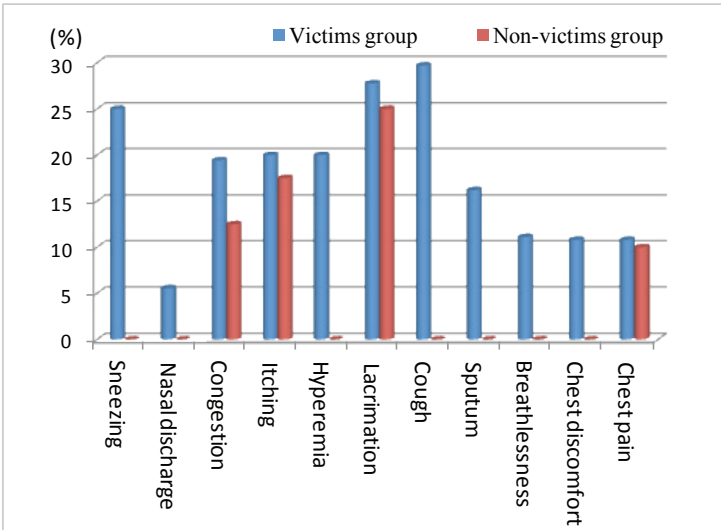

Fig 2. Comparison for subjective symptoms between victim group and non-victim group

Results

There were 11 victims and 34 non-victims from total subjects in this study. The results of the compared subjective symptoms show that proportion of victims group showing symptoms was higher than non-victims group (nonsignificant) (Fig 2). For QOL, the scores of all SF-36 subscales for victims group were lower than non-victims group. Moreover, multiple regression analysis results showed statistically significant correlation between victims group and RP ($\beta=-0.260$, $P<0.1$) (Table 1).

Table 1. Result of multiple regression analysis

SF-36	Age *(20-65 years)*	Gender *(Female=0; Male=1)*	Effects of dust storm *(Non-victims=0; Victims=1)*
Vitality (VT)	-0.247*	0.198	-0.203
Mental health (MH)	-0.080	0.117	-0.123
General health (GH)	-0.274*	0.073	-0.067
Role-physical (RP)	-0.124	0.052	-0.260*

The values are standardized partial regression coefficients obtained by multiple regression analysis, *P<0.1

Discussion

A large number of QOL evaluation methods have been developed during the past three decades. The SF-36 was designed for use in clinical practice and research, health policy evaluation, and general population surveys (Ware et al. 1993). The SF-36 is one of the most frequently used generic measurements of QOL (Ohsawa et al. 2003). Up to now, in Mongolia, there were few studies to assessing QOL of inhabitants by SF-36. In this study, QOL was assessed by using a four-subscale survey of GH, VT, MH, and RP. The scores were lower among the victims group than the non-victims group. In the results of the multiple regression analysis, effects of dust storm were significantly related to RP. The result suggests that the dust storm was an important factor decreasing the scores of SF-36 subscales. Recent studies have shown that Asian dust storm events coincide with an increase in daily admissions and clinic visits for asthma (Yang et al. 2005), allergic rhinitis (Chang et al.2006), or conjunctivitis (Yang et al. 2006). Therefore, our results suggested that a decreased QOL level of the victims group may be the result of damage from a dust storm event.

Conclusion

In summary, as the long-term effects of dust storm for nomads, the possibility of the QOL decline was indicated. The psychological sense of fear, the loss of the property, and the physical impediment were concluded as the factors of QOL fall.

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4. Effects of the Asian dust events and atmospheric heavy metal deposition on healthy subjects in Japan

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Abstract

The occurrence of Asian dust events is a frequent problem, with associated health issues throughout Northeast Asia. It is thought that these events are an environmental problem due to human's impact caused by forest reduction, soil degradation, and desertification, rather than being simply a natural seasonal phenomenon. The effects of Asian dust on human health are not well-known in Japan. We evaluated the association between daily symptoms and Asian dust events in Yonago, Japan. The subjects were 54 healthy individuals who were given survey sheets to fill regarding their nasopharyngeal, ocular, respiratory, and skin symptoms, and they were quantified in spring 2009.

We investigated the symptoms of the subjects on Asian dust days and non-dust days, and compared the symptom scores with meteorological data and measures of suspended particulate matter (SPM), which is the indicator of Asian dust. At the same time we analyzed the metallic constituent that adhered to particulate of Asian dust. The scores for symptoms were significantly higher on dust days than on non-dust days. Skin symptom scores were positively correlated with the SPM and nickel levels. Our results provide preliminary evidence that Asian dust influences the symptoms of healthy subjects, although the symptoms are not severe. Moreover, skin symptoms during this study may be an allergic reaction to metals bound to Asian dust particles.

Introduction

Asian dust phenomenon is the result of long-range transport of atmospheric pollutants originating in the arid and semi-arid areas such as the Taklamakan Desert, Gobi Desert, and Loess Plateau in inland China. Mineral or soil particles blown up into the atmosphere by winds are carried by westerly winds and often reach Northeast Asia, including Japan. The so-called 'kosa (yellow sand)' phenomenon is often observed in Japan in spring, and sometimes in autumn. These events are considered to be an environmental problem arising from human impact via forest reduction, soil degradation, and desertification, rather than simply representing natural seasonal phenomena.

The occurrence of Asian dust events is a common problem with associated health issues throughout Northeast Asia. There are some previous studies regarding the adverse health effects associated with such increases in particulate pollution in Korea and Taipei (Kwon et al. 2002; Chen et al. 2004). However, the effects of Asian dust on human health are not well known in Japan. Therefore, in healthy subjects, we evaluated the association between daily symptoms and Asian dust events.

Methods

The subjects were 54 healthy volunteers selected after informed consent in Yonago, Western Tottori Prefecture, Japan. Yonago is one of the cities with most frequent Asian dust events in Japan. These subjects were 31 men and 23 women with a mean (± SD) age of 36.2 ± 12.5 years without moderate or severe underlying disease with jobs as desk workers spending indoor the better part of a day. They were given survey sheets for recording their nasopharyngeal (sneezing, nasal discharge, congestion, itching, sore throat, and scratchy throat), ocular (itching, lacrimation, hyperemia, and bleary eyes), respiratory (cough, sputum, breathlessness, chest pain, chest discomfort, and dyspnea), and skin (itching, eczema, pain, and reddish skin) symptoms from the 1st to the 25th of February, 2009. The severities of these symptoms were quantified as follows: 0 point, no symptom; 1 point, slight involvement; 2 points, mild involvement; 3 points, moderate involvement; 4 points, severe involvement; and 5 points, extreme involvement. The symptom score was taken as the average number of points per symptom per person.

Asian dust information in Yonago was obtained from the Japan Meteorological Agency. In total, 6 Asian dust days (visibility of less than 10 km) were identified from the 1st to the 25th of February, 2009. We compared non Asian dust days with Asian dust days during the same period. Hourly measures of suspended particulate matter (SPM, a diameter of less than 10 μm: SPM is often used as an indicator for airborne particulates) in Yonago was obtained from Tottori Prefectural Institute of Public Health and Environmental Science during the same period.

Daily total suspended atmospheric particulate (TSP) was collected by high-volume air sampler (Model 120FT, KIMOTO, Japan) at the rooftop of 32 m above sea-level of the volunteers office in Yonago during same period. Nine elements; lead (Pb), chrome (Cr), manganese (Mn), cadmium (Cd), nickel (Ni), zinc (Zn), iron (Fe), calcium (Ca), and aluminum (Al), from TSP were measured by inductively coupled plasma atomic emission spectroscopy (Model SPS3520UV, SII nano technology, Japan).

For statistical analysis, the symptom scores and SPM levels on Asian dust days were compared with non Asian dust days using the Student's *t*-test. Pearson's product moment correlation coefficient was used to determine the correlation between the symptom scores and SPM levels. The correlation of the skin symptom score and the analyzed metallic amount was examined by multiple regression analysis. All data analyses were performed using SPSS for Windows (SPSS Inc.), and a significance level of 5% was used.

Results

Table 1 shows the overall symptom score, the average value for SPM levels, and heavy metal levels from TSP in Yonago for Asian dust days and non Asian dust days. The overall symptom score for Asian dust days was significantly higher than for non Asian dust days. The average SPM level and each metal level for Asian dust days were significantly higher than that for non Asian dust days. The correlation coefficients between SPM levels and nasopharyngeal, ocular, respiratory, and skin symptom score were 0.01, -0.08, 0.20, and 0.61 respectively. There was a positive correlation between the skin symptom score and SPM level (R^2=0.37, P<0.001, Fig. 1).

The correlation coefficient between each metal level and skin symptom score is shown in Table 2. The level of nickel was significantly positively correlated with the skin symptom score (P<0.05).

Table 1. The overall symptom score, the average value for suspended particulate matter (SPM) levels, and heavy metal levels from total suspended atmospheric particulate (TSP) for Asian dust days and non Asian dust days

	Asian dust days	**Non Asian dust days**
Variable	(n=6)	(n=19)
Symptom score	0.23 ± 0.03*	0.19 ± 0.04
SPM (μg/m³/h)	33.0±10.1***	15.6±7.9
Pb (ng/m³)	44.4±23.6***	12.3±10.0
Cr (ng/m³)	10.2±3.7***	4.1±4.6
Mn (ng/m³)	72.8±32.4***	18.7±11.1
Cd (ng/m³)	1.3±0.4***	0.4±0.3
Ni (ng/m³)	8.0±1.7***	3.8±2.1
Zn (ng/m³)	84.0±40.0**	35.4±19.6
Fe (μg/m³)	2.0±1.1***	0.4±0.2
Ca (μg/m³)	1.8±٠,8***	0.5±0.2
Al (μg/m³)	1.6±0.9***	0.4±0.2

**P<0.05, **P<0.01, **P<0.001 vs. non Asian dust days*

Table 2. The correlation coefficient between each metal level and skin symptom score.

Variable	**Standardized partial regression coefficient**
Pb (ng/m³)	0.323
Cr (ng/m³)	0.166
Mn (ng/m³)	0.292
Cd (ng/m³)	0.131
Ni (ng/m³)	0.483*
Zn (ng/m³)	0.342
Fe (μg/m³)	0.205
Ca (μg/m³)	0.174
Al (μg/m³)	0.039

*P<0.05**

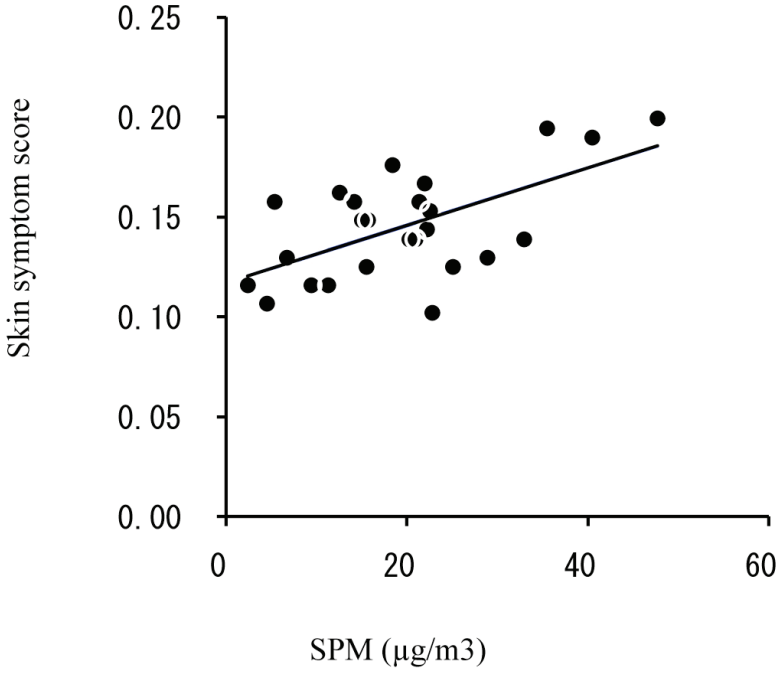

Figure 1. Correlation between the skin symptom scores and the suspended particulate matter (SPM) levels (R2=0.37, P<0.001).

Discussion

The overall symptom score for Asian dust days was higher than for non Asian dust days despite below environment quality standard of SPM in Japan: the daily average for hourly values shall not exceed 100 µg/m³. Our results provide preliminary evidence that Asian dust events influence the symptoms of healthy subjects. Particulate of Asian dust is principally composed of rock-forming minerals such as quartz and feldspar, and clay minerals such as mica, kaolinite, and chlorite. Analysis of Asian dust particles has shown the presence of ammonium ions, sulfate ions, nitrate ions, and metallic compound which are not considered to originate from the soil. The possibility has been suggested that Asian dust particles adsorb anthropogenic atmospheric pollutants during transport (Hong et al. 2010).

Recent epidemiologic studies have shown that Asian dust storm events coincide with increases in daily admissions and clinic visits for allergy diseases such as asthma (Yangi et al. 2005), allergic rhinitis (Chang et al. 2006) and conjunctivitis (Yang 2006). Some experimental studies have reported aggravating effects of Asian storm dust on allergen-induced eosinophilic inflammation in the murine airway (Hiyoshi et al. 2005; Ichinose et al. 2006). SPM associated with Asian dust may act as a type of allergen. There have been no reports about an association between skin symptoms and Asian dust events. The range of particle diameters reaching Japan peaks at approximately 4 µm, and therefore, it is unlikely that some skin symptoms are caused by physical irritation of Asian dust. Our results show that skin symptoms during this study may be an allergic reaction to metals bound to Asian dust particles.

Analyses of Asian dust particles have revealed the presence of lead, chrome, cadmium, nickel and zinc, which are not considered to originate from soil. There is a possibility that Asian dust particles adsorb anthropogenic atmospheric pollutants during transport. It is well known that the important health problems due to exposure to nickel and nickel compounds are allergic dermatitis

(Bencko 1983). The levels of nickel from TSP on Asian dust days were significantly associated with the skin symptom scores in our study, although the relationship between nickel allergy and nickel pollution is unclear (Smith-Sivertsen et al. 1999). Therefore contact dermatitis caused by nickel stuck to Asian dust particles would increase the skin symptom scores.

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5. Challenge of concurrent biofuel and food production: A case study of Jatropha cultivation by small scale farmers in Mexico

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Abstract

The production of biofuels has been increasing rapidly to combat global warming and addressing depletion of fossil fuels by setting up the biofuel introduction targets in European countries and others. In 2008, food prices were 64% above the levels of 2002, partly attributed to diversion of food crop area to producing feedstocks for biofuels because of the growing demand of biofuels. Potential negative impacts on society and environment, such as buy up farm land, depletion of water resources, biodiversity loss, etc., have revealed and criticisms of large-scale biofuel plantations have mounted. This case study presents an attempt to reconcile the needs of meeting the food security concerns with the concerns for environment by promoting Jatropha production by small scale farmers in Mexico.

Introduction

Energy crop plantations have been expanding as part of reducing greenhouse gas emission and reducing dependence on fossil fuels in many parts of the world (Thornley 2009). In 2008, food prices were 64% above the levels of 2002 along with the growing demand of biofuels (FAO 2008). Potential negative impacts on society and environment, such as buy up of farm land, depletion of water resources, biodiversity loss, etc., have been revealed and the criticism of large-scale biofuel plantations has been mounting (Grain 2007).

To cope with this situation, a statement on Global Food Security was issued in Hokkaido Toyako Summit in 2008 to develop biofuels from non-food plant materials and inedible biomass to ensure the compatibility of policies for the sustainable production and use of biofuels with food security (The White House 2008). In response to this development, efforts have been accelerating to produce biofuels without damaging environment and society by following sustainable biofuel production standards or criteria (UN-Energy 2007). Since these deliberations, millions of gallons of petroleum oil have spilled into the Gulf of Mexico in 2010. After the on-site inspection, the President of USA declared on June 15, 2010 for the first time the necessity to transit to a clean energy from a long-term perspective because the country was running out of places to drill oil on land and in shallow water (The New York Times 2010).

Furthermore, World Energy Outlook 2010 published a report that suggested the possibility that the petroleum-based fuel production had already peaked in 2006 (IEA 2010). As the world population is projected to surpass 9 billion by 2050 (United Nations 2009), development of renewable energy compatible with environment, society and economy, not competing with food production, is becoming essential today (UN-Energy 2007).

Under this scenario, *Jatropha curcas* L., a non-edible shrub with high drought resistance, native to Mexico and Central America, has drawn international attention as a biofuel plant (Heller 1996). *Jatropha* cultivation is expanding especially in India, China, Myanmar (Burma), the Philippines and several African countries (Fairless 2007).

Mexico is located in the geographical region which is considered to be a part of the centre of origin of *Jatropha*; however, the development of *Jatropha* cultivation here has started relatively late in comparison with other countries mentioned above. The first set of trials on *Jatropha* in Mexico has been set up in the state of Chiapas, in the southernmost part of the country. In 2006, when a new government was elected in the Chiapas State, the start of the Bioenergy Programme of Chiapas (*el Programa Bioenergético de Chiapas*) was made public; thereby the State Government promoted *Jatropha* cultivation as one of the biofuel producing plants and in response to this, the proactive efforts by farmers were started. The farmers are trying to cultivate *Jatropha*, while maintaining the cultivation of such food crops as maize, bean and groundnut. Furthermore, the farmers are supported by different institutions of the Government and by the farmers' association called USB (*Unio'n de Sociedades Bioenerge'ticas Chiapas S.C. de R. L. de C.V.).*

Objective

The objective of this study was to illustrate the present situation of food crops and *Jatropha* cultivation by farmers and the support system to farmers in Mexico through field survey and interview with farmers and related organizations, and then to learn lessons and best practices to realize concurrent production of food and biofuel plants.

Materials and methods

Field surveys and interviews were conducted in Tierra Santa Village and El Parra Village in the Chiapas State of Mexico and the USB staff in April, July and October in 2010.

Results

1. The present situation of *Jatropha* cultivation

In southern Mexico, farmers are attempting to realize food production and *Jatropha* cultivation concurrently receiving various supports from different level of institutions since 2006, when the new government of Chiapas State announced the start of the Chiapas Bioenergy Programme (*el Programa Bioenergético de Chiapas*). The staff of IRPAT (*Instituto para la Reconversión Productiva y la Agricultura Tropical del Estado de Chiapas*) of the Chiapas State Government visited many villages and promoted *Jatropha* cultivation. In response to the initiative by the Government, farmers came together from 2007 and the substantial *Jatropha* cultivation started from 2008.

The Chiapas State Government had imported *Jatropha* seeds from India in 2007 and 2008, and they raised seedlings and supplied them at no charge to farmers. In addition, the farmers collected native *Jatropha* seeds and cuttings from live fences in and around their villages and they planted them at a spacing of 2m x 2m in their field.

In the Chiapas State, Tierra Santa Village and El Parral Village are early front-runners in the cultivation of *Jatropha*. In both villages, *Jatroph*a is planted where efficient agriculture using farming equipment is difficult due to rocky and sloping agricultural land and most agricultural works are carried out by hand. So far, *Jatropha* is intercropped with maize, frijol bean and groundnut; however, most farmers are planning to stop intercropping by 2011, after the *Jatropha* plantation has become 3 years old, because the large growth of *Jatropha* plants by that time would make intercropping difficult. They will then continue to grow food crops only on fallow fields.

2. Support mechanism for *Jatropha* cultivation to farmers

Farmers are actively engaging themselves in cultivating *Jatropha* as they are receiving support of CONAFOR (*Comisión Nacional Forestal*) and INIFAP (*Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias*) of the Federal Government, IRPAT (*Instituto para la Reconversión Productiva y la Agricultura Tropical del Estado de Chiapas*) of the State Government, and the USB. Among these organizations, the USB plays a central role in the support system for farmers. Some of the functions of each organization are summarized as follows:

2.1. USB: USB was established in 2008 to support the *Jatropha* growers in the Chiapas State. Farmers form a *Jatropha* cultivation group in the villages and the USB represents these groups. Each organization of the Federal and the State Government has different support activities for farmers, while the USB coordinates these activities and serves as a bridge between producers and governmental organizations. Specifically, the USB coordinates between CONAFOR, INIFAP, IRPAT and farmers, and provides technical assistance and consultation in terms of *Jatropha* cultivation in the field (Fig. 1). USB staff members provide guidance to farmers to cultivate *Jatropha* on the land preferably unfit for agricultural use.

2.2. CONAFOR: CONAFOR is one of the Federal Governmental organizations, which is in charge of forest administration. It supports farmers with funds for *Jatropha* plantation as a reforestation activity. Farmers receive funds if they plant 2,500 *Jatropha* seedlings per hectare and also the plantations comply with requirements of CONAFOR through two years monitoring. USB assists all the necessary procedures for farmers.

2.3. INIFAP : INIFAP is one of the Federal Governmental organizations, which is in charge of investigation and extension activities of agriculture, livestock and forestry. INIFAP provides training in *Jatropha* cultivation techniques to USB staff and the USB staff provides technical guidance of *Jatropha* cultivation to farmers in the field.

2.4. IRPAT: IRPAT is one of the Chiapas State Governmental organizations, which promotes tropical agriculture. IRPAT imported *Jatropha* seeds from India and provided the seeds and seedlings to farmers free of charge.

Discussion and conclusions

In Tierra Santa Village and El Parral Village in the Chiapas State in Mexico, the farmers are actively engaged in cultivating *Jatropha* concurrently with food crops such as maize, frijol bean and groundnut on rocky, sloping agricultural land which is not suitable for efficient agriculture. The farmers are receiving a diverse range of supports from the Federal and the State Government

and a non-government association. Among the support institutions, USB, the non-government association, is the unique and the most important one that performs all necessary functions and coordinates with the different institutions concerned with *Jatropha* cultivation. They also provide technical assistance and consultations to farmers. As described above, concurrent food crops and *Jatropha* cultivation are based on such factors as voluntary and creative attitude of farmers, supports by different Governmental Institutions, coordination and technical assistance by USB and access to enough land by farmers.

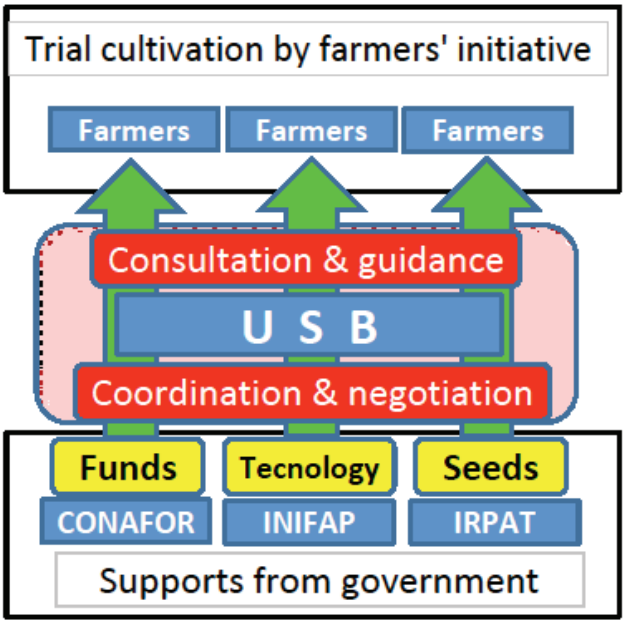

Fig. 1 Function of the USB

The first harvest of *Jatropha* by the farmers will be made in 2011; however there is no identified market for their produce as yet. So, the farmers are worried about the situation and they are thinking about cutting down *Jatropha* to plant another crop such as avocado if *Jatropha* does not make profit. To continue concurrent food crops and *Jatropha* cultivation, it is strongly recommended to create a market with an appropriate price setting of *Jatropha* by the Government.

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Concluding Session of the 10th International Conference on the Development of Drylands

15 December 2010

Session Chair: Prof Dr. Adel El-Beltagy, Chair

I. Panel Discussion for Developing Cairo Declaration

Panel Members

- Dr. Adel El-Beltagy, Chair, IDDC and Chair Agriculture Research and Development Council of Egypt
- Dr. Hans van Ginkel, Emeritus Rector of UNU
- Dr. Farouk El-Baz, Director, Center for Remote Sensing, Boston University
- Dr. Stephen G. Wells, President, Desert Research Institute, Nevada, USA
- Dr Gareth Wyn Jones, Emeritus Director, Center for Arid Zone Studies, University of Bangor, Wales; Secretary General, IDDC
- Dr M.V.K Sivakumar, Director, Climate Prediction and Adaptation Branch, WMO
- Dr J.S. Samra, CEO, National Rainfed Area Authority of the Government of India
- Dr. Mohan C. Saxena, Member National Academy of Agricultural Sciences of India, Senior Advisor to ICARDA Director General; Executive Secretary, IDDC

Summary of the Deliberations

1. The Chair emphasized that the global climate change was occurring at the rates faster than those predicted by various reports of the Intergovernmental Panel on Climate Change (IPCC), and there was urgency for developing and applying adaptive and mitigation strategies to protect the vulnerable communities in the dry areas as they constitute a large segment of the populations that reside there and suffer from poverty. However, the development of effective interventions would very much depend upon the precision with which the assessment can be made of the impact of the climate change locally in different agro-ecologies. The assessment heretofore has been global or at the lower end at the regional scale. The local assessment will have to be driven by the tools and information generated in the global and regional assessments, and the process will have to iterative and continuous. He also emphasized that the adaptation and mitigation strategies will have to be applied simultaneously so that there is sustainability of the benefits accruing to the vulnerable communities from adaptive interventions. In order to chart out the course of future action, under the title 'The Way Forward', the Chair said he had requested the members of the panel as well as Dr Charles Kennel, Professor Atmospheric Science, Scripps Institute of Oceanography (SIO), UC San Diego and Dr. Ayman Abou-Hadid, President of ARC, to distill the recommendations emerging from the deliberations of the Conference over the last couple of days and present them to the open house for developing consensus and frame a declaration - Cairo 10th ICDD Declaration. He invited the Dr Gareth Wyn Jones, Secretary General of IDDC to introduce the recommendations.
2. Dr Wyn Jones, referring to the presentation of Dr Rattan Lal, reminded that there was only a period of 20 years before the situation with respect to the climate change could become out of control and hence both adaptive and mitigating actions would have to be simultaneously

applied. The presentations in the last three sessions have provided scientific evidence that the carbon foot prints of agriculture could be considerably reduced through appropriate adaptive interventions. He then invited Dr M.V.K. Sivakumar to present the recommendation.

3. Dr Sivakumar presented the preamble, the main recommendations and suggestions for action through a series of slides. The panel members made additional comments to complement the information presented or to elaborate it. The presentation was then opened for discussion.
4. There was a general acceptance of the recommendation by the members present in the audience. In addition, the following points were made by some of the participants:

a. Dr Ahmed Osman, while appreciating the recommendations, asked about the mechanism that would permit monitoring of the implementation of the recommendation.
b. Dr Stefanie Christmann reminded that there would be a need to cover the areas that are currently not dry, but would become so after some time, particularly in the high altitude areas being affected by melting and disappearance of glaciers, e.g. Tajikistan and Kyrgyzstan.
c. Dr Adel Aboul-Naga said that although reference to agriculture would encompass the livestock as well, but it would be desirable to make this point more explicit in the recommendation as there will be very serious implications of climate change on the livestock sector. The mitigation issue will have be more emphasized, and role of livestock in this regard will have to be more clearly articulated.
d. Dr Wang Tao emphasized the need for connecting with UNCCD so that the recommendations being made are implemented within the intergovernmental framework.
e. Referring to the point related to the monitoring of implementation of the recommendations, the Chair indicated that the COP in Cancun has already asked the developed and developing countries to submit reports on yearly and biennial basis, respectively.
f. Dr van Ginkel referring to the recommendation #9 said that its coverage should be expanded to cover areas in addition to WANA. He suggested to use the term CWANA-Plus, which would then cover all major dry areas.
g. Dr Wyn Jones appreciated the comprehensive coverage in the declaration, but underpinned the need for more clearly reflecting the sense of urgency for action. The Chair agreed and suggested that this should be reflected in the end of text.
h. Dr Wells agreed to more explicitly reflect the urgency element. He added that there would be also opportunities arising from the challenge of climate change and these may also have to be reflected. Use of modern communication tools and the art of storytelling might enhance the adoption of risk-mitigating and environmental friendly technologies/interventions.
i. Dr Samara also emphasized the need of not overlooking the opportunities arising from the anticipated changes and not rstrict only to the negative impacts. With respect to carbon sequestration, he emphasized the need for actions that would also promote sequestration of inorganic carbon in addition the organic carbon sequestration. In the desert landscape the competition between the solar energy farming and wind energy farming and their impact on local communities will have to be considered.
j. Dr Sivakumar thanked the participants for their valuable comments and assured that these will be appropriately reflected in the 'Declaration'.
k. The Chair thanked the panel for developing the draft declaration and particularly appreciated the effective manner in which the contents were articulated by Dr. Sivakumar. He assured the participants that final version of the 'Cairo Declaration' will be sent to all concerned soonest possible.

II. Date and Place of the 11th ICDD

The Chair reminded the participants that during the 9th International Conference on Dryland

Development held at Alexandria in November 2008, there was an invitation on behalf of the Indian Council of Agricultural Research (ICAR) to host the 10th ICDD in India at the Central Arid Zone Research Institute (CAZRI) located in the Thar Desert area. However, before the official confirmation could come there was a strong request from the Sultanate of Oman to hold the10th ICDD in Muscat and therefore the follow up on the invitation from India was deferred. He said, he was glad that Dr Murari Roy, the present Director of CAZRI, was present in this Conference and has come up with renewed invitation. He invited Dr Roy to take the floor and present his proposal.

Dr. Roy confirmed that the Indian Council of Agriculture is interested in hosting the 11th ICDD in India in 2013, either at New Delhi or at CAZRI. The most appropriate time would be November/ December. If the Conference were to be held in Delhi, which might be more convenient from the logistics point of view, the participants could be taken to CAZRI for a post Conference scientific visit. The Chair greatly appreciated the invitation presented by Dr Roy and said he was fascinated by the research and development work for sustainable development of dry areas being done there. Hence, holding the 11th ICDD there would be very rewarding. He then opened the invitation to the house. The proposal was welcomed by a very big applause. The Chair thanked Dr Rao and, through him, the Indian Council of Agricultural Research for the invitation. He informed the house that the decision on the exact date and time will be taken in consultation with the hosts and communicated to all the participants.

III. Vote of Thanks

Dr. Mohan Saxena, Executive Secretary of ICDD proposed a vote of thanks:

- H.E. Mr. Amin Abaza, Minister of Agriculture and Land Reclamation for providing the patronage to the Conference.
- Professor Dr Ayman Abou-Hadid, President of ARC for hosting the Conference, Chairing the Local Organizing Committee and providing all the necessary logistic support.
- Members of the Local Organizing Committee and staff members of ARC responsible for providing IT support and arranging and guiding field visit.
- BELCO Farm for demonstrating application of modern production technology for sustainable and profitable use of desert lands and for hosting the participants for a sumptuous lunch.
- Members of the International Scientific Committee for their input in developing technical program and reviewing the abstracts of voluntary submissions for oral and poster presentations.
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- All the delegates for their effective participation in the scientific deliberations of the Conference and contributing to its success in meeting the objectives of the International Dryland Development Commission (IDDC).
- The Chair of the IDDC for his leadership in organizing the Conference.

Cairo IDDC-10 Declaration

The Tenth International Conference on Development of Drylands: *Meeting the Challenge of Sustainable Development in Drylands under Changing Climate – Moving from Global to Local,* was organized by the International Dryland Development Commission (IDDC) and hosted by the Agricultural Research Centre (ARC) of Egypt in Cairo, Egypt from 12 to 15 December 2010. The Conference was co-sponsored by the Association of Agricultural Research Institutions in the Near East and north Africa (AARINENA); the Arid Land Research Center (ALRC), Tottori University, Japan; the Chinese Academy of Sciences (CAS), China; the Desert Research Institute (DRI), Nevada, USA; the International Center for Agricultural Research in the Dryland Areas (ICARDA); the International Fund for Agricultural Development (IFAD); the International Development Research Center (IDRC), Canada; the Japanese International Research Center for Agricultural Sciences (JIRCAS); the Japanese International Cooperation Agency (JICA); the United Nations University-Institute for Water, Environment and Health (UNU-INWEH); and the World Meteorological Organization (WMO). The Conference was attended by around 147 participants from 18 countries and 12 international and regional organizations.

Recognizing that:

Drylands are among the world's most fragile ecosystems and support some of the world's poorest populations;

The global temperature increase, regional precipitation decreases, changing seasonal patterns, and more frequent and intense extreme events driven by global climate change are already placing considerable stress on dryland agriculture and that these stresses will intensify in the coming decades;

The soil degradation and desertification due to erosion, fertility depletion, salinization, and acidification will become worse without vigorous human efforts to counter them and that the area under drylands and out-migration of populations from drylands is expected to increase;

Agri-food activities (primary production, land use/land cover changes and food chain, storage, distribution and cooking) currently account for more than 20% of the global emissions of greenhouse gases;

The mitigation of and adaptation to climate change go hand in hand, especially in dryland regions, and are essential parts of the sustainable development agenda.

Based on 23 years of IDDC activities and deliberations during the IDDC-10, the participants of this Conference therefore make the following key recommendations:

1. We recommend that the best approach to an uncertain future in the drylands is the recognition and management of adaptation, mitigation, and development as linked processes. We must therefore think and act in terms of "process-planning", not of "blue-print" planning. This approach implies an ongoing commitment to regional climate change impact assessments and periodic updating of the adaptation, mitigation and development strategy (referred to hereinafter as AMD) to fill the gap between the global expertise and the local capacities.

2. We recommend that the primary purpose of a regional assessment is to inform and motivate decision-making resulting in timely action at the local level. The focus should be on minimization of risks to rural livelihoods from possible climate change and extreme events. This means that key decision-makers and local stakeholders must be part of the assessment process from the very beginning.

3. We recommend that dryland regions in different parts of the world should begin by assembling a knowledge action network that connects experts in the international and national communities with regional knowledge leaders and decision-makers, and these to local stakeholders and news media. This human social network should define the taxonomy of issues to be considered and collaboratively design the assessment process to inform and empower the communities.

4. We propose that all nations with significant dryland areas should undertake agroclimatic zonation and develop vulnerability indices for each of the zones to prioritize and implement appropriate AMD actions.

5. We advise that the effective and timely dissemination of climate information and their consequences for agricultural practices (preferably in local languages) is crucial for adaptive management by individual farmers and their communities at the local level and National Climate Services should be developed on a priority basis to facilitate this process.

6. We advise that the preparation and open access of topographical, climatological, vegetation, resource, land-use and similar maps is an essential first step in the assessment process. Supplementing such geographical information with historical research then defines the assessment baseline.

7. We recommend that the assessment then generates or acquires downscaled regional climate forecasts and satellite observation data and combines them with the agricultural and ecological studies and local knowledge. The goal is to understand the impacts on the socioeconomic activities of people in the region and the ways in which it would be possible to improve these activities and new ones eg., solar and wind farming.

8. We advise that the knowledge so produced in the above recommendations be framed for decision-makers in economically and politically effective terms and conveyed to local stakeholder communities in culturally sensitive ways.

9. AMD implies an ongoing commitment by policy makers to periodically repeated assessments. Institutional innovations are needed and can be justified by the commitment to adaptive management. These assessments will require regional information centres that assemble, integrate, and communicate weather, climate, and agricultural information on a transparent and open basis. We suggest that Centers such as the Climate Change Information Centre (CCIC) in Cairo, Egypt, be upgraded to serve all the drylands in order to educate the general public about climate change and how the government, local communities, and individuals can deal with the impacts of climate change. Finally, climate change extension officers should convey the best practices to individual farmers and their communities.

10. We suggest that safety nets of enabling policies, insurance, debt servicing, market interventions, food and employment security such as those implemented in India may be adopted.

11. We recommend that diversification of activities to livestock, horticulture etc., be encouraged to provide alternative sources of income to improve the livelihoods of local communities in the drylands.

12. Climate change is going to proceed well into the indefinite future. We recommend that capacity building activities in developing countries in the dryland regions be undertaken at different levels ie., individual farmers, communities, extension services, governments, policy makers etc., to ensure that adaptation and mitigation actions recommended by COP-16 in Cancun, Mexico, are taken up and implemented assiduously. The current UN Decade on Education for Sustainable Development could serve as a major starting point.

The Conference urges:

a. International Organizations such as the World Bank, the CGIAR programs (such as the CGIAR Research Program on Integrate Production Systems for the Poor and Vulnerable in the Dry Areas led by ICARDA), the UN Agencies such as WMO, UNEP, UNCCD, FAO, UNESCO, UNU, IFAD etc., and Regional Organizations such as ASEAN, ECOWAS, IGAD, SADC, SAARC, UEMOA etc., to help implement recommendations 1-3;

b. National Meteorological and Hydrological Services, National Agricultural Research Services, National Extension Services, Research Organizations, and Academic Institutions to work together in implementing recommendations 4-8;

c. National Policy Makers and Ministries to help implement recommendations 9-11. Policy-makers to take immediate action to support farmers and others in drylands areas in the management of risks resulting from drastic fluctuations in weather patterns. Furthermore, we urge that governments expand funding for research to mitigate effects of climate change and adapt as required;

d. All agencies mentioned in (a) to (c) to help implement recommendation 12.

15 December 2010, Cairo, Egypt

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International Conferences organized by

The International Dryland Development Commission in the past

1. First International Conference on Desert Development: Application of Science and Technology for Desert Development, Cairo, Egypt,1978.

2. Second International Conference on Desert Development: Desert Development Systems – technologies for Desert Agriculture, Energy and Communities, Cairo, Egypt, 1987.

3. Third International Conference on Desert Development, Beijing, China 1990.

4. Fourth International Conference on Desert Development: Sustainable Development for our Common Future, Mexico City, Mexico, 1993.

5. Fifth International Conference on Desert Development: Desert Development- The Endless Frontier, Lubbock, Texas, 1996.

6. Sixth International Dryland Development Conference: Desert Development-Challenges in the New Millenium, Cairo, Egypt, 1999.

7. Seventh International Dryland Development Conference: Sustainable Development and Management of Drylands in the 21st Century, Tehran, Iran, 2003.

8. Eighth International Dryland Development Conference: Human and Nature working together for Sustainable Development of Drylands, Beijing, China, 2006.

9. Ninth International Conference on Dryland Development: Sustainable Development in Drylands-meeting the Challenges of Global Climate Change, Alexandria, Egypt, 2008.

Tenth International Conference on Development of Drylands
Meeting the Challenge of Sustainable Development in Drylands under Changing Climate – Moving from Global to Local

12-15 December 2010, Cairo, Egypt

International Scientific Committee

Chairman

Prof. Dr Adel El-Beltagy, Chair of IDDC, Chair of Agricultural Research and Development Council of the Ministry of Agriculture and Land Reclamation, Government of Egypt

Members

H.E. Dr Hilal Al-Hinai, Secretary General, The Research Council, Sultanate of Oman

Prof. Iwao Kobori, Senior Program Advisor, United Nations University, Tokyo, Japan

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Prof. Dr R.G. Wyn Jones, Associate Director, Center for Arid Zone Studies, University College of North Wales, UK, Secretary-General, IDDC

Prof. Dr Atsushi Tsunekawa, Director of Arid Land Research Center, Tottori University, Japan

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Prof. Dr. Wang Tao, Director General, Cold and Arid Regions Environmental & Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China

Prof. Dr Mohan Saxena, Senior Advisor to the Director General, ICARDA, Gurgaon, Haryana, India, Executive Secretary, ICDD