

COMBATING DESERTIFICATION

ASSESSMENT, ADAPTATION AND MITIGATION STRATEGIES



Edited by Donald Gabriels, Wim M. Cornelis, Murielle Eyletters
and Patrick Hollebosch

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MONITORING, ADAPTATION AND RESTORATION STRATEGIES

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PREFACE

Considering that the world's drylands is home to more than 2 billion people and being concerned that many drylands are subject to desertification as a result of extended droughts, climate change and human activities, new scientific challenges and opportunities for research and development have emerged. The recent scientific results need to be addressed in order to promote sustainable development through action plans for combating desertification.

On Tuesday, January 22, 2008, Ghent University received the honour to be selected for the establishment of a UNESCO Chair of Eremology (science of drylands and desertification).

The foundation of this UNESCO Chair was a result of a long-standing cooperation with and support to UNESCO of scientists from ICE (International Centre for Eremology) through a science dedicated (Flanders/Belgium) Trust Fund. Activities are carried out in UNESCO's scientific programmes among which are mentioned the Intergovernmental Oceanographic Commission (IOC), the International Hydrological Programme (IHP), and Man and Biosphere (MAB). Within MAB, the programme SUMAMAD (Sustainable Management of MArginal Drylands), is focusing on improving land and water management in arid and semi arid areas, with a special attention to improve the livelihood of the populations living in these drylands.

A second UNESCO/PHI/Flanders Trust Funds project is CAZALAC (Centro del Agua para Zonas Áridas y Semiáridas de América

Latina y El Caribe, located in La Serena, Chile) were attention is given to research and education in drylands.

The UNESCO Chair for Eremology opens possibilities for international cooperation and projects related the actual problems of climate change, causes of desertification and land degradation, and means and ways to combat desertification.

As a follow-up of the inauguration of the 'UNESCO Chair on Eremology', the International Centre for Eremology (ICE) and the Belgian Expert Group on Desertification (Belgian Development Cooperation) organized the 'Conference on Desertification' on 23 January 2008 at the Faculty of Bioscience Engineering of Ghent University, Belgium.

The conference focused on recent research findings from the following main topics: (1) desertification and climate, (2) methods for assessing and monitoring desertification, (3) combating desertification. The results were presented in 11 oral papers and 30 posters, the latter being given ample attention. More than one hundred participants attended the one-day conference and papers were selected for publication in the proceedings of that conference, printed with support of the Belgian Development cooperation.

The organizers like to convey their thanks to UNESCO-Vlaanderen, the Belgian Development Cooperation, and Ghent University with its Faculty of Bioscience Engineering.

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Wim Cornelis (International Center for Eremology, Ghent University)
Murielle Eyletters (Université Libre de Bruxelles)
Patrick Hollebosch (Belgian Development Cooperation)

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THE BELGIAN DEVELOPMENT COOPERATION AND THE PROBLEMS OF LAND DEGRADATION AND DESERTIFICATION

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INTRODUCTION

The Unesco Chair on Eremology, inaugurated on 22 January 2008, chaired by Prof. Donald Gabriels and hosted at the ICE (International Center for Eremology), is not only putting Ghent University on the map of combating desertification, but also the entire Belgian community of scientists working in this complex field of science.

Desertification and land degradation are environmental and human-induced processes, affecting a large part of the Earth's surface, certainly the poorest parts of our planet. Desertification ranks amongst the greatest environmental challenges today and is a major impediment to meet the MDG's (Millennium Development Goals) and basic human needs in arid and semi-arid regions.

Drought and desertification are affecting the livelihood of 2 billion people, 90% of which are living in developing countries. Half of the people living below the poverty-line is settled in drylands and depends highly on ecosystem services from arid and semi-arid nature.

PARTICIPATION OF DIRECTORATE GENERAL FOR DEVELOPMENT COOPERATION (DGDC) IN THE MANAGEMENT AND EVALUATION

The Belgian Development Cooperation has been concerned with the problem of land degradation and desertification even before the United Nations Conference on Environment and Development (UNCED, 1992). Traditionally, land degradation has been included in the agricultural bilateral projects and programs. Numerous

activities in agricultural research, e.g. in ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) and ICARDA (International Center for Agricultural Research in Dry Areas) have been undertaken. On the other hand, activities in the water sector have impacts on the aridity of certain regions which is the reason why conservation of water resources is of great importance for our cooperation.

Belgium has always been a great defender of synergies between the three Rio conventions (Climate Change, Biodiversity and Desertification). This attitude should be followed for other Multilateral Environmental Agreements (MEA). Cooperation amongst scientists, in a multidisciplinary way, should be one of our targets certainly in combating desertification.

From the early start of the UNCCD (UN Convention to Combat Desertification) in 1996, the Belgian Directorate General for Development Cooperation (DGDC) has been involved in the process of negotiations for better management of land degradation and desertification. The attention went essentially to the financing of projects and programs by the GEF (Global Environmental Facility).

In 1997 Belgium joined the UNCCD with the Conference on Parties (COP) being its highest body with a secretariat in Bonn, Germany. The COP is supported by a Committee on Science and Development (CST) and by the Committee for Review of the Implementation of the Convention (CRIC). A Global Mechanism (GM) coordinates the bilateral and multilateral funding to combat desertification. The secretariat of GM is in the hands of IFAD (International Fund for Agricultural Development) and coordinates also the GM-information system FIELD (Financial Information Engine on Land Degradation).

Since 2002, and as result of a call from the World Summit on Sustainable Development (WSS, Johannesburg), the Global Environment Facility (GEF) became a financial mechanism for the Convention, with regard to sustainable land management.

The Convention puts emphasis on the coordination between the donors, introducing the concept of leadership whereby in a specific country one of the donors is appointed as coordinator. Important is the 'bottom-up' participation involving local communities with their local and traditional knowledge. However the bottleneck in all

the negotiations is the lack of a financial mechanism. Besides the voluntary contributions for running the secretariat, the Convention counts on existing financial resources such as bilateral and multi-lateral support and GEF (Global Environmental Facility) contributions.

Belgium established a Negotiation Committee for the Convention on Desertification who represents and defends the position of Belgium in the Convention. Prof. W. Van Cotthem has been the external scientific advisor for that Committee which role has been taken over in 2005 by the COORMULTI Desertification in order to have an official platform for the development of the Belgian position in the international negotiations concerning desertification. The group of Belgian Experts on Desertification, with its co-presidents being Prof. Murielle Eyletters (Université Libre de Bruxelles) and Prof. Donald Gabriels (Ghent University), gives advice on scientific and technological matters.

FINANCIAL CONTRIBUTION OF DGDC

Since 1996 Belgium contributes voluntarily through its DGDC an annual sum of 50,000 Euro to UNCCD for running its Permanent Secretariat. However, from 1999 on the Permanent Secretariat is no longer financed by UN, but the costs are covered by the Parties of the Convention. The budget for 1999 was almost 5,000,000 US\$. The repartition of it according to the UN-scale system resulted in a significant increase of the Belgian contribution because the most important donor, namely the USA, did not yet ratify the Convention. Since 1999 the contribution of Belgium amounted to about 80,000 Euro.

Belgium also supports numerous activities in agricultural research, e.g. in ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) and ICARDA (International Center for Agricultural Research in Dry Areas). DGCD also intervenes through outreach activities such as special editions of DIMENSIE 3 to enhance awareness among interested parties and the general public. Finally DGCD plans to bring a toolkit for environmental assessment at the disposal of planners in developing countries and to those who prepare and formulate such environmental programmes (and projects) to be financed in order to achieve the targets of MDG 7.

SOME CONSIDERATIONS

Global threats such as climate change are well known to the larger public. However, the threats by land degradation for the livelihoods of the poorest communities in most parts of Africa and in certain regions in South Asia and Latin America, are drawing less attention but are of great concern for the Belgian cooperation.

It is important to emphasize that, next to the pressure of biophysical conditions, socio-economic elements intervene largely in most cases. It is of utmost importance that local communities understand these threats and work towards broadly acceptable solutions. Also the environmental considerations will be integrated into the Belgian Development Cooperation and studies on environmental impact assessment will be implemented in the field.

For the upcoming years the following targets are set:

- updating the list of Belgian experts on desertification by the UN-CCD, in order to meet the challenges of the 10 year Strategic Plan and Framework for Desertification;
- setting up a CHM (Clearing House Mechanism, or website) for desertification, in relation with biodiversity and climate change, in order to collect ‘best practices’ of our cooperation in the field of land degradation and desertification;
- cooperation with member states of the EU on desertification, in order to arrive at multilateral programs and projects in the field of desertification.

These targets can only be met with the full cooperation of the academic world and the NGO’s who are active in the field.

LINKING DROUGHT TO DESERTIFICATION IN AFRICAN DRYLANDS

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INTRODUCTION

For a long time the word 'desertification' had many obscure definitions and desertification has developed into a complex and vague construct. Recently, however, it was internationally agreed to define desertification as 'land degradation in drylands'.

When African dryland farmers are asked to prioritize their major productivity-reducing problems, drought always ranks higher than land degradation. However, in the last century, a great deal of research in sub-Saharan Africa has focused on desertification and projects focusing on desertification mitigation were implemented with limited success.

Farmers' notion of drought relates to the occurrence of dry spells. Several recent studies in areas where farmers suffer from droughts, however, have yielded little evidence of an increase in the length and/or frequency of such dry spells. It is not possible to influence timing and amount of rainfall. A focus on more efficient rainwater use, a concept called 'more biomass per drop', can be a link between farmers and scientists.

VIEW OF SCIENTISTS AND FARMERS

Natural resources scientists study the dynamics of land (use) with a number of methods. Given the beta background of most natural resource scientists quantitative methods are preferred. Methods are scale dependent. At the regional scale remote sensing in combina-

tion with geographical information systems are often used. At lower scales measurements of soil characteristics and physical models are popular. Since the 1976 UN Conference on desertification in Nairobi a large number of publications with a 'doom' character have been published. These papers indicate that with respect to the state of land degradation 1700 million ha are affected by water and wind erosion (Oldeman, 1991). With respect to the rate of land degradation a soil loss of 30-40 t ha⁻¹ yr⁻¹ is mentioned for Africa (Pimentel et al., 1995). With respect to the impact there is 10 million ha of abandoned land due to land degradation and there is a productivity loss of 8% per year (Pimentel, 2006). These conclusions, in firm figures, hardly talk about variability and uncertainty.

Farmers on the other hand use different ideologies, norms and values with respect to the dynamics of land (use). These are often well described in ecological anthropological literature. Farm communities can be described as risk societies (Douglas, 1992) with a lot of uncertainty (Croll and Parkin, 1992) and insecurity (DeBruijn and van Dijk, 1995). This literature tries to find qualitative answers to questions such as 'how do farmers perceive their environment when insecurity is part of normal life?' and 'what does variability mean for farmers'.

This paper tries to bridge the gap between on the one hand how local people in African drylands consider constraints to productivity, and on the other hand, what scientist traditionally see as the major problem to sustained production.

PROOF OR PUZZLE?

Besides the wealth of literature claiming that land degradation is serious (the 'doom' papers) there are as many other papers questioning land degradation claims. One of the first of these was by Tiffen et al. (1994) and a more recent one is by Fleskens and Stroosnijder (2007). These latter authors studied soil erosion in olive groves in Portugal and Italy. Alarming erosion rates have been reported in olive groves on sloping and mountainous land with some regional averages supposedly as high as 40 – 100 ton ha⁻¹ y⁻¹. The variation in reported erosion values is enormous; a literature review (of various types of assessments) yielded erosion rates with upper and lower limits differing more than a factor of 10 000. Based on experimental

data from rainfall simulations, runoff plot studies and field assessment of erosion symptoms, they suggest seven factors to be taken into account, to achieve more realistic estimates of erosion. Results suggest that average soil erosion rates in olive groves are unlikely to surpass $10 \text{ ton ha}^{-1} \text{ y}^{-1}$, which is nevertheless still more than the soil renewal by weathering (about $1 \text{ ton ha}^{-1} \text{ y}^{-1}$).

According to Lal (2001) the extent, severity, and economic and environmental impacts of soil degradation by accelerated erosion are debatable. Estimates of the global and regional land area affected are tentative and subjective. The impact of erosion on soil qualities and productivity is also uncertain (Stocking and Murnaghan, 2001), and field measurements are scale- and technique-dependent (Stroosnijder, 2005; Stroosnijder, 2007). Although considerable progress has been made in modeling soil erosion, the validation of the models remains poor. In conclusion, many of the authors of the ‘how serious is soil degradation?’ papers have concluded that there appears to be little evidence of widespread soil degradation, though this does not preclude severe local degradation in sub-Saharan Africa. It seems that when assessing soil degradation the ‘experts’ may very well be overestimating it.

Farmers relate their notion of drought mainly to the occurrence of dry spells. The success or failure of a crop depends more on the distribution of rainfall over the growing season than on the total rainfall in that period, Sivakumar (1991). A method to characterize the ‘goodness’ of this distribution is an analysis of the probability of dry spells. In meteorological analysis (using Markov chain methods) a dry spell is a period without effective rain. In agricultural terms (using a water balance model) a dry spell is a period with consecutive dry days resulting in a soil water deficit causing crop water stress (Barron, 2004). Meteorological analysis either over- or underestimates agricultural dry spell analysis, depending on the soil’s waterholding capacity. Barron et al. (2003) consider a dry spell between 5–15 days to be harmful for sub-Saharan Africa. In Kenya and Tanzania, a 10-day dry spell has the potential to damage a maize crop due to water deficit.

However, in several recent studies there is little evidence that the length and/or frequency of dry spells have increased. Seleshi and Camberlin (2006), using daily rainfall of 11 key station from

1965-2002, found no trends in the yearly maximum length of Kiremt and Belg dry spells over Ethiopia. Similar conclusions were drawn for other African drylands by Niemeyer and Mazzucato (2002) and Conway et al. (2004). So, there should be another explanation why farmers experience dry spells nowadays as more harmful than before. Slegers and Stroosnijder (2008) found that farmers' perceptions most closely resemble the concept of agricultural drought, i.e. that to farmers, "drought" implies much more than just shortage of rainfall. The water holding capacity (WHC) of soils plays a key role in their analysis.

WHC: BRIDGING THE GAP

What farmers mean by drought has little to do with rainfall anomalies or climate change but is instead an indirect result of soil degradation. Farmers' perception of dry spells refers to soil water drought, i.e. situations where plant production suffers because water is not available. Frequency and intensity of soil water droughts increase due to deteriorated physical properties of soil.

Rain that hits bare soil causes soil aggregates to break up. Due to this surface sealing, only a small portion of rainwater can infiltrate the soil; most of it runs off over the soil surface and is therefore lost for biomass production (Stroosnijder and Koné, 1982). The drying of a surface seal results in soil crusting, that may hinder or impede the germination and emergence of seeds. In other words, in a complex combination of both direct and indirect soil physical/hydrological processes, the proportion of the rain that can be used by vegetation decreases and the proportion that discharges increases. Pimentel (2006) considers the lower water availability due to soil degradation a major global food and environmental threat.

Rainfall meets land at the soil surface and is divided over several pedo-hydrological components. Rain falling on the land may be intercepted by vegetation, run off the ground surface, or infiltrate into the soil. This is reflected in the rain water balance:

$$P = INT + I + R \quad (1)$$

with P = rainfall (mm), INT = interception of rain by vegetation (mm), I = infiltration (mm) and R = runoff (mm). It is assumed that

runoff is lost from the field, giving notion to the terms on-site and off-site water.

Infiltrating water may be stored (S in mm) in the root zone or drain (D in mm) below the root zone to groundwater and stream base flow, contributing what is nowadays called 'blue water'. These processes are reflected in the infiltration water balance:

$$I = \Delta S + D \quad (2)$$

with ΔS (positive value) the change in amount of water stored in the root zone (mm) and D drainage below the root zone (mm).

Water stored in the root zone may be lost (negative value of ΔS) as evaporation from the soil surface into the atmosphere (E) or taken up by plants and lost as transpiration (T). This is reflected in the soil water balance:

$$\Delta S = E + T \quad (3)$$

The maximum amount of stored water in the root zone available for plant growth (i.e. plant roots can extract the water from the soil) is a very important soil characteristic because it determines the potential survival of plants in case of a dry spell. This Total Available Water (TAW) in the rootable part of the soil profile is reflected in the plant water balance:

$$TAW = RD * 0.9 (FC - WP) \quad (4)$$

in which RD is the rootable depth (mm), WP is the wilting point, i.e. the moisture content if the water potential equals -1.6 MPa (pF 4.2). When plants are in soil at WP they will die, hence the safety factor of 0.9. During complete wetting by rain the moisture content of root zone may become close to saturation. In the next 24 h, however, the moisture content will decrease due to drainage to below the root zone. This process stops when the soil water potential has reached a value that is called (by definition) field capacity (FC). The soil water potential then is between -10 kPa (pF 2.0) and -33 kPa (pF 2.5).

Soil degradation affects many of the terms in the above four equations. Soil degradation decreases infiltration, waterholding ca-

capacity and transpiration, but enhances runoff and soil evaporation. In a complex combination of both direct and indirect soil physical/hydrological processes, the proportion of the rain that can be used by vegetation decreases leading to an increased drought vulnerability.

An example of such increased drought vulnerability can be given. In a non-degraded soil with average physical properties the rootable depth can be 600 mm and $(FC-WP) = 0.13$. Hence $TAW = 70$ mm. With an actual evapotranspiration (ET) of 2.5 mm d^{-1} ($E = 2$; $T = 0.5$) this implies that the stock of water for a crop as described above is sufficient for a dry spell of 28 days or four weeks. Of course, this is only the case if the soil was fully replenished at the start of the dry spell, i.e. if infiltration of previous rain was good. In a degraded soil the rootable depth often is reduced due to the removal of top soil by erosion. Also the texture of the soil has become coarser due to selective removal of the finer particles and the structure has degraded due to the decrease of soil organic matter. In the above example this leads to a rootable depth of only 400 mm and a FC-WP of only 0.10. This implies that TAW is only 36 mm. Sufficient for only 14 days or two weeks! This change in the length of the dry spell that plants can overcome is what farmers mean with their 'drought' problem.

WHC is an important issue at various scales, from the plot to the watershed. Mahe et al. (2005) gave an interesting example for the watershed scale. They studied the hydrological regime of the Nakambe in Burkina Faso from 1955 – 1998. The catchment in Burkina Faso is about 20 000 km². Their data analysis showed the following paradox: over the 1965-1995 period the river discharge has increased with 60% in spite of 20% less rainfall and an increase in dam storage volume from 55 to 170 106 m³. The explanation for this paradox can be found in a decrease in WHC of 33-62% due to land use changes with subsequent changes in runoff. Cultivated areas and bare soil have increased at the expense of natural vegetation (Table 1).

IMPROVING RAIN WATER USE EFFICIENCY

Water scarcity is undermining our habitat, economy and society (ISRIC, 2008). The replenishment source of fresh water is rainfall. At the global level, two thirds of our renewable fresh water is green water held in the soil. Only one tenth is accessible stream flow and

Table I. Land use changes and runoff coefficients in the 20 000 km² Nakambe catchment in Burkina Faso (after Mahe et al., 2005)

	% in 1965	% in 1995	Runoff %
Natural vegetation	43	13	13
Cultivated area	53	76	20
Bare soil	4	11	50

groundwater, blue water, of which more than two thirds is already used for irrigation (Fig. 1). Hence improving rainwater use efficiency in rainfed agricultural production systems is urgently needed to feed (and fuel) the world.

In scientific terms farmers, with their notion of drought, refer to what may be called Green Water Use Efficiency (GWUE), i.e. the fraction of rain that is used for plant transpiration. Land use changes often affect the quantity of green water and reduce GWUE. But GWUE not only decreases due to land cover changes but also due to deterioration of physical soil qualities as a result of land degradation. Land degradation decreases infiltration, waterholding capacity and transpiration, but enhances runoff and soil evaporation. These agro-physical processes decrease the GWUE; in drylands in sub-Saharan Africa the GWUE ranges from 5–15%, which is very

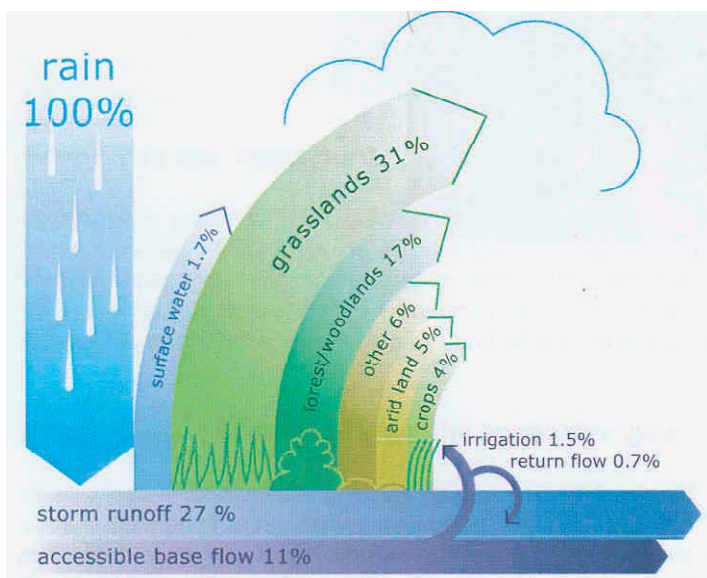


Figure 1. Global flows of green and blue water (ISRIC, 2008)

low. In East Africa it may reach 20%, but in comparable climates in the USA the GWUE may be above 50%.

Water use in African drylands is mm work; plants can produce with little water. An example is millet grown in West Africa. With a subsistence grain harvest of about 500 kg dry matter (DM) ha⁻¹ and straw and roots are each 1000 kg DM ha⁻¹, total dry matter is 2500 kg DM ha⁻¹. Millet has a C4 photosynthesis mechanism so that it uses water rather efficient. The transpiration coefficient is 200 kg water per kg DM. The total crop then consumes 2500 * 200 = 500,000 kg water ha⁻¹. This is only 50 mm ha⁻¹. It often occurs in African drylands that with a growing season of 100 days with a rainfall of 600 mm, E equals 200 mm and T only 50 mm. This reflects the very inefficient use of precipitation.

There is great potential to mitigate soil water drought in sub-Saharan Africa via appropriate land management practices (Table 2; Stroosnijder, 2003; Stroosnijder, 2008). The concepts of such drought mitigation can be derived from knowledge of the above four field water balances. They can be classified according to their function: for reducing runoff (e.g. hedgerow barriers and terraces); for improving water availability (e.g. mulch and soil fauna); and for improving GWUE (e.g. water harvesting and water–nutrient synergy).

Table 2. Land management practices and their effect on different terms of the four field water balances

	Reduce Runoff & improve Infiltration Eqs. 1, 2	Improve Storage & reduce Drainage Eq. 2	Reduce soil Evapora- tion Eq. 3	Improve TAW & GWUE Eq. 4
<i>On-site: area practices</i>				
Mulch	x		x	
Stimulating soil fauna	x			x
Conservation tillage	x	x	x	x
Crust breaking	x			
Organic amendments	x	x		x
Water–nutrient synergy			x	x
Exclosure	x	x		x
<i>On-site: line practices</i>				
Hedgerows	x			x
Stone rows	x			x
Vegetation barriers	x			x
Trees			x	x
Terraces	x	x		x
<i>Off-site practices</i>				
Water harvesting				x

CONCLUSIONS AND DISCUSSION

From the perspective of poverty reduction (Millennium Development Goal no. 1) and the conservation of natural resources in Africa (MDG no. 7), it is of importance that the perception of the farmers' production-reducing obstacle 'drought' is taken into consideration. Farmers' problems with soil water drought can be solved by applying land management practices that not only conserve water but also make better use of the available water. By enhancing GWUE, water conservation practices can easily provide more available water for both more food crops as well as for the greening of current land use systems. Farmers recognize the positive effects of increasing the vegetation cover. Science has not found significant proof yet but farmers are convinced and say 'planting trees brings rain'.

Soil and Water Conservation (SWC) includes all actions that stop the further decrease of or restore (1) the vegetation cover in order to protect the soil against the impact of rain, (2) the efficiency of the rainwater use and (3) physical, chemical and biological soil qualities. During the last decades the focus in SWC was mainly on soil conservation. Returns to soil conservation, however, are usually retarded in time, i.e. it takes some years. We are convinced that returns to water conservation show-up faster than for soil conservation. In semi-arid Africa water conservation can easily double GWUE and can largely improve food security. The best way to do so is to combine water conservation with nutrient management because this leads to the highest resource use efficiencies. Still the problem of high investment costs remains. Farmers should receive monetary support for that.

With a growing recognition of environmental services (Millennium Ecosystem Assessment, 2005) the idea of paying farmers 'credits' for providing these services came up. Farmers should be seen as caretakers of our precious planet earth (Hurni et al., 2006) providing healthy food and water in a healthy environment and those who profit from that should pay for these services. In other words urban people pay rural farmers or downstream farmers pay up-land farmers.

At present there are too many definitions for land degradation. In fact it may be questioned whether changes in land or land qualities that result from deliberate changes in land use, for instance due to economic development, may be called land degradation. Since

humans have influenced the land since the origin of mankind, it may be better to call such changes 'land development' to distinguish them from undesired changes in ecosystem services.

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DROUGHT MITIGATION THROUGH PREDICTION FOR AN ARID ZONE IN CHILE

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INTRODUCTION

A common observation in semi-arid zones is the occurrence of climatic variability between one year and another, resulting in droughts in some years and in water excess or flooding in others. Figure 1a shows the variation in total rainfall amount in arid La Serena (Chile, see Fig.3) observed during the period that is considered the wet season (May-June-July-August), indicating a large climatic variability between individual years. Additionally, a negative trend in rainfall amounts has been identified in the IVth region during the last century, as shown in Fig. 1b, resulting in a higher probability for droughts to occur.

On the other hand, climatic variability has increased during the last decades, as shown for example by an increase in Climatic Aggressivity (Modified Fournier Index, Fournier, 1960) in recent years (Fig. 2), which indicates a larger vulnerability of the ecosystem to soil degradation by erosion.

This increased climatic uncertainty affects that part of the population that is dependent on annual rainfall resources, such as farmers practicing rain fed agriculture and cattle farmers that use the natural vegetation as a fodder (approximately covering an area of 2.5 million hectares) (INIA, 2005). This climatic uncertainty is probably one of the reasons why the rural population has declined in favor of a further urbanization in that region (80% population increase in the last 20 years), a common observation in many dry parts of the world (Linden, 1996).

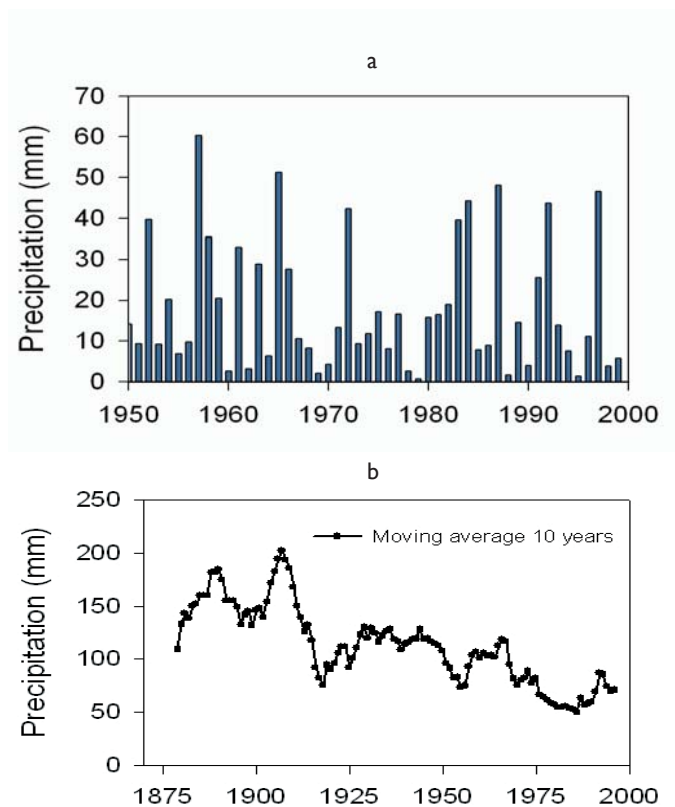


Figure 1. Total precipitation in the wet season (a) and 10-year moving average total rainfall amount (b) for La Serena, Coquimbo Region

Prior knowledge of climatic extremes, through climatic predictions, would be of mayor importance to a large part of the population, as well as to the public sector dealing with disaster relieve plans. Such an early warning system (EWS) could also play a role in improving rain fed agriculture, optimizing crop choice depending on predicted rainfall conditions. For the same reason, such a EWS would have its impact on forestation programs to combat desertification, whose successes are highly dependent on water resources during the first year(s). As an illustration it can be mentioned that forestation programs with (*Prosopis juliflora*) in North Peru are already coordinated to coincide with the occurrence of the El Niño phenomenon, to effectively use the extra rainfall associated with that phenomenon. Therefore, an early warning system for climatic extremes could be considered as an important improvement for dry-land management in the arid zones of Chile. In this short paper, the fundamentals of such a system are described and the feasibility to perform climatic predictions for the Coquimbo Region (Fig. 3) is evaluated.

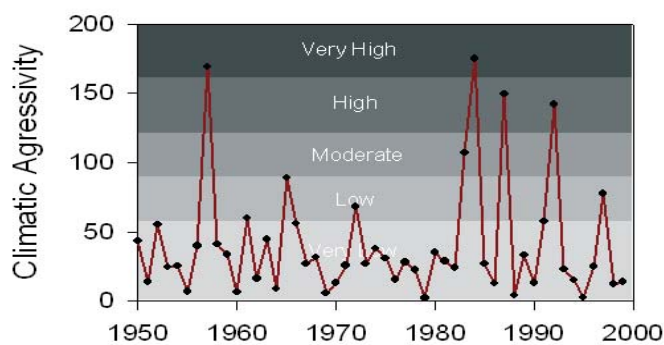


Figure 2. Climatic aggressivity at the La Serena climatic station

Figure 3. Map of the Coquimbo Region and the La Serena measurement station



THEORETICAL FRAMEWORK

Although weather can not be predicted for more than 10 to 15 days in advance, climatic variables, such as rainfall totals, number of wet days, etc. have certain predictability, due to their dependence on global phenomena. The best known example of this behavior is the influence of El Niño Southern Oscillation (ENSO) on rainfall in the tropics. Less known is that this phenomenon is also influencing climates in locations that have no physical connection with the origin of the phenomenon (the tropical Pacific), through so called tele-connections, that are only recently being understood.

The El Niño and la Niña phenomena indicate respectively, an increase or decrease in sea surface temperature (SST) in the Equatorial Pacific, in a region comprised between 5S-5N and 170W 120W, also known as the NIÑO 3.4 area (Fig. 4a). The SST is expressed in terms of its anomaly with respect to an average year, as observed in Fig. 4b, indicating El Niño conditions with SST 0.5°C above normal and La Niña, when SST is below normal using the same threshold.

El Niño provokes heavy rains at the coast of Ecuador, Peru and the North of Chile, from Guayaquil to the South, regions that are

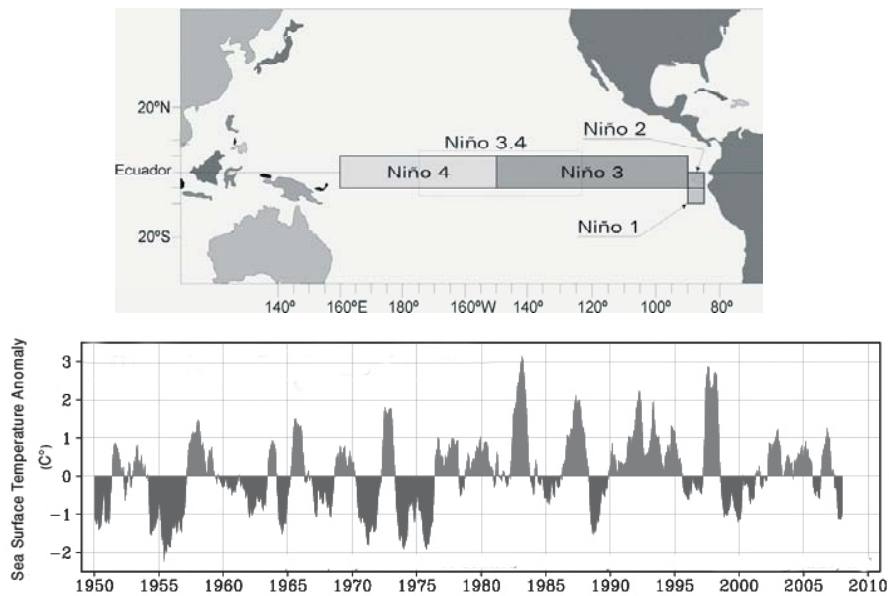


Figure 4. Regions in the Equatorial Pacific Ocean whose temperature anomalies are used as indices to determine the intensity of ENSO (a) and Sea Surface Temperature Anomalies in the Niño 3.4 area (b)

normally extremely dry. The precipitation is caused by high evaporation at sea, whose surface temperature registers temperatures that are various degrees above normal. Additionally, storms are favored by the low pressures that are observed at the same time in those regions. On the other side of the Pacific Ocean, the decrease of the SST and increase in atmospheric pressure provoke droughts in Indonesia and the North of Australia, regions that are normally very humid (Voituriez and Jacques, 2000; Uriarte, 2003).

In this study, two methods were used to make climatic predictions. In the first place, a Global Climate Model (GCM) was applied, ECHAM 4.5, that couples oceanic, atmospheric and land interactions to predict variations in SST at the medium term. Figure 5 shows an example that predicts the SST anomaly using a GCM, resulting in a series of different predictions starting from the same initial situation, due to the complexity of the processes involved. Nevertheless, it is possible to identify a tendency in the results, indicating an increase in the SST and the development of an ‘El Niño’ event, which effectively occurred in 2002.

RESULTS

CORRELATIONS

Figure 6a shows correlations between SST in the Pacific Ocean and precipitation measured in the Coquimbo Region from 1950 to 2000, resulting in high positive correlations ($r > 0.6$) for the Niño 3.4 region, indicating that high sea surface temperatures are related to increased rainfall measured in the Coquimbo Region. Since sea surface temperatures change slowly, and since changes in SST cause effects at a later time in the Coquimbo Region, showing a clear 'lag', this already gives the opportunity of predicting possible climate effects with up to two months anticipation, although correlations drop significantly at these time lags.

A better solution however, is using a GCM to obtain predictions at the medium or long term, since these models can use SST to predict precipitation with various months of anticipation, which in turn, can be related to observed precipitations in the region. In Fig.6b this relation between observed and predicted precipitation is presented, where it should be mentioned that the precipitation predicted by the GCM is correlated with the rainfall in two regions, that of the Niño 3.4 area and the North of Chile. This shows the GCM's ability of representing the influence of ENSO on precipitation in the Coquimbo Region. It also increases the anticipation with which predictions can be made for the region up to 6 months.

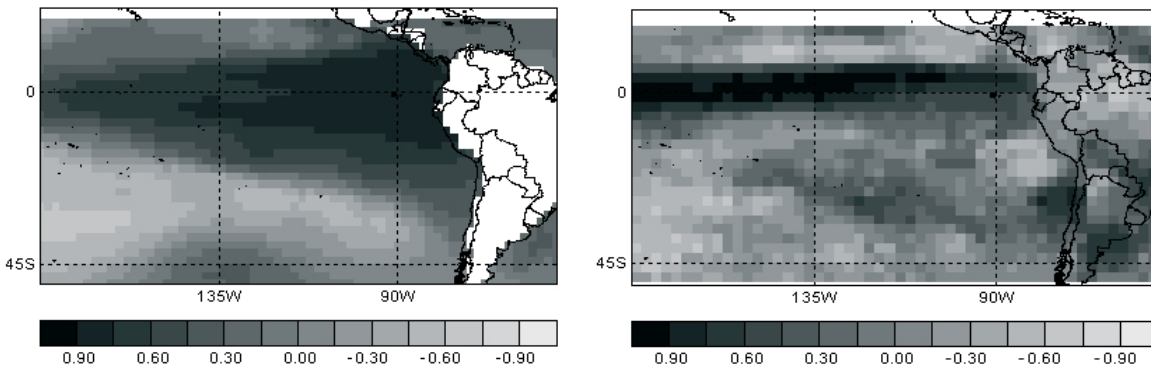


Figure 6. Spatial correlations between sea surface temperatures in the Pacific Ocean a) predicted precipitation using a GCM and b) average precipitation measured in the Coquimbo Region for the period 1950-2000

PREDICTION MODELS

These correlations show that there exists a certain feasibility to predict the climate in the region with anticipation, and that by using statistical models a useful tool can be developed to perform prognostics. This is further explored using a Canonical Correlation type Analysis (CCA), a data reduction technique retaining those characteristics of the data set (principal components) that contribute most to its variance, and therefore help to identify trends hidden in the data set.

Using CCA a preliminary model was constructed using the predicted precipitation as explanatory variable (X) and the measured rainfall in the Coquimbo Region from 1979 to 1999 as response variable (Y). This resulted in a strong correlation ($R^2 > 0.7$, see Fig. 7) between the principal components from both variables, indicating that the model is incorporating large part of the variance of both data sets. Since the model was constructed using data from 1979-1999, a

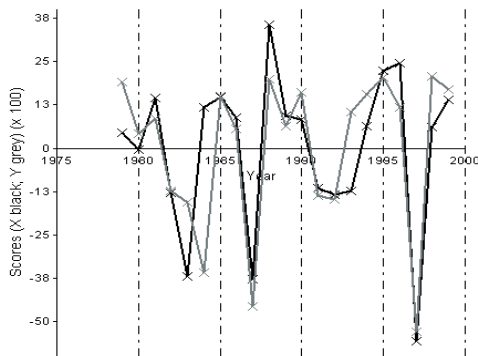


Figure 7. CCA plots of the measured precipitation data set (grey line) versus the predicted precipitation data set (black line) for the period used in the model development (1979-1999)

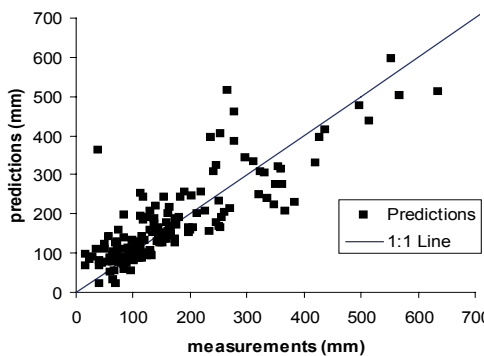


Figure 8. Relation between registered precipitation (X) and predicted precipitation (Y) for the climatic stations in the region in the period 2000-2007

validation was performed with data from 2000 to 2007, as presented in Fig. 8. This clearly shows the skill of the model to make predictions for these events that were not included in the model-building process.

DISCUSSION

These results show that the precipitation regime in the Coquimbo Region is highly influenced by the El Niño and La Niña phenomena, making it possible to make some general predictions on probable precipitation behavior in the next rainy season. The model constructed in this study was able to predict precipitation satisfactorily for a 6 years period, outside its calibration range, indicating that an early warning system for drought prediction could be constructed based on this type of statistical modeling.

ACKNOWLEDGEMENT

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ARIDITY AND EXTREME DROUGHT IN DOBROGEA, ROMANIA

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INTRODUCTION

With global warming, an increase in aridity is predicted for many areas in some model scenarios. Such scenarios evaluating the impact of global warming in Romania have shown that aridity will increase in the southern parts of the country (Marica and Busuioc, 2004).

In addition to aridity, drought is widespread in the world. Drought is considered as the most complex and least understood of natural hazards, and affects more people than any other hazard (Hagman, 1984) as it is spread over large areas and is not localized as are most other hazards (Wilhite, 2000). To characterize droughts, McKee et al. (1993, 1995) developed the standardized precipitation index (SPI) to compare the precipitation anomalies with mean values for various periods: 3, 6, 9, 12 and 24 months. This facilitates comparisons between geographical regions. Conceptually, SPI is the number of standard deviations by which the precipitation values recorded for a particular location would differ from the mean over certain periods.

In Romania, Paltineanu et al. (2000), Paltineanu et al. (2007), among others, have reported data on arid or drought-affected areas, such as soil moisture dynamics, water-crop responses, aridity distribution and irrigation water requirements for various regions.

The aims of this paper are: i) to analyze extreme drought in Dobrogea using the concept of standardized precipitation index (SPI), ii) to assemble point data for the climatic water deficit (WD), i.e. the

difference between Penman – Monteith reference evapotranspiration (PM-ET_o) and precipitation (P), and iii) to assess the link between SPI and WD, and understand more clearly the regional soil moisture regimes, so that water can be managed better.

MATERIALS AND METHODS

We used the mean monthly and annual values for the main climatic factors from 42 weather stations and precipitation-collecting centres located in Dobrogea, Romania. The period of investigation was from 1961 to 2000, for which reliable and continuous precipitation records exist (Clima RSR, 1966). Air temperatures, sunshine hours, solar radiation, precipitation, relative humidity and wind speeds at heights of 10 m and 2 m were available for the weather stations. The quality of the data sets has been tested using standard quality control methods.

PM-ET_o (Monteith, 1965; Allen et al., 1998) was computed and WD was calculated as the difference between P and PM-ET_o (Paltineanu et al., 2007).

SPI was computed according to the method of McKee et al. (1993). Spatial interpolations between WD and SPI values at each weather station were made by the point kriging method with no drift and ordinary options (Cressie, 1990), using the Surfer Program (Surface Mapping System, Golden Software Inc 2002). This gave an interpolation density of 200 grid lines for both latitude and longitude.

RESULTS AND DISCUSSION

THE ANNUAL CLIMATIC WATER DEFICIT (WD)

Spatial distribution of the WD in Dobrogea is depicted in Fig. 1. This suggests that the most arid region is the Black Sea coast, specifically the Danube Delta, where WD ranges from less than –450 mm to –400 mm. Only slightly less arid are the western and south-western parts of the Dobrogea region, where WD values generally were between –320 and –400 mm (Paltineanu et al., 2007). The average value of WD across Dobrogea is –355 mm.

In contrast to WD values, an approach based on more than one factor, (the real water deficit, RWD, not presented here), dependent on climate, relief and soil data, is more complex but closer to reality (Paltineanu et al., 2007).

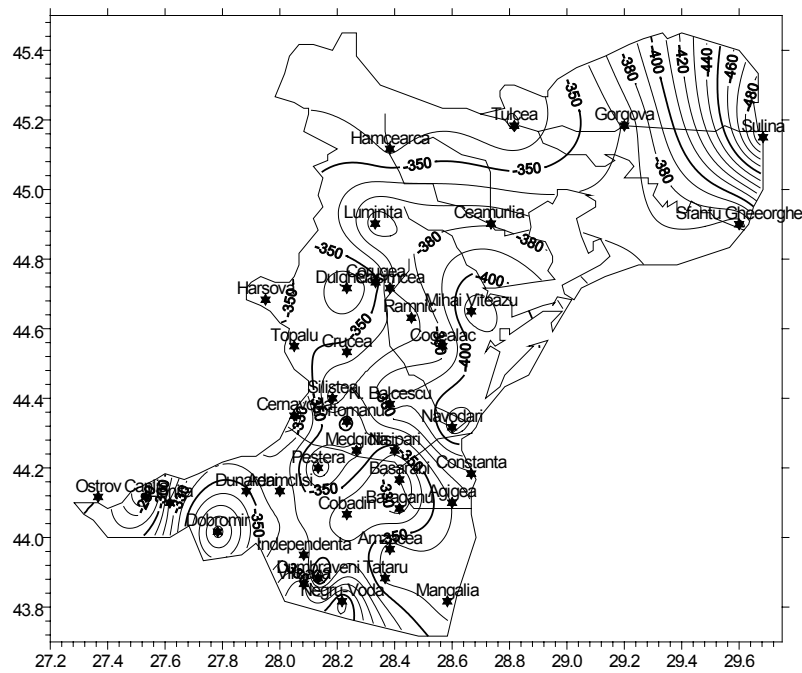


Figure 1. Spatial distribution of mean annual climatic water deficit (WD, mm) in Dobrogea, Romania

EXTREME DROUGHT CHARACTERIZATION USING SPI VALUES FOR DOBROGEA

Figure 2 shows the spatial distributions of $SPI < -2.0$ values for the 12-month intervals for the extreme droughty periods. The 12-month interval was chosen as it covers the natural annual cycle of the climate and vegetation.

Extreme droughts occurred in 1.8% of the years and showed a low spatial distribution variation from 0 to 4.1%. In these periods, especially in areas with WD values below -200 mm, the requirements for water were usually not met. The consequences for the most strongly affected areas during 3 – 4% of the years were usually dramatic especially for rainfed agriculture.

Except the north-western and south-western parts of the territory which are characterized by one or two consecutive months of extreme drought, the rest of the region presents isolines ranging from 4 to 12 consecutive months, Fig. 3. Even if such extreme monthly

droughts occur with a frequency of about 2%, the consequences of water management in economy, especially in agriculture, are drastic.

Analyzing the data of $SPI < -2.0$ from all the 42 locations across Dobrogea, it has been found (Table 1) that the highest frequency of the extremely droughty range occurred in winter (from 10.0 to 11.3%), and that the lowest one in late spring and summer (from 3.3 to 7.3%) when aridity is maximum. This climate feature is very important in alleviating drought severity in this region.

The hierarchy of the extremely droughty years in all the 42 locations investigated in Dobrogea over the 1961-2000 period was as follows: 1974 and 1972 were the droughtiest years, with 10 to 14% out of the 40 years studied (data not shown). Other years showing high values of $SPI < -2$ were 1983 (9%), 1991 (9%), 1990 (8%) and 1993 (8.7%). On the contrary, another 17 years showed no extreme droughts, e.g. many years of the 1961-1970 decade.

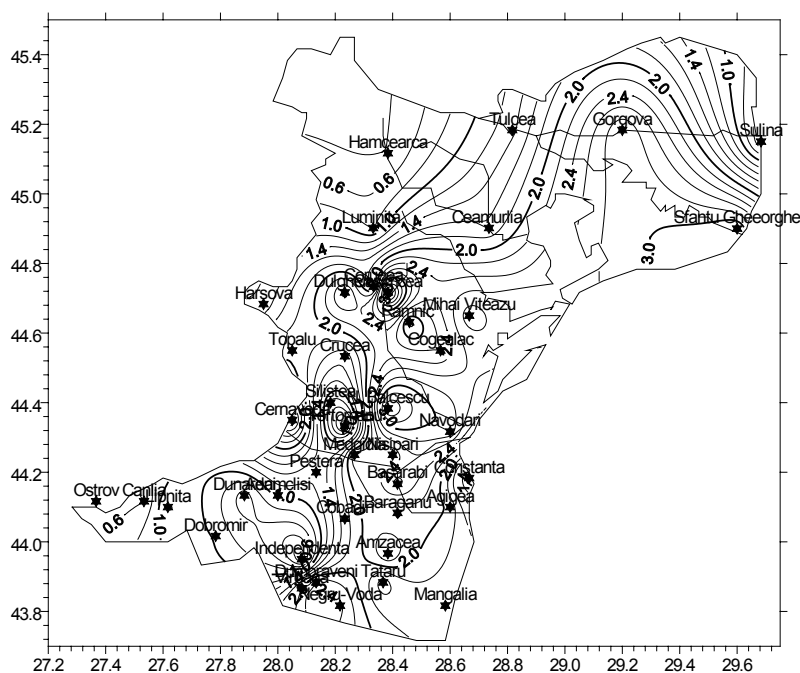


Figure 2. Spatial distribution of SPI values (%) for the 12-month interval for the extremely droughty range ($SPI < -2.0$) in Dobrogea, Romania

Table 1. Monthly distribution of the frequency of extremely droughty range (SPI<-2) in Dobrogea, Romania, over 1961-2000

Frequency/ Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
Absolute values (months)	34	30	24	29	10	16	22	22	25	29	26	33	300
Relative values (%)	11.3	11.0	8.0	9.7	3.3	5.3	7.3	7.3	8.3	9.7	8.8	11.0	100

It is also interesting to mention that the frequency of extreme droughts in the region increased with time for the 1961-2000 period, from about 2.1 % in the 1960s to 3.5% in the last decade of the century (Table 2). However, within each decade the time variability was high (coefficient of variation between 124 and 168%). This trend could be attributed to the global warming.

The data obtained in Dobrogea show a similar time pattern to the SPI values reported by McKee et al. (1993) for the United States.

Table 2. Average frequency of the extremely droughty years on decades in Dobrogea, Romania, over 1961-2000

Decade	Frequency of SPI<-2 (%)	Standard deviation of SPI <-2 (%)	CV of SPI <-2 (%)
1961-1970	1.2	2.07	167.6
1971-1980	2.5	4.2	165.9
1981-1990	2.7	3.6	131.6
1991-2000	3.5	4.33	123.6

DROUGHT OVERLAPPING ARID AREAS

The most arid regions of Dobrogea do not necessarily coincide with the driest areas with the lowest negative SPI values. Also there is no altitudinal zonation of SPI in Dobrogea as there is for other climatic factors, soils and vegetation (Paltineanu et al., 2000). In other words, there is no correlation between SPI and WD or between SPI and any other aridity index for this region, though in Greece there is a correlation between SPI and the De Martonne aridity index (Livada and Assimakopoulos, 2007). This situation in Dobrogea results from the specific way of computing SPI values for each site, as a deviation from the precipitation means.

SPI characterizes the droughty and humid periods versus the multi-annual means as deviations of precipitation from the means and whose intensity is given by the SPI class value regardless of the aridity of the region. However, a real problem with water resources appears when a region, in particular Dobrogea, has both SPI values characterizing extremely droughty periods and WD values exceeding -200 mm per year. For example in this region, the annual precipitation is mainly between 350 and 400 mm (Paltineanu et al., 2000), and severe droughts can result from annual precipitation values of 250–300 mm and WD values of -250 to -400 mm.

There is a clear difference between drought and aridity, even if sometimes these terms are confusingly used. Aridity is a permanent feature of a region, which is characterized by a low mean precipitation, whereas drought is a temporary feature meaning scarcity of water for a certain period in any region (Wilhite, 2000). Thus, an arid region is not necessarily droughty.

CONCLUSIONS

On average, extreme droughts occurred in 1.8% of the years in Dobrogea; the most arid areas of the region did not necessarily coincide with the most severe droughty areas, as there was no correlation between WD and SPI, and there was no altitude-based zonation of SPI in Dobrogea.

Most of the area is characterized by extreme droughts from 4 to 12 consecutive months.

It has been also found that the highest frequency of the extremely droughty range occurred in winter and that the lowest one in late spring and summer when aridity is maximum.

The frequency of extreme droughts increased with time from about 2.1 % in the 1960s to 3.5% in the last decade of the century. This trend could be attributed to the global warming.

A real problem with water resources appears when a region has SPI values characterizing both extremely droughty periods and is a dryland, and WD greatly exceeds -200 mm per year.

The combined use of SPI and WD characterizes region dryness better than one factor alone.

With increasing aridity in Eastern Europe due to global warming we emphasize that this approach could contribute to a better water management system for agriculture.

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DESERTIFICATION UNDER CLIMATE CHANGE AND CHANGING LAND USE IN MEDITERRANEAN ENVIRONMENTS

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INTRODUCTION

The processes of land degradation affect the conservation of soil and water resources, because they are strongly linked to unfavourable changes in the hydrological behaviour affecting soil water balance and soil moisture regime. They are related to soil and climate characteristics, but inappropriate land use and management is the main factor responsible of those processes. In the past decades, the degradation of previously naturally vegetated or productive agricultural lands, leading in many cases to barren, desertified, landscapes, has dramatically extended in many regions of the World. The reasons are mainly unfavourable biophysical conditions and negative human impacts. The negative human impacts are mainly through inadequate land use, including deforestation, overgrazing, and deficient agricultural practices, leading to soil erosion, salinization and vegetation degradation, as a consequence of drastic changes in the water balance. This might be further aggravated by the ongoing threat of climate change (Fig. 1).

Land degradation in the more vulnerable areas with arid and semiarid climate in the Mediterranean region goes back over millennia (Dupre, 1990). The most important human actions that have triggered or intensified the processes of land degradation have been overgrazing, deforestation and forest fires, and in recent decades new land management practices, associated to agricultural intensification, mechanization, inadequate maintenance or abandonment

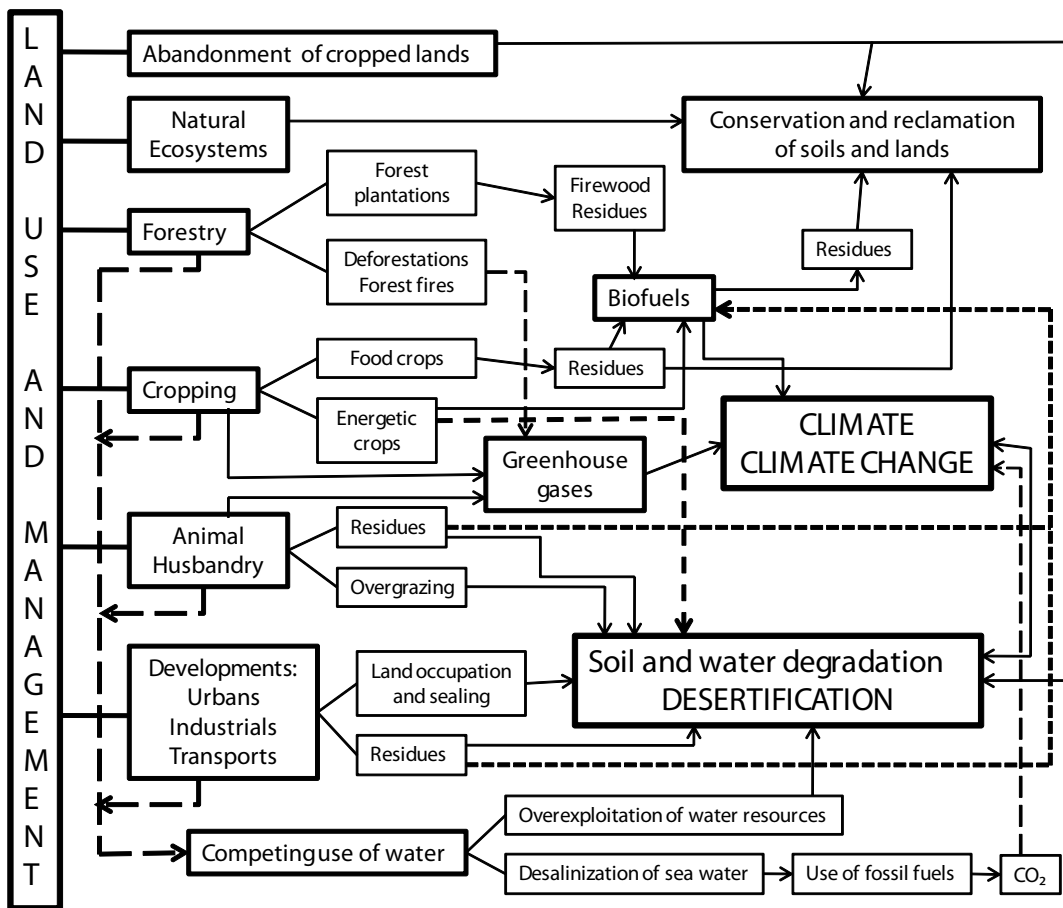


Figure 1. Relations between land use and management and climate change with soil and water degradation and desertification (Pla, 2007)

of vast areas of terraced agriculture, over-drafting of surface and groundwater for irrigated agriculture, tourism, etc. (EC, 2003). These new land use and management practices are a consequence of changes in social economic conditions, market prices and public policy-led subsidies, consumption patterns, etc, associated to technological progress and changing production systems. Land degradation has affected more hilly sloping lands, but in valley bottoms where irrigation is being used for increasing productivity, salinization and sodification have become a widespread form of soil degradation. There are evidences that land degradation processes leading to desertification in the Mediterranean region are getting worse, because of different or mixed causes varying from one place to the other (EC, 2003).

The prevention and choice of solutions for the problems of land degradation leading to desertification must depend on the right identification of the processes involved and in the precise analysis, diagnosis and understanding of the causes and potential effects at specific places. Not doing so may lead to catastrophic effects. Despite the modernization of observation facilities by the use of satellite imagery and computer programs to analyse the data, there are still many uncertainties at the regional and national levels in the Mediterranean regions, on the causes, the extent and the seriousness of land desertification. These uncertainties prevent those who manage land resources from planning properly, and introduce constraints in operation of early warning systems with regard to agricultural production and disasters such as flooding and landslides (Pla, 2006).

HYDROLOGY AND DESERTIFICATION IN MEDITERRANEAN ENVIRONMENTS

Water, that is often the main limiting factor of plant growth, is also the main factor directly or indirectly responsible for soil and land degradation processes. These processes are strongly linked to unfavourable changes in the hydrological processes responsible for the soil water balance and for the soil moisture regime, which are affected by the climate conditions and variations, and by the changes in the use and management of soil and water resources (Pla, 2002a).

The soil moisture regime, determined by the changes in soil water content with time, is the main single factor conditioning moisture availability, plant growth and crop production. It is mainly conditioned by soil properties affecting the capacity and possibilities of infiltration, retention and drainage of rainwater, and the limitations to root growth under the particular rainfall characteristics (Pla, 2002a). These conditions may be modified by soil and plant management practices as tillage, irrigation, drainage, etc. Moisture availability is determined both by water gains from precipitation and water losses through runoff and evapo-transpiration (Table 1).

In the arid and semiarid Mediterranean climate, the rainfall is highly variable among years and during the year, and usually occur in erratic storms of short duration and high intensities. The concentration of rainfall in a relatively cool season (autumn and winter) permits reliable cropping in areas with annual rainfall as low as 330-400 mm (see Table 1). Under non-protected soil surface, associ-

Table 1. Potential length of the growing period in days year⁻¹ (LGP) under semi-arid Mediterranean climate conditions, as affected by the main critical factors derived of climate changes, land use and management, and soil degradation

	runoff	available soil water retention capacity			
		50 mm	100 mm	200 mm	400 mm
dry year	0%	93 d y ^{-1**}	100 d y ^{-1*}	100 d y ^{-1*}	100 d y ^{-1*}
R: 300 mm RP: 5 years	50%	56 d y ^{-1**}	56 d y ^{-1**}	56 d y ^{-1**}	56 d y ^{-1**}
average year	0%	150 d y ⁻¹	193 d y ⁻¹	200 d y ⁻¹	200 d y ⁻¹
R: 500 mm RP: 2 years	50%	122 d y ^{-1*}	136 d y ^{-1*}	136 d y ^{-1*}	136 d y ^{-1*}
humid year	0%	196 d y ⁻¹	207 d y ⁻¹	230 d y ⁻¹	266 d y ⁻¹
R: 800 mm RP: 10 years	50%	187 d y ⁻¹	195 d y ⁻¹	202 d y ⁻¹	202 d y ⁻¹

d y^{-1**}: critical for any kind of crops including perennial crops as vines and olives; d y^{-1*}: critical for annual crops like cereals (wheat, barley) and some new introduced varieties and planting densities of vines; R: yearly rainfall; RP: return period

ated to some intensive agricultural practices and overgrazing, extra precipitation in winter, occurring in intense episodes, may not be stored in the soil, but lost as runoff (Pla and Nacci, 2001). These factors increase the risks of land degradation leading to desertification processes. The previewed effects of global climate changes would mainly affect hydrological processes in the land surface, mostly related to the soil water balance. In terms of ecological and social impacts of climate change, changes in moisture availability are more important than changes in precipitation alone. Low levels of moisture availability are associated with droughts and desertification. Reductions in mean annual rainfall leads to drier conditions, but increase in climate variability during the year, or increasing frequency of very dry years, could be equally or more important. Therefore, the term aridity for evaluating desertification, instead of only considering average rainfall conditions, would be more appropriate if it also consider variability through the whole hydrological cycle as well as climatic variations and fluctuations.

Human activities leading to land degradation processes may affect more the soil hydrological processes than the previewed cli-

mate changes, or may increase the influence of those changes (Pla, 2001). Forests usually regulate stream flows, protect land from erosion, reduce flooding in adjacent areas, minimize the silting of rivers, canals and dams, and contribute to a stable hydrology essential for providing stable sources of water for human needs and irrigated agriculture. This water balance may be drastically upset by deforestation and forest fires, and especially by the consequent land degradation. Supply of available water may decrease irreversibly under unchanged soil properties and stable hydrological soil parameters due to reduced water income, increasing water consumption, or both. Under unchanged water income by rainfall, the hydrological parameters of soils may change irreversibly as a result of soil degradation (sealing, compaction, erosion, decreased water holding capacity, etc), leading to the same effects of decreasing available water supply (see Table 1).

Irrigation causes drastic changes in the regime and balance of water and solutes in the soil profile, which may result in soil salinisation, one of the processes of soil degradation leading to land desertification. The salinity problems are a consequence of salt accumulation in zones and depths where the soil moisture regime is characterized by strong losses of water by evaporation and transpiration, and by reduced leaching of the remaining salts. The salt accumulation may conduce to a partial or complete loss of soil capacity to provide the required amounts of water to plants, changing fertile lands to deserts (Pla, 1996).

From the previous arguments, it follows that approaches based on water balance models are the more adequate to predict the reliability of the water supply for a plant during its growth. This would be the main basis for determining the suitability of the land for various uses under given conditions of management. There is required research into the basic hydrological processes of land degradation, including climate and soil data. Research is also required on the hydrological changes as a result of various alternative land uses and agricultural systems and practices. The degree of aridization of soil may be quantitatively determined in terms of certain physical properties and water regime of soils (annual supply of available water in the root zone), using soil hydrological parameters (Pla, 2006).

EVALUATION OF DESERTIFICATION IN MEDITERRANEAN ENVIRONMENTS

A large scale integrated assessment of land/soil degradation and desertification is required in the Mediterranean region, in order to formulate the related prevention and mitigation strategies. Assessments should begin at the local levels, rather than begin at the global or regional levels. The assessment must include past trends, current state and prospective development of soil degradation and land desertification, which should be based mainly in soil hydrology related indicators. The most serious constraints are due to the soil data provided by the national soil surveys, which is mainly static information without any indication on changes and trends, very important for environmental protection purposes. There are also required soil monitoring systems, aim to deliver information on changing soil parameters, important for soil functions, based on systematic sampling and measurements.

Rainfall, which is very variable in the arid and semiarid Mediterranean climates, becomes the most fundamental data source for monitoring desertification. Also there is required a systematic tracking of vegetative production and soil conditions. A watershed approach for the biophysical resources would help to effectively integrate the information for estimating degradation processes. For tackling large watersheds, it is recommended to carry out first a reconnaissance level analysis of the problems to identify the areas that need focused attention, and then launch a detailed analysis in the targeted small areas.

Assessment and monitoring of desertification have the primary objective to forewarn about some impending crisis of land degradation and desertification, as well to suggest some preventive and remedial measures. These objectives cannot be met without a proper understanding of the processes responsible for desertification, which is the main limitation with the empirical methods generally used presently for assessing desertification and land degradation. There are required other methods, based on hydrological evaluations, to evaluate the problem. In most of the cases a weak knowledge of the hydrological processes involved and of the nature of desertification, and the inadequacy of the methods for the assessment and moni-

to-ring of such processes hamper the adoption of integrated use of soil and water resources and of management policies and rehabilitation programs (Pla, 1998). Oversimplified indices like drought, using climatic maps; vegetation cover, using satellite imagery, and others, which fluctuate year after year, have limited diagnostic criteria (UNCCD, 2003). When mostly qualitative indicators are used, elements of subjectivity are many times involved in the assessment of desertification, depending on interpreters experience or bias. There is a need for searching more acceptable and easily determinable criteria that are measurable.

It may be concluded that in order to assess and to predict adequately desertification there is required the collection of sufficient field observations and data, mainly of hydrological nature, to reflect temporal and spatial conditions and variations. This information would be used for the identification of the causal processes and for the development, calibration and use of simulation models that can predict future changes. In all cases the used criteria must be clear, relevant, environmentally specific and scale-specific.

MODELLING DESERTIFICATION

The existing criteria of desertification, based mainly on climate and vegetation cover, have limited diagnostic criteria. The use of the so called soil quality attributes and indices to assess the vulnerability of soils to degradation and land desertification processes, scored from empirical judgements, do not allow to relate the evaluation to the overall sustainability of alternate land use systems for production, control of environmental impacts, etc. There are needed other ways to evaluate the problem.

An hydrological approach to the assessment and prediction of the conservation of soil and water resources against degradation and desertification processes, has proved to be essential for an adequate development, selection and application of sustainable and effective land use and management practices (Pla, 1998; 2001). The increased requirements of more quantitative results in probabilities and risks of soil degradation and land desertification, and its influence on crop production and environmental damage may be partially satisfied with the use of modelling, where the large number of important variables involved in the desertification processes, and their

interactions, may be integrated. Analysis and suitable modelling of data and processes helps to find out the trends in desertification and the responsible factors, under different bio-physical and social-economical settings. Modern techniques of digital remote sensing and geographical information systems (GIS) may be very helpful in the analysis and processing of the original and generated information. Modelling desertification requires a previous identification of the main desertification processes. Appropriate models must help in gaining more insight into the processes and on the understanding of the system as a whole. Although models cannot replace deciders, they supply them with valid and quantitative alternatives, required to take successful actions. In any case, simulation modelling has to be used with caution and should be based on sufficient local information. Field-based information is essential, and data obtained through digital remote sensing need to be verified in the field to be useful (Pla, 2002b).

Empirical models, like the so called Universal Soil Loss Equation (USLE) and its revised version RUSLE (Renard et al, 1991) have been commonly used in the countries of the Mediterranean region, frequently without verification, for large scale water erosion (one of the more important soil degradation processes leading to desertification) risk mapping. Although the outputs and mapping using GIS may be impressive, they can hardly be used with a guaranty of success for development or prevention of desertification purposes (Pla, 2002b). There are required other non empirical modelling approaches mainly based on soil hydrological processes, deduced from soil hydrological properties together with historical rainfall records, under different scenarios of changing climate, soil properties, topography, and land and crop management, which may be combined in computer-based programs. The bio-physical data, mainly of hydrological nature, may be taken as surrogates for human impact, but in some models the social economic data are also fed into calculation procedures with variable success. Simulation models based on hydrological processes may be very helpful to integrate and convert the measured or estimated soil, climate, plant and management parameters into predicted soil water balances and soil moisture regimes for each particular combination of them, actual or previewed (Pla, 2002b). These models not only help to understand the complex pro-

cess of desertification, but they may also serve as decision-making tools to reduce or to avoid negative environmental impacts leading to desertification under different and changing scenarios (Richter and Streck, 1998).

Hydrological approaches allow to combine the characteristics of climate with the characteristics of soils and landforms and land-use systems, for interpretation and prediction of land desertification hazards. When applied to a series of scenarios of land use and potential environment and climate change impacts, the results can be used by decision makers for future land use planning and implementation. This approach also makes the extrapolations more soundly based and provides a scientifically solid base which leaves little space for subjective interpretations leading to alternatives for different land use and management for agricultural and non-agricultural purposes. Modelling hydrological processes has proved to be a very reliable tool for evaluation and prediction of land degradation processes for guiding planning strategies for soil and water conservation and management practices, under very different climate, topography, soils, cropping and management conditions (Pla, 1997; 1998; 2001; 2002a; Pla et al. 2005).

CONCLUSIONS

A hydrological approach to the assessment and prediction of conservation of soil and water against desertification processes is essential for an adequate development, selection and application of sustainable and effective land use and management practices. Weak knowledge of the hydrological processes involved, and of the nature of desertification, and the inadequacy of methods for assessing and monitoring of such processes, usually hampers the adoption of integral resources use and management policies and rehabilitation programs in areas subjected to desertification in the Mediterranean region. The assessment of the degree of land desertification will require research on the water regime of soils under desertification, using an adequate methodology. Without such research, other considerations of degree of desertification will be mostly subjective, being based on indirect criteria and not in the direct measurement of hydrological parameters.

The evaluation of the hydrological processes, under different scenarios and changing climate, soil properties and land use and

management, with flexible simulation models based on those processes may help to predict and to identify the biophysical causes of desertification at local, national and regional levels in the Mediterranean region. This is a required previous step for a rational land use planning, and for the selection and development of short and long term strategies and technologies to reduce or to control land degradation processes leading to desertification, and to the related social economic and security problems.

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DESERTIFICATION RISK IN THE SOUTH OF MOLDAVIA, ROMANIA

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INTRODUCTION

Desertification is defined by the United Nations (UN-CCD 1994) as “land degradation in arid, semiarid and sub-humid areas, resulting from climatic various factor including climatic variations and human activities”. According to this definition, the area with desertification risk covers much of south-eastern Romania, and perhaps some other areas of the country. After pollution, desertification represents the second major problem of mankind. The extend of this phenomenon is put in evidence by the climate data which predict a progressive heating of the atmosphere and a reduction of rainfall amount leading to drought. The persistence of this phenomenon leads to aridity (the first stage of a dry climate installing) and then to desertification. Desertification is mainly recognized by the significant reduction of available water resources, production and extend of sandy areas. Not only climate conditions have an influence upon the degree of desertification but also the anthropologic pressure. Man, by its unreasonable action can start and amplify drought and desertification phenomena. Climate change will cause significant shifts in climate zones which affect the suitability of land for agricultural use. Environmental changes at the global scale (including desertification) are so complex that they can only be understood properly by the highest quality of interdisciplinary research.

The paper presents the analysis of some climatic factors (Dragomirescu and Enache, 1998) influencing the phenomenon of desertification in the south of Moldavia (see Fig. 1). During recent years, a deviation of the climatic factors from the multiannual average leading to desertification has been observed. The research was done at Bujoru R&D Station for Viticulture and Vinification, Galati County, Romania. The weather was studied between 1979 and 2007. The evolution of the climatic factors as well as its trends were evaluated in the hilly area of the Southern Moldavia, Romania. The weather observations were recorded at Bujoru Meteorological Station of the R.D.S.V.V. (Viorica, 2004) as follows: regime of precipitations (annually and during the vegetation period), frequency of annual precipitations, frequency of annual precipitations during the vegetative period; average temperature evolution (annually and during the vegetative period); insolation (total annual solar radiation) for the period 1997-2007; soil moisture in the period 1987-2007 upon the depth 0-100 cm.

In the first stage, the evaluation of desertification risk in South Moldavia, Romania, required some observations and determina-



tions related to the knowledge about the evolution of climate factors and soil water supply.

The climate records were provided by Meteo Station belonging to Bujoru Research and Development Station for Viticulture and Vinification. The average annual rainfalls have a randomized variation, resulting in favourable and unfavourable years. The variation of rainfall across the time is pointed out by the high difference between the amount of rainfalls registered in the same month but in various years, an aspect which emphasizes the deficit of rainfalls in that area. Showers, falling mainly in the hot period of the year, are peculiar for the studied area.

Analyzing the data presented in Fig. 2, we may notice an increasing trend of air temperature which is still continuing. In South Moldavia, starting from the year 2000, the average annual temperature has increased by 1.5-2 °C compared to the multiannual average level.

The annual rainfall from the period 1979-2007 have a cycle trend every 7-8 years, when rainy periods alternate with extreme dry periods (Figs. 3 and 4). Starting with the year 2000, the annual rainfalls are below the multiannual average level. An ununiform rainfall distribution was noticed during the period of vegetation, short periods of rains alternating with showers, framed by long dry periods.

The torrential character of the rainfall during the vegetation period, frequently leads to a water deficit in soil, soil humidity reach-

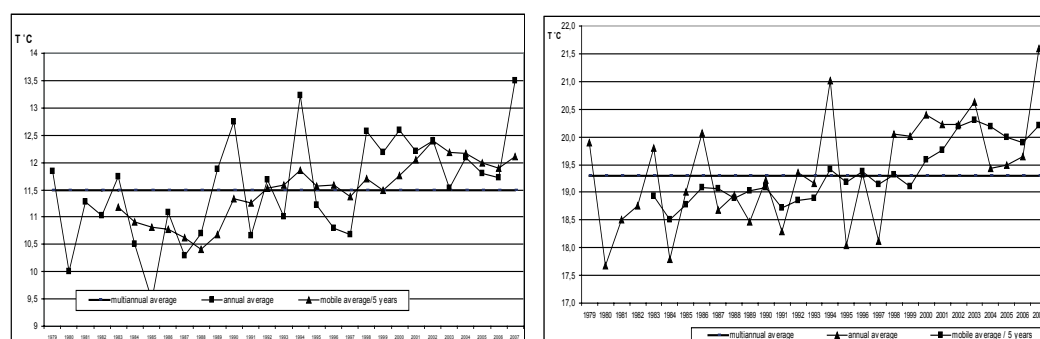


Figure 2. The annual average temperature of the air for the period 1978-2007 (a) and for the vegetative period of 1978-2007 (b)

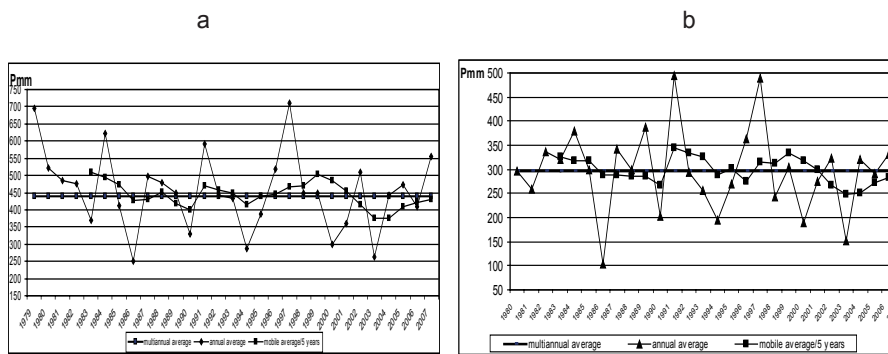


Figure 3. Distribution of the annual precipitation a) for the period 1979-2007 and b) for the vegetative period of 1979-2007

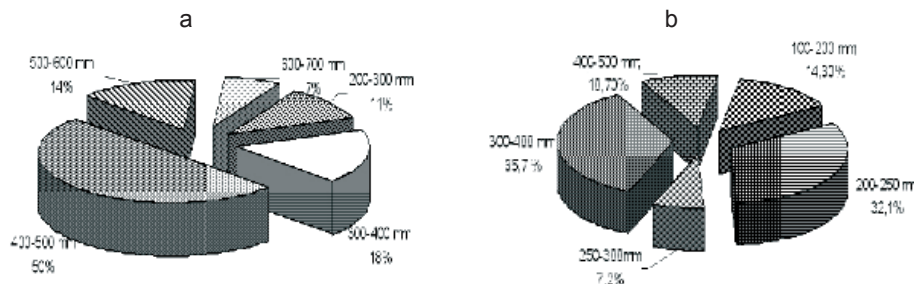


Figure 4. Annual precipitation frequency a) for the period 1979-2007 and b) for the vegetative period of 1979-2007

ing the withering level at the end of the vegetation period (Fig. 5). Also, we may notice that in the last years, at the beginning of the vegetation period soil water provision is not recovered anymore during the winter season and frequently it takes values representing 50-70 % of the active humidity interval on April 1. A major problem for the Southern area of Moldavia (Romania) is the presence of extreme values for the climate factors, of which temperature is the most aggressive one, followed by torrential rainfalls.

Annual solar radiation is slightly increasing compared to air average temperature evolution

CONCLUSIONS

Taking into account the weather data regarding the monthly and annual average precipitations, and the monthly and annual average temperatures, we may draw the conclusion that: (1) in the last two decades there is a zone drying tendency, with a 7-8 years cyclicity when the rainy periods alternates with those extremely dry; (2) simple air temperature increase in the 1990-2002 interval, which is continuously growing up till present, was recorded.

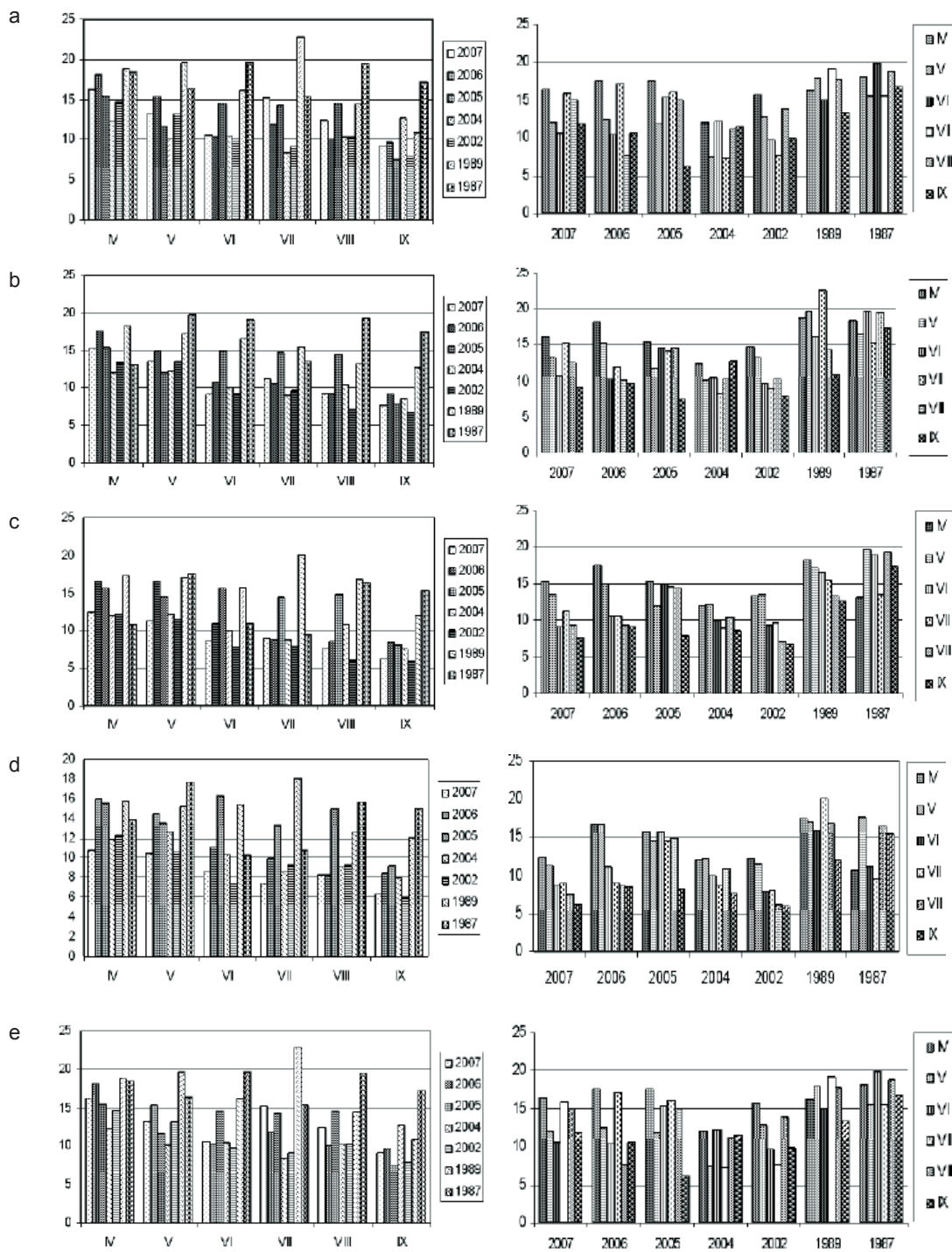
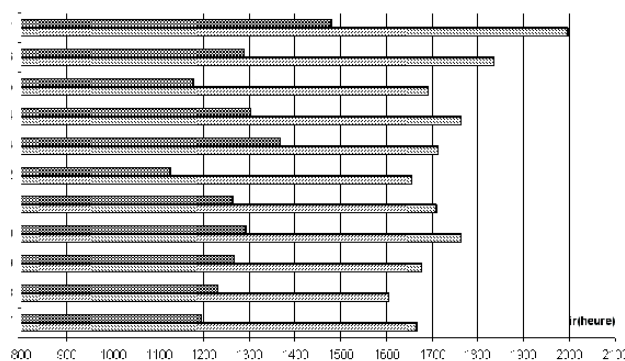


Figure 5. Soil moisture in the period 1987-2007 at a) 0-20 cm, b) 20-40 cm, c) 40-60 cm, d) 60-80 cm and e) 80-100 cm

Figure 6. Total annual solar radiation for the period 1997-2007



Starting from the year 2000, at the Dealu Bujorului Vineyard, we noticed an increased air temperature by 1.5-2 °C compared to the multi annual average temperature and also a gradual reduction of precipitations below the multi annual average precipitation.

Precipitation is weakly used by the soil profile and the soil moisture frequently registers values at the level of wilting coefficient at the end of the vegetative period.

During the studied period, rainfall shows some critical aspects, especially concerning the lack of an uniform distribution completely uncorrelated to the vegetation period.

A major problem is the presence of extreme values of the climatic factors which were considered as accidental and during the last years they have been frequently noticed. Among those factors, temperature is the most aggressive.

The obtained results allowed us to make a draft evaluation of the vulnerability to desertification of the studied territory. At this research stage, we consider our results as a first knowledge level which has to be expanded in the future introducing other representative indices for the phenomenon of desertification.

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TRADITIONAL APPROACH AND REMOTE SENSING TECHNIQUES IN THE DEVELOPMENT AND IMPLEMENTATION OF DESERTIFICATION INDICATORS

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INTRODUCTION

Over the past 50 years humans have changed ecosystems, more rapidly than in past ages, to meet demands for resources. It is increasingly clear that environmental degradation and resource depletion play an important role in creating or exacerbating human insecurities (Dabelko et al., 2002). There is growing understanding that environmental degradation, especially when coupled to inequitable access to critical natural resources, increases the probability of conflict and instability and pose a risk to human security.

A main issue in any strategy aimed at the fight against desertification should be based on the technical and institutional capacity to study environmental degradation processes and natural catastrophes through assessing, quantifying and monitoring phenomena and to implement prevention through adequate intervention.

The present paper focuses on monitoring approaches and methods as a tool to support land degradation and desertification strategies and measures. In fact a leading role is played by the environmental emergencies linked to desertification (MA, 2005) that is a complex process involving the interaction of various components: the socio-economic issues, such as food security, poverty, migratory flows and political stability, and different environmental issues, such as climate change, biodiversity and water supply.

DISCUSSION

ISSUES

Countries involved in the fight against desertification have to establish specific information systems based on quantitative approach, such as the Desertification Monitoring System (DMS). DMS must be able to provide a diagnosis based-monitoring of the state of natural resources and of populations in the affected regions and support the decision-making process, as well as operational support to a wide range of activities. In order to achieve this scope, they should be based on tools like indicators. The international community has understood that it is impossible to define a universal set of indicators, but rather that it is necessary to come up with common methodologies. In this context the Nucleo di Ricerca sulla Desertificazione (NRD-UNISS) of the University of Sassari has done/contributed to several initiatives that have had wide impact particularly from a methodological standpoint (Enne et al., 2003). In the frame of the EU-funded research project DESERTLINKS (Linking science with stakeholders) NRD-UNISS developed a database of indicators that constitutes the heart of the Desertification Indicator System for Mediterranean Europe (DIS4ME). A list of some 220 candidate indicators was compiled, gathering information from different sources. The DESERTWATCH project (Tracking Desertification with Satellite Data), funded by the European Space Agency (ESA), developed an operational remote monitoring systems based on the integration of ground data and remote sensed data.

INTEGRATED SET OF INDICATORS

The need of integrated and multidisciplinary set of desertification indicators for desertification monitoring has been stressed by the research community as well as by the main international organizations involved in the fight against desertification. The DESERTLINKS Project began in 2001 and was completed in 2005. It had 11 partner institutions that previously worked together on other desertification-related EU funded projects, in particular the MEDALUS. The aim of DESERTLINKS was to develop a desertification indicator system for Mediterranean Europe. This would be a contribution to the work of the UNCCD and in particular for the Annex IV sub-region countries of Portugal, Spain, Italy and Greece. The indicator

system (called DIS4ME) is published on the web. DESERTLINKS made a 4-steps approach (Fig.1).

Firstly, from a wide range of sources the main desertification issues were identified. Secondly, again from a wide range of sources, a long list of candidate indicators was compiled. Thirdly, sub-sets of indicators of particular relevance were selected from the long list. Finally the indicator descriptions were written, further refining the definitions and removing indicators from the list which did not meet the necessary selection criteria. After a series of refinement, the following 11 themes emerged as the major ones in Mediterranean desertification, as identified by both national and local stakeholders. In the frame of DESERTLINKS, all the indicators are included in a specific web-based database, consultable on-line, and each of them is described through a specific description sheet, including, among others, information on definitions, scales, objective, method of measurement, benchmarks, bibliography, author of the indicator.

On the basis of the acquired experience, studies and interventions related to indicators should be finalised to respond to the criteria and methodologies proposed by the UNCCD. For example, it is necessary to promote a better integration of the frameworks in order to facilitate the exchange of data and experiences and to contribute to the necessary harmonisation of the efforts towards this direction.

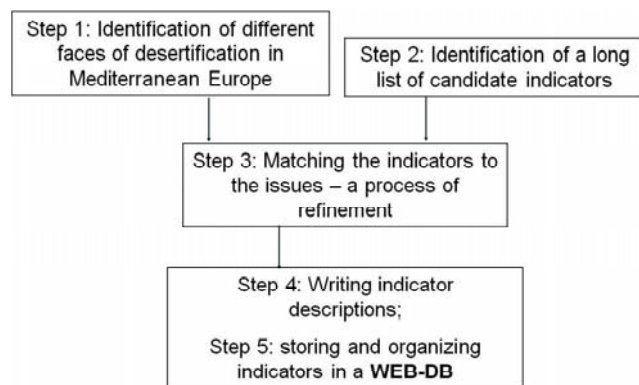


Figure 1. DESERTLINKS methodological approach and structure

From the technical point of view, among the main open issues are: (1) the organisation of structured sets of Benchmarks and Indicators (B&I) able to represent the land degradation systems; (2) the integration of different disciplines and different spatial and temporal scales involved in the phenomena; (3) the evaluation and quantification of effectiveness and benefits of mitigation interventions, including the socio economic ones.

From the institutional point of view, the main difficulties at the national and local levels are linked to inter-sectoral coordination, whereas at the supranational level methodological harmonisation is urgently needed.

OPERATIONAL REMOTE MONITORING SYSTEMS

Remote sensing plays an important role in the most recent research experiences on desertification monitoring. In fact, remote sensing produces images that can be used to create thematic maps for the analysis and estimation of desertification status or to abstract indicators of land changes from different images in order to realize a dynamic monitoring. One of the main issues in monitoring and managing desertification processes through indicators is due to the subjectivity of the methodologies that can be carried out and applied. The development and the implementation of operational monitoring systems constitute an essential step to limit such subjectivity and to make desertification monitoring reliable and repeatable. Thus, the use of this kind of system can provide the potential users with a tool based on standard framework and methodology that shall serve as common infrastructure.

The DESERTWATCH Project is focused on land degradation and desertification monitoring under the framework of UNCCD on the north Mediterranean region. It is not a research project, but a development activity to create a user-tailored operational system to assess and monitor desertification and its trend over time on the base of Earth Observation (EO) technology. The project intends to valorise the outcomes of ten years of European research, by integrating the more consolidated procedures and algorithms into an operational highly automatized system. DESERTWATCH aims at supporting national and regional authorities of Annex IV countries by giving an operational responses to the needs and requirements of

the user community. It is based on the integration of data of different nature (ground data and remote sensing data). The logic of the system is shown in Fig 2.

On the left there is data input, including DEM (Digital Elevation Model), Socio-economic data, Meteorological data, Soil quality and Management Quality from the users, and the most important one is the Remote Sensing data (Landsat and Meris images). After pre-processing, all these data are input into a sequence of elaboration procedures, including different Modules such as SMA, LDI, Auto Classification and Scenario Modelling (Blue color boxes). The products are listed on the right. The project shall be implemented in Portugal, Italy, Greece and Turkey and foresees a close involvement of the institutional Users (National Committees to Combat Desertification). The outputs will be transferred to the specific users through a process based on direct demonstration and operation from the consortium. The goal is to bridge the gap between the scientific

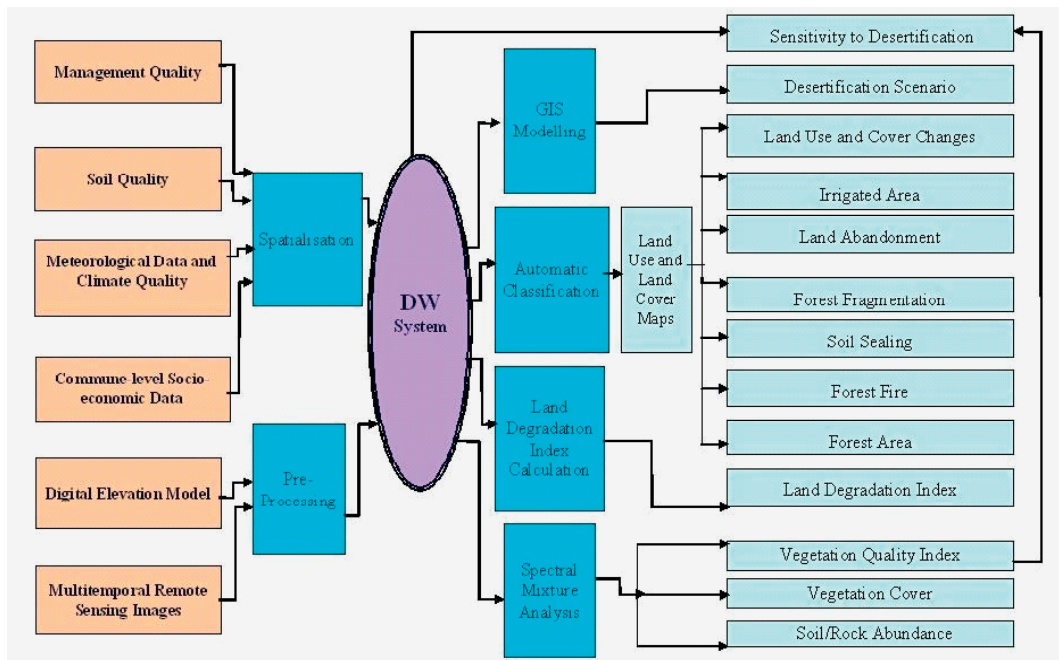


Figure 2. The logic and the structure of the DesertWatch System

usage of Earth Observation (EO) data and the set-up and operation of reliable services tailored to specific users needs and validated by the user. In fact, the users shall be provided with a system, which can be routinely used by non-experts, for generating the required indicators about desertification. The system will enable an objective comparison of data generated over different areas.

CONCLUSIONS

Land degradation and desertification monitoring and assessment should be based on systems, such as DMS, able to monitor/predict phenomena and to quantify impacts of desertification and benefits of mitigation. These systems can be effective if they use quantitative approaches based on desertification indicators. In this context desertification indicators constitute an essential tool for they can provide the required and necessary reliability and objectivity to make DMS operational. Thus, the development of projects focused on methodological issues related to indicators is an important step to design reliable and improved systems in order to safeguard environmental (and social and economical) security. As a further consideration, we can observe that, although there is a large number of experiences and technological capabilities about monitoring, they often remain largely under-utilised and inadequately shared. Hence, dissemination is poor and restricted and information cannot be directly used by decision-makers, at both the national and international levels.

The contributions developed by DESERTWATCH, through the implementation of an operational and user-tailored information system, gave input to the improvement of fight against desertification in terms of limiting subjectivity related to the collection and the elaboration of data. Concerning DESERTLINKS, the developed approach was based on the work with local stakeholders to find out how they perceive and are affected by desertification provides valuable insight for the research and institutional communities and engages the stakeholders in efforts to combat it. Finally, the process of reviewing the practicality of indicators leads to confidence and trust in the wider of these indicators, within and outside Mediterranean Europe. In fact DIS4ME proved to be a transversal and ductile tool able to host indicators coming from different experiences linked to desertification and other environmental issues (e.g. integrated coastal management).

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DETECTION OF LAND COVER CHANGES USING LANDSAT DATA IN THE ARID AREA OF YAZD-ARDAKAN BASIN, IRAN

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INTRODUCTION

Due to increasing changes of land-use, mainly by human activities, detection of such changes, assessment of their trends and analysis of the recent land cover dynamics through the integration of remote sensing and GIS provide base information for documenting land degradation and trends of desertification changes in the Yazd-Ardakan basin.

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). A wide variety of digital change detection techniques have been developed over the last two decades.

Desertification is actually a complex group of phenomena that occur in arid and semi-arid environments, which can be initiated by human land use, inter-annual climate variability or long-term climate change. Lack of information is one of the greatest threats to dry lands and their inheritance. Timely, relevant, and reliable information concerning the extent and risk of desertification is also extremely useful to institutions interested in stemming desertification.

The objectives of this study are therefore as follows: (1) to develop a methodology to map and monitor land cover changes through post classification change detection; (2) to assess the accuracy of multitemporal Landsat classifications and change detection; (3) to develop indicators for desertification in the Yazd-Ardakan basin ; (4) to link the change detection results with the desertification indica-

tors; and (5) to find out more detailed information about the processes of desertification in the Yazd-Ardakan basin, e.g. to identify possible 'hot spots' of desertification.

MATERIALS AND METHODS

STUDY AREA

The Yazd-Ardakan basin (study area) comprises 11740 km² and is located in the province of Yazd, in Central Iran. Its geographic position lies between 53° 24.7' to 54° 56.7' E longitude and 31° 13.5' to 32° 36.1' N latitude. The altitude of the study area ranges between 970 and 4075 masl. The average altitude is about 1 500 m.a.s.l. The location of the watershed outlet is the Siahkooh playa.

The mean annual air temperature is about 19.1 °C. The average of annual precipitation is about 85 mm for the whole study area. About 75–85% of the precipitation falls during the winter (Zare Ernani, 2002). Referring to the climate data, Yazd-Ardakan basin had been in the grip of severe drought in 1998. The amount of precipitation in Yazd weather station was 26 mm in compare with long-term average of 61.2 mm for the duration 1953 to 2005. But in the years 1976 and 2002 there were no droughts. Nevertheless, the amount of precipitation in most of weather stations in this area in 1990 is lower than the long-term precipitation average of those stations.

IMAGE PREPARATION

The basic premise in using remote sensing data for change detection is that changes in land cover result in changes in radiance values which can be remotely sensed.

Landsat MSS (Multi Spectral Scanner), Landsat TM (Thematic Mapper), Landsat ETM+ (Enhanced Thematic Mapper) imagery constitutes the base data layers from which the land cover maps of Yazd-Ardakan basin were derived (Table 1). SRTM 30-m DEM; time series of NDVI maps and field observations were required for validating the adopted classification and detection techniques. In addition to satellite data, other ancillary data such as aerial imagery, DEM derived datasets (slope and aspect), climate data such as precipitation and temperature, and vector overlays such as geology and geomorphology maps have used to increase the accuracy of the classification.

Imagery for use in change detection should be prepared so that the before and after images match each other as closely as possible spatially, spectrally and radiometrically. In this way, the only differences detected will be those that have actually occurred on the ground.

All images were rectified to UTM zone 39 N, WGS 84 using the rectified ETM+ 2002 image as the reference source for image to image registration, and also 1:25000 scale digital topographic maps and 32 well distributed ground control points. Image processing was performed using mainly ENVI version 4.0 and ERDAS Imagine version 8.6 software package.

IMAGE CLASSIFICATION

The creation of 1976, 1990, 1998, and 2002 land cover maps for the Yazd-Ardakan basin were derived utilizing ISODATA unsupervised classification. In this case 20 classes, each represented by a different colour, were created. The next step is to label these classes with the nine land cover classes which were spectrally separable.

A hybrid approach combines the advantages of the automated and manual methods to produce a land cover map that is better than if just a single method was used. With this approach which is used in this research, user can get a reasonably good classification quickly with the automated approach and then use manual methods to refine the classes that did not get labelled correctly. As a following step, very poor range, poor range, medium range classes were group into a single 'rangeland' class. Finally we end up with six classes: (1) bare land, (2) saline land, (3) rangeland, (4) farmland, (5) afforestation and (6) sand dune.

Table 1. Landsat data used in this study

[WRS: P/R]	Acquisition Date	Landsat Number	Sensor	Resolution (m)	Format
2: 162/038	2002-05-07	7	ETM+	28.5	GeoTIFF
2: 162/038	1998-05-20	5	TM	28.5	GeoTIFF
2: 162/038	1990-10-13	4	TM	28.5	GeoTIFF
1: 174/038	1976-10-14	2	MSS	57	GeoTIFF

CHANGE DETECTION ANALYSIS

Change detection analysis encompasses a broad range of methods used to identify, describe, and quantify differences between images of the same scene at different times or under different conditions. In a variety of studies, the post classification change detection method was found to be the most suitable for detecting land cover change (Weismiller et al., 1977; Wickware and Howarth, 1981).

In this research, Post classification method -the most concerned and intuition change detection method- is used (Jensen, 2004). Post classification comparison that is sometimes referred to as 'delta classification' determines the difference between independently classified images from each of the dates under discussion (Jensen, 1981; Singh, 1989; Jensen, 1996). This traditional post classification comparison yields "from" land cover change class and "to" land cover change class information and the kind of landscape transformations that have occurred can be easily calculated and mapped. The principal advantage of post classification lies in the fact that the two dates of imagery are separately classified; thereby minimizing the problem of radiometric calibration between dates (Coppin et al., 2004). The main disadvantages to post classification change detection are that it requires two separate classifications (time consuming) and also errors in each classification will be brought forward to the final change image (Deer, 1995).

Following the classification of imagery from the individual years, a multi-date post classification comparison change detection algorithm was used to determine changes in land cover in six intervals, 1976-1990, 1976-1998, 1990-1998, 1990-2002, 1998-2002, and 1976-2002.

ACCURACY ASSESSMENT

Classification accuracy assessment is necessary for comparing the performance of various classification techniques, algorithms, or interpreters (Congalton and Green, 1998). A most common and typical method used by researchers to assess classification accuracy is the use of an error matrix [sometimes called a confusion matrix or contingency table] (Congalton, 1991). These tables produce many statistical measures of thematic accuracy including "overall classi-

fication accuracy" (the sum of the diagonal elements divided by the total number in the sample), percentage of "omission error" (errors of exclusion), "commission error" (errors of inclusion) by category, and "KHAT coefficient" (an estimate of the Kappa coefficient, an index that relays the classification accuracy after adjustment for chance agreement) (Congalton and Oderwald, 1983).

The importance and power of the Kappa analysis is that it is possible to test if a land use and land cover map is significantly better than if the map had been generated by randomly assigning labels to areas (Congalton, 1996). The Kappa coefficient lies typically on a scale between 0 and 1, where the latter indicates complete agreement, and is often multiplied by 100 to give a percentage measure of classification accuracy. Kappa values are also characterized into 3 groupings: a value greater than 0.80 represents strong agreement, a value between 0.40 and 0.80 represents moderate agreement, and a value below 0.40 represents poor agreement (Congalton, 1996).

A preliminary accuracy assessment was performed on four post classification change detection maps. In addition, a change detection error matrix was created for the post classification techniques.

RESULTS AND DISCUSSION

Classified images of 1976, 1990, 1998 and 2002 were generated (Fig.1) and the individual class area and change statistics for the four dates are summarized in Table 2. From 1976 to 2002, saline land area increased approximately 42000 ha (171.2%) while bare land decreased 65000 ha (19.3%), sand dune decreased 7200 ha (61%). The cause of decrease in sand dune area is afforestation and change into bare land (27%); saline land (19%) and rangeland (20.5%). Since 1976 to 2002, farmland (irrigated) is increased about 22000 ha (280 %) and rangeland is also increased about 13300 ha (1.8 %).

To further evaluate the results of land cover conversions, matrices of land cover changes from 1976-1990, 1976-1998, 1990-1998, 1990-2002, 1998-2002, and 1976-2002 were created. In the table, unchanged pixels are located along the major diagonal of the matrix. These results indicate that increases in saline land mainly came from conversion of bare land and rangeland to saline land during the 26-year period, 1976-2002 (Table 3). Of the 42000 ha of total growth in saline land from 1976 to 2002, 76.1% was converted from

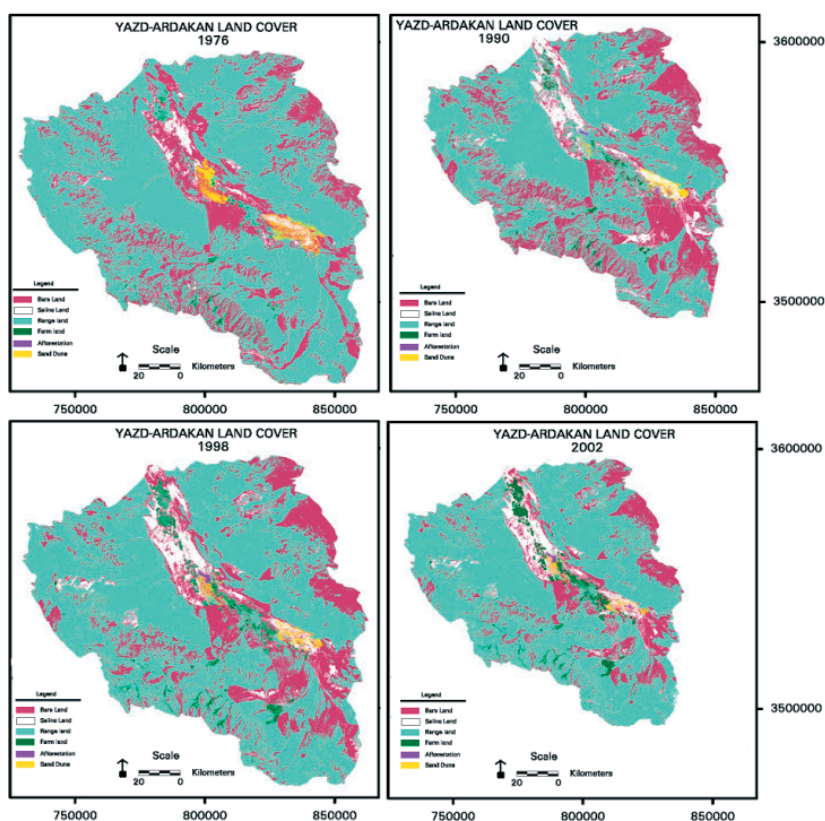


Figure 1. Land covers maps of 1976, 1990, 1998 and 2002 of the Yazd-Ardakan watershed

Table 2. Summary of image classification area statistics for 1976, 1990, 1998, and 2002

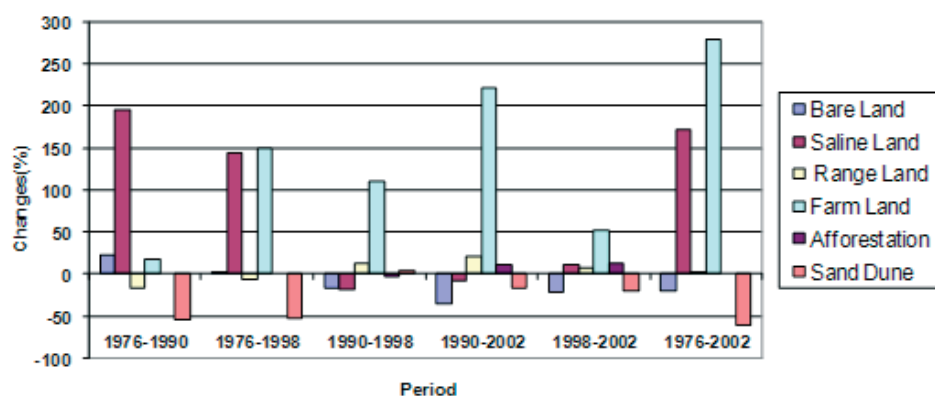
Land Cover Class	1976		1990		1998		2002		1976- 2002 Relative Change %
	ha	%	ha	%	ha	%	ha	%	
Bare Land	338563.7	29.7	415655.9	36.5	346586.0	30.3	273276.3	23.9	-19.3
Saline Land	24386.8	2.1	71962.7	6.3	59472.9	5.2	66145.7	5.8	171.2
Range Land	755836.6	66.3	632975.0	55.6	711752.7	62.2	769166.2	67.2	1.8
Farm Land	7923.2	0.7	9392.5	0.8	19732.1	1.7	30125.0	2.6	280.2
Afforestation	0.0	0.0	1084.5	0.1	6537.6	0.6	1203.7	0.1	-
Sand Dune	13442.4	1.2	6251.1	0.5	1072.7	0.1	5236.8	0.5	-61.0

Table 3. Matrices of land cover changes (in hectare) from 1976 to 2002

1976-2002	1976									
	Bare Land		Saline Land		Range Land		Farm Land		Sand Dune	
	ha	%	ha	%	ha	%	ha	%	ha	%
Unclassified	1	0	0	0	1	0	0	0	0	0
Bare Land	162766	48	3071	13	100769	13	726	9	3613	27
Saline Land	36670	11	17835	73	8958	1	28	0	2561	19
Range Land	127925	38	2043	8	631136	84	2734	35	2757	21
Farm Land	9235	3	1210	5	14345	2	4434	56	893	7
Afforestation	144	0	70	0	15	0	0	0	975	7
Sand Dune	1822	1	158	1	814	0	0	0	2843	20
Class Total	338564	10	24387	100	755837	100	7823	100	13442	100
Class Changes	175798	52	6552	27	124701	16	3489	44	10799	80
Image Difference	-65288	-19	41759	171	13327	2	22202	280	-8206	-61

bare land and 18.6% from rangeland. Of the 22000 ha of total growth in farmland from 1976 to 2002, 56 % was converted from rangeland and 36% from bare land.

Figure 2 shows the difference in the total number of equivalent-ly classed pixels in the two paired images (1976-1990, 1976-1998, 1990-1998, 1990-2002, 1998-2002, 1976-2002) in percent, computed by subtracting the initial state class totals from the final state class totals. In urban and industrial division, urban extension only in city of Yazd since 1976 to 2002 was about four times.

**Figure 2.** Land covers image differences for 6 time periods of the Yazd-Ardakan Basin

Accuracy assessment is an important final step of the classification process. The goal is to quantitatively determine how effectively pixels were grouped into the correct land cover classes. Reference data for the four images were obtained from aerial photos, historical ground data, GIS layers those previously are used in the classification process and direct field observation. Stratified random sampling was used for selecting samples. 250 random points are used for each classification map.

Error matrices as cross-tabulation of the mapped class vs. the reference class were used to assess classification accuracy. The overall accuracies for 1976, 1990, 1998, and 2002 were, respectively, 82.0%, 86.0%, 87.2%, and 90.8%, with overall Kappa statistics of 0.7521, 0.8232, 0.837, and 0.8819. Producer's accuracy and user's accuracy of individual classes were consistently high, ranging from 77.42% to 100%. Kappa values for 1990, 1998 and 2002 maps are greater than 0.80 (80%) representing strong agreement. The 1976 scene has a value about 0.7521 that is between 0.40 and 0.80 which represents moderate agreement and is better than one obtained by chance.

CONCLUSIONS

There is a gradual increase in improvement of range condition in the Yazd-Ardakan basin. The trend of changing rangeland to bare land is decreasing. During the period 1976-1990, this rate was 24.71% compared with 10.58 % and 2.31% respectively for 1990-1998 and 1998-2002. This was an unexpected but pleasant discovery.

The resulting spatial data yielded from these study shows, in spite of improvement of the rangeland condition, that farmland in this arid zone is increasing and has resulted in a lowering of the ground water level. Since 1976 to 2002, farmland has increased about 22000 ha (280 %). Most of the farmland or irrigated areas are assigned to garden and greenery which have much high water requirements. In fact, the amount of biomass in this region has increased. But the Yazd-Ardakan basin has encountered two main risks: (1) the amount of consumed water that is very rapidly increasing and results in a depletion of the ground water resources which is putting a threat on the life in this arid ecosystem; (2) increases in soil salinization. In 1976, there were about 27500 ha of saline land but in 2002 the amount of saline land was 47000 ha.

According to the results, it can be noted that desertification in the Yazd-Ardakan basin has not stopped. In this area the type and shape of desertification has changed. Heretofore desertification was referred as vegetation degradation or surface erosion. But nowadays desertification is occurring with groundwater degradation and to some extent to soil salinization. These two types of desertification are more dangerous than the previous types of desertification.

According to the results, it can be concluded that the developed methodology to map land cover changes using three different sensors and generations of Landsat satellite have great results more than expected in this arid area. In other hand, through post classification method, most of the land cover changes in this arid land over a span of 26 years have detected and mapped. These results can be used as desertification indicators in assessment of desertification in this arid region. With linking the change detection results with the desertification indicators, we can find out more about desertification processes. Consequently proper plan to combat to desertification in this basin can be programmed.

Overall accuracy and Kappa coefficient statistics indicated that the post classification change detection method is very effective in discriminating land cover changes in this arid area. Performing the post classification analysis in the Yazd-Ardakan basin allowed for the monitoring of natural landscape overtime. This change detection study provides a beneficial insight into the extent and nature of change that has taken place in this arid land from 1976-2002, and lays the foundation for assessment of desertification. This research can also be applied to other arid regions encountering desertification and vegetation change.

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DESERTIFICATION IN JORDAN IN THE LIGHT OF PALEOSOLS AND PAST ENVIRONMENTAL CHANGE

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INTRODUCTION

The United Nations recently issued a new desertification alert, warning that global warming may lead to expanding deserts (UN, 2007). While it is acknowledged that climate change is the trigger of the increasing desertification threat, member countries are advised to strengthen efforts reducing human pressure on the land. But can reduced human pressure compensate for increased climatic forcing? An answer might be given considering past examples of desertion, which played an important role for the evolution of the actual understanding of desertification¹. In particular, the Mediterranean and its transition zones to the desert host impressive ruins from the Roman-Byzantine period, which raise the question why these once densely settled areas were abandoned. Three fundamental explanation approaches can be differentiated:

1. Population growth or conquest by uncivilized tribes caused over-exploitation of the land, leading to soil erosion and irreversible degradation of the agricultural potential. As well, it is discussed whether erosion and reduced vegetation may lead to decreased precipitation (Lowdermilk, 1944). This is the prevailing theory and basis of many current measures combating desertification.

¹“Desertification” in the first place did not mean an invasion of sand, but depopulation of an area (from Latin “desertere”, the meaning of which is preserved in the German words “wüst fallen/Wüstung”). The term desertification as an expansion of deserts was coined in the 1930ies during the U.S. dust bowl.

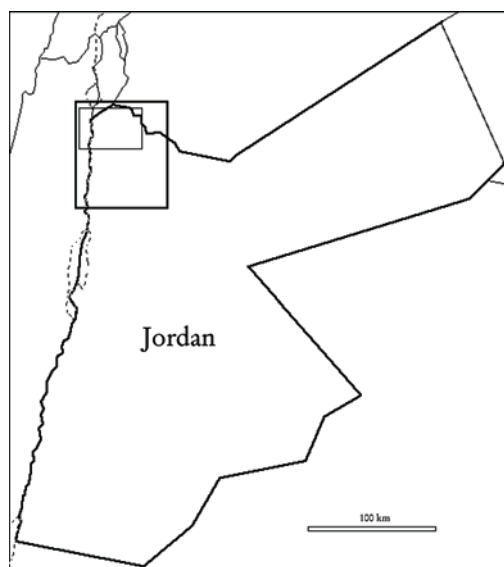
2. Natural climate variations determined settlement history. According to this model, phases of decline were connected with drought and bad harvests. This thesis gained attention recently due to new climate reconstructions and the increasingly obvious global warming (Issar and Zohar, 2004). Considering vegetation and soil erosion, climate change and mismanagement can have identical impacts.

3. Many archaeological studies found no evidence for environmental changes and concluded that political or economic developments were behind the ups and downs of settlement history (Walmsley, 1992). Authors who support this thesis do not exclude environmental changes, but consider their effect subordinate compared with the meaning of socio-economic factors. The limited area of an archaeological excavation also allows for only limited conclusions about environmental change.

For the current land use planning under global warming, it is most important which of the above mentioned theses is closest to reality. Does it make sense to conduct large-scale reforestation programs, or are these forests going to die anyway under continued warming? Does a rise of temperatures lead to drier conditions, or is the opposite going to happen? Is human action most relevant for landscape dynamics, or is climate? Many countries in semi-arid regions face a strong growth of population and industry while water resources are diminishing. The necessary expansion of water harvesting and general land use is increasingly risky, because it is unknown whether the environment will remain stable.

The look into the past is a key for dealing with the future, since what already happened may happen again. Past environmental systems are “closed” and cannot change any more, which allows improved understanding of causal relationships. In cooperation with several archaeological missions, these questions are currently investigated by the Chair of Environmental Planning in a project funded by German Research Foundation (DFG) on “Interactions of land use, climate and soil development in the context of settlement history in the Decapolis-Region (Northern Jordan)”. The Decapolis region extends from the Jordan valley over a Mediterranean highland into the Arabian desert (Fig. 1).

Figure 1. Map showing the approximate location of the Decapolis region in Northern Jordan (big box) and the investigation area (small box).



PALEOSOLS AS ARCHIVES OF ENVIRONMENTAL CHANGE

In many areas in Jordan, paleosols were discovered which can contribute to reconstructions of past environments, and are in particular important for desertification studies since soils are indicators of land degradation. However, many paleosols in Jordan were only recently recognised as such because of their similarity to present soils, and because archaeological missions lacked the expertise to identify and examine them.

A soil is a paleosol when it is disconnected from ongoing soil-forming processes, for example after being built over by a town, or after being buried by a landslide which deposited enough material to put the soil out of reach for soil-turning animals. This preserves the status of soil-formation at the time of burial. But paleosols are not proxies for single parameters like annual precipitation, since many other variables like vegetation, human activity, dust deposition and temperature are involved in soil-forming processes. The challenge for the paleosol researcher is to understand which of the many factors changed. Regarding climate reconstruction, other proxies like e.g. speleothems or lake sediments deliver more precise and specific results (which can be combined with paleosol examination). The advantage of paleosols lies in their greater spatial distribution, and the need to consider various factors can turn out as a benefit since it delivers better clues about causal relationships.

A set of factors makes the Decapolis region the ideal investigation area for studying environmental history and differentiating the influence of humans from the effect of climatic changes. On the one hand, the situation in the transition zone to the desert permits the investigation of soils and colluvia along climatic gradients. On the other hand, historical dating of landscape changes and a comparison of soil development with reference to the source rock and relief are made possible by the good archaeological documentation and simple geological structure. In the Decapolis region, the geological structure consists of chalk limes and horizontally structured limestones shaped by Karst, which are at some places covered by basalt. The picture of the landscape is that of a high plateau incised by deep valleys (in Arabic wadis). While the plateau is covered by red soils (Terra Rossae), the slopes show white-grey soils (Rendzinas).

RESULTS: CLIMATE AND GEOLOGY AS LANDSCAPE-FORMING FACTORS

The Decapolis region was counted a classic example for the narrative of man's destructive impact on the land. In this context, it seemed to be out of question that the designers of the impressive monuments from the Roman-Byzantine era could not have been responsible for the degradation. That was attributed to the Muslim conquerors who supposedly allowed nomads to take over, neglect terraces, cut the forests, and overgraze the land. In essence, the immigration of uncivilized tribesmen was seen as the prime reason of desertification, and only their education by more civilized powers could turn things to the better (Lowdermilk, 1944; Hillel, 1991).

However first doubts about this paradigm arose when development aid projects could not achieve their goals. Such a project was conducted in the Zarqa valley close to the city Jerash, where sediment deposition into the King-Talal dam should be decreased and soils be stabilized by construction of terraces and stone walls (GTZ, 1991). It was even hoped to exert a positive impact on local climate by large-scale reforestation. However, a heavy rainstorm in February 1992 led to dramatic sedimentation into the dam in form of landslides, despite the construction of the terraces (al-Sheriadeh and al-Hamdan, 1999). Besides, no general positive effect of the forest could be determined so far. Newer studies point to the opposite, showing that the monoculture afforestation with pine leads to a very

high forest fire risk, may move the grazing pressure to ecologically more sensitive areas, and reduce groundwater formation (van der Leeuw, 2004).

Investigations of paleosols and archaeological archives brought further insight. They show that the erosion of the Terra Rossa occurred mainly at the end of the last Ice Age and during the Younger Dryas (Cordova, 2005; Maher, 2005; Lucke, 2007). The colluvia found in the wadis show that sedimentation since the Neolithic constitutes a very small portion of the entire deposits. No Neolithic site was found to be covered by red soil: erosion of the Terra Rossa in the Decapolis region had mainly come to end when agriculture was invented. But the sediment record also revealed that dramatic landscape changes with massive landslides and erosion of Terra Rossa took place at the end of the last Ice Age, during the Younger Dryas (Cordova, 2005; Maher, 2005), and during the “Yarmoukian landslides” 8200 BP (Weninger et al., 2005; Lucke, 2007). At the end of the Byzantine period (~650 AD), and possibly at the end of the Mamluk period (~1500 AD), these phases of landscape instability may have resumed to a minor extent. Nevertheless no Terra Rossa was eroded any more, which is probably due to the fact that the landscape is in the stable state of completed erosion since the Neolithic period (NSM&LUP, 1993).

In general, the soil pattern points to a dominant role of local factors in soil formation (Lucke et al., 2005; Schmidt et al., 2006; Lucke, 2007). The deepest soils are located in the east, where wadis are least incised and drainage is minimal. In this context, long-term erosion seems not so much a matter of average annual rainfall, but relief. Soil variations are strongest on the deeply incised Mediterranean limestone plateau, the level appearance of which seems to be the outcome of considerable soil movement. As indicated by a profile close to the Yarmouk river, one of these movement processes might have taken place around 6880 BC, which lets a connection with the regional “Yarmoukian landslides”-event seem possible. Basalt soils are characterised by a strongly contrasting uniformity. This illustrates that not only the relief, but also the source rock played an important role for the formation of the soils. The uniformity of the basalt soils might be related to mixing processes that obliterate horizons as visible in the limestone soils, indicated by the drought cracks and slickensides. Even though the deep limestone soils show

slickensides, too, their vertic behaviour seems not so pronounced which might be related to different sets of clay minerals (Lucke, 2007).

The large-scale pattern repeats in the small scale. Soil distribution in the Wadi el-Arab supports the conclusion that soil development took place in a geological time scale. Soil properties are again related to the underlying rocks and relief, with red colluvia in the depressions, exposed chalk ridges, and grey soils covering the natural terraces of harder rocks. The latter might once have carried red soils, as still present on the adjacent high plateau, but there is so far no reason to attribute their erosion to historical periods. If they had been eroded recently, much more red colluvium should be visible in the Wadi el-Arab (e.g., at the foot of a hill formed by ruins (Tell) as a sediment obstacle), and not only in depressions between the chalk ridges. Although the lower wadi terraces give evidence of recent soil movements, no red colluvia could be observed there. Especially interesting is the paelosol which Maher and Banning found in Wadi Ziqlab, suggesting that the *Terrae Rossae* were eroded before 11,000 BC (Maher, 2005), but that some red colluvia in the wadi bottom were not yet covered by Rendzinas until the late Byzantine period (Fig. 2).



Figure 2. Paleosol with excavated surface from the Kebaran (11,000 BC). Further upwards is a Byzantine field border wall (on top of the meter scale) which was covered by a weakly developed Rendzina and chalk from the slopes. Wadi Ziqlab, northern Jordan, excavation by E. Banning and L. Maher. Photo: B. Lucke.

Table 1. Iron oxide ratios pretend intense soil development of the chalk, but CaCO_3 -content, magnetic susceptibility and manganese oxides show clearly how the paleosol in Wadi Ziqlab is more developed than the sediments covering it.

Sample No.	CaCO_3 %	$\text{Mn(d)}/\text{Mn(t)} \cdot 10$	$\text{Fe(d)}/\text{Fe(t)}$	Magnetic susceptibility χ (I kg^{-1}) $\cdot 10^{-3}$
TZ 54 (chalk)	74	0.04	0.51	15.83
Ziq 1 (10 cm)	65	0.05	0.16	36.1
Ziq 2 (40 cm)	63	0.11	0.78	49.7
Ziq 3 (70 cm)	50	0.35	0.42	214.1

Progress could be achieved regarding the methods of soil analysis. Soils rich in CaCO_3 as present in the Decapolis region are an analytical challenge since pre-weathered iron and clay is bound in the calcium carbonate in varying degrees. It was found that the “classic” soil investigation methods of iron oxide ratios and texture provide no meaningful results (Lucke, 2007). But manganese oxides, magnetic susceptibility and CaCO_3 -content show very clear tendencies, indicating that the overall soil development decreased since the end of the last Ice Age (Table 1). Especially the wadis seem to have changed from densely vegetated places with periodic waterlogging to traps of chalk accumulation.

The additional analysis of air photos and historic travel reports indicates that old field patterns can be traced according to remains of field borders, and possibly weak differences of soil development, which again indicates that historic desertification in the sense of massive erosion did not take place (Lucke et al., 2005; Lucke, 2007). Evaluating the descriptions of 19th-century travel reports, the landscape changed much less in the recent past than previously assumed. For example, oak forests are still present where they were reported 200 years ago, and the remains of Byzantine field systems under the trees make clear that the Muslim conquest led to a natural reforestation. The overall picture is that of a very stable landscape, but the productivity of which is determined by water availability.

CONCLUSIONS

Our results from the Decapolis region let many current actions of combating desertification seem questionable. This is not to say

that reducing human pressure on the land would not be desirable, but the impact of climatic changes dwarfs the impact of man in the environmental record of the soils of Jordan. There is no indication that Terra Rossa was eroded during history. Younger colluvia since the mid-Holocene consist of weakly developed chalk from the wadi slopes. In this context, manganese oxides and magnetic susceptibility point to much moister conditions in the past, possibly connected with periodic waterlogging. While man may locally have altered soils, and probably contributed to additions of calcareous dust, climate and the geological pre-disposition were decisive for landscape development.

It is important to note that the last period of major global warming, which is the end of the last Ice Age, and the last major global cooling, which is the Younger Dryas, led to dramatic landscape instability in Jordan. The sediment record indicates massive erosion in form of land slides, and possibly strongly reduced vegetation cover. The most likely explanation for this pattern is an increased frequency and intensity of heavy rainfall events. Global warming may not linearly lead to drier or warmer conditions, but to a switch from one climatic equilibrium to another, with a transition phase characterised by extreme and unusual weather. If confronted with instabilities as documented from the end of the Ice Age in the sediment record, it is likely that none of the present land use systems will survive (Lucke, 2007). But given alone that global warming leads to increasing dryness, a calcification of soils in the area has to be expected. This could strongly impact the vegetation cover and soil productivity, and will most likely be more threatening than erosion (Lucke et al., accepted). The only measure to counter calcification might be irrigation.

Further research is planned to better understand the time-frames and occurrence of periods of landscape instability, feedbacks between land cover and climate, and to assess whether local or regional forcing was behind changes. With regard to present programs of combating desertification, the best strategy seems to prepare for extremely heavy rainstorms and unusual weather. It is so far not possible to say how land suitability will look like in 2100, but a careful cost-benefit analysis in the light of the environmental history seems imperative before conducting large-scale land recovery programs.

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THE INFLUENCE OF SHORT-TERM LAND USE CHANGE ON SOIL EVOLUTION IN THE CENTRE-SOUTH COASTAL AREAS OF SARDINIA

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INTRODUCTION

The land use change in short-term (time and space) in the Mediterranean context can be induced by phenomena like destruction of the autochthonous plant species, land abandonment, overgrazing, fire, urbanization (above all for touristic purpose), etc. These phenomena can lead to soil's degradation conditions causing a loss of physical and biological productivity and the consequent emphasis in desertification processes. Desertification is considered one of the biggest environmental problems in Mediterranean areas (ICCD, 1994), and Sardinia is one of the most affected regions in Europe (UNEP, 1992; Imeson and Emmer, 1992). In Sardinia changes happened during the last decades (such as industrialization, coastal urban areas expansion, etc.) have often resulted in repercussions on the environmental ecosystems and foremost on soils. An important decrease of fertile lands and a consequent increase of marginal and unproductive areas have been observed; this fact has taken to manifest environmental and economic repercussions. In Sardinia such degradation phenomena are particularly evident in coastal areas, where the uncontrolled urbanization and the natural touristic vocation represent relevant impact types. In fact, in 1897 km of coastal lands (500 km are represented by dunal systems) 40% is subjected to deep erosion phenomena, that often are caused by wrong management actions. For these reasons the knowledge of their nature and expansion is of primary importance to carry out correct choices in land use. This

work shows an example of a comparative investigation on coastal ecosystems particularly under human pressure. The investigated areas are located along the Centre–North coast of Sardinia. Particularly they concern: a) soils on limestone formations, forestry live oak cover and pasture land use (goat and swine); b) soils on fixed dunes, reforestation with pine and touristic-recreational land use foremost. In the areas several soil profiles have been realized to investigate the influence of the land use change, occurring in short-term in both places, on the evolution and degradation processes of soils.

MATERIALS AND METHODS

STUDY AREA

The study areas are located in the centre north-east coast of Sardinia. The first area (site 1) is located at Dorgali town, Nuoro province, in the centre-east Sardinia. This region has a typical Mediterranean climate, with cold and rainy winters and autumn, and warm and dry summer. The mean annual temperature is 18.3 °C with the warmest and coldest monthly mean temperatures of 26 °C in August and 11.7 °C in January, respectively. Mean annual precipitation is 647 mm. From a geologic point of view the research area consists of middle Triassic-lower Cretaceous bioclastic limestones, oolitic cherty limestones and mudstones (Carmignani, 2001). Geomorphologically, the region is characterized by undulating hilly lands. The natural vegetation is dominated by *Quercus ilex* forest with brushwood rich in shrubs such as *Cistus albidus*, *Cistus incanus*, *Cistus savifolius*, *Pistacia lentiscus*, *Rosmarinus officinalis*, *Euphorbia dendroides*, *Genista corsica*, *Juniuperus phoenicea*. However, as a consequence of the intense brushwood grazing (mainly goat and swine), in several areas the native shrubs had been cleared and the remaining natural forest has deteriorated due to short-term disorganized forest management. In fact, in pasture areas, in the last 25 years, brushwood clear-cutting is regularly carried out. This practice is very popular in Sardinia as a way to reduce fire risk. As a consequence of this forest management two main forestry covers can be identified: the first is characterised by a natural wood with brushwood very rich in bush and grass species. The second is characterised by wood hardly disturbed by human factors and presenting brushwood subjected to heavy pasture. This second type of wood, is periodically subjected

to a non-selective cut and for this reason it is very poor in bush and grass species; moreover, it presents a very low renewal rate of woody part. The main degradation risks for soils belonging to this area can be related to the high pasture pressure and to the wrong forestry management.

The second area (site 2) is located in the dune coastal system of Siniscola in the south-east Sardinia. The climate is typically Mediterranean and is characterised by irregular rainfall events as well as a warm and dry summer period. The mean annual temperature is 16.9 °C with a maximum average of 26.0 °C in August and a minimum average of 10.1 °C in January. The mean annual precipitation is 710.6 mm. The dune system in this area of north-east Sardinia was formed in the quaternary period by transport and deposition of sands over a base of micashistis and paragneisses of the Hercynian metamorphic complex from the Paleozoic period (Carmignani, 2001). The natural vegetation of the dune system is dominated by a complex alternation of herbaceous and shrubs species in relation to characteristics such as distance from the sea shoreline, groundwater level, micro-topography, etc. In the stabilized dunes the higher strata of vegetation is formed by Mediterranean shrubs of *Juniperus phoenicea* and *Pistacea lentiscus*; in the mobile dunes, at summit positions, the vegetation is dominated by rhizomatous grasses of *Ammophila arenaria*; in the inter-dune areas the vegetation cover is normally denser than in the other positions, with species like *Juncus maritimus*. However, only in few areas the natural vegetation remains due to an important reforestation with *Pinus pinea* and *Pinus halepensis* carried out in the 1939 in order to avoid the movement of sand towards the inland. In addition, and as a consequence of the reforestation, this environment is subjected to very high human pressure due to intensive urban development and tourism recreational areas. This system has been heavily modified in a very short time, changing from a state of high naturalness to one under a heavy human pressure. Table 1 shows the main characteristics of the two studied sites.

FIELD INVESTIGATION AND SAMPLING

In the two sites a pedological survey was realized. In site 1 ten profiles were investigated: five located in areas with grazing and period-

ical brushwood clear-cutting; five in areas with a smaller anthropic impact. In site 2 ten profiles were realized: five in areas subjected to a high recreational use, and the other five to a lower use. In both cases the level of use and the anthropic impact (grazing and brushwood clear-cutting for site 1, recreational use for site 2) was defined on the basis of observation in the field and statistical data provided by public administration.

The soils were described by standard soil survey methodology (Soil Survey Division Staff, 1993), classified according to the Soil Taxonomy (Soil Survey Staff, 2003) and analysed with the official procedures of the Ministero delle Politiche Agricole e Forestali (2000).

RESULTS AND DISCUSSION

SITE 1

The study showed that pasture of the under wood and the brushwood clear-cutting results in a significant soil degradation. In this kind of conditions soil showed scarce development, with an A–C/R, A-B-C/R type profile and a solum with an average depth of 15–20 cm. The solum development was considerably greater in areas with low pasture and without clear-cutting. In those pedons surface horizons were almost all characterized by the presence of a transition surface

Table 1. The main characteristics of the study area

	Location	Land cover		Land use	Main environmental problems
		Natural areas	Anthropized areas		
Site 1	centre-east Sardinia	Forest of live oak with a brushwood rich in shrubs and herbaceous species	Forest of live oak with a poor brushwood	goat and swine grazing	overgrazing and periodical brushwood clear-cutting
Site 2	south-east Sardinia	<i>Juniperus phoenicea</i> , <i>Pistacea lentiscus</i> , <i>Ammophila arenaria</i> , etc.	<i>Pinus pinea</i> , <i>Pinus halepensis</i>	tourism and recreational areas	increase of urban development and recreational demand

horizon (OA), with remarkable organic matter content, several times strongly humified. The content of soil organic matter decreased in the areas with grazing and brushwood clear-cutting and this can be attributed to the significant reduction in litter, but also to the poor living conditions for soil organisms in compacted soils. Moreover the clear-cutting activities caused reduced vegetation cover leading to litter being washed away by heavy rainfall. The nitrogen contents results were instead particularly modest, especially in those areas with intense pasture. Consequently, elevated C/N ratios were often recorded in the surface horizons of the soils under grazing: this is an index of a low mineralization of the soil organic substance with relative low turnover. Particularly, a net predominance of humification processes in comparison to those of the mineralization of organic substance in soil is underlined. In fact, the determination of the humification parameters, in accordance with precedent researches related to this topic (Ciavatta et al., 1990; Trinchera et al., 1998), shows elevated levels of humification against low levels of mineralization. In such sense, the grazing seems to directly or indirectly influence the degradation processes of the SOM: in the first case, through a great input of hardly mineralizable organic substance; in the second case through a great selection of not pabular and often rich substances characterized by a slower mineralization (lignin, cellulose, etc.) species. In both cases, the result of such influence is: the stabilizing of surface horizons being strongly humified; an elevated bringing in of hardly mineralizable organic substance; a slow turnover of the SOM; a net predominance of the humification processes.

Generally, from the taxonomic point of view (Soil Survey Staff, 2003), soils in areas with grazing and brushwood clear-cutting belong to Entisols and Alfisols, while the soils of non-grazed areas are Mollisols. It was particularly observed that the soils in grazed areas could satisfy the prerequisite for belonging to the order of Mollisols but this condition was not met, above all, due to the low organic matter content and the insufficient thickness of the surface horizons. The investigations developed in the area allow, in fact, to hypothesize that in past times the area was more markedly characterized by a great presence of Mollisols in comparison to the actual conditions. The intense exploitation of the native vegetable component

(above all live oak) inevitably affects the underlying soils, causing a marked accentuation of degradation phenomena. For such reasons future uses should foresee a more careful environmental planning and management, above all settled to a definite decrease of the grazing pressure and to a rational brushwood exploitation with total cessation of the indiscriminate non selective cutting.

SITE 2

The research showed that all the studied pedons had scarce development (O-A-C), mostly in those areas under the heaviest human pressure (O-C, C), and a degree of soil compaction significantly higher on the areas subjected to high use than the low-use areas.

In the area recreational impact also reduced the amount of litter and organic matter in the upper soil horizons. This process is very important in stabilised sand dunes because many soil properties depend on organic matter content (Kutiel, 1998-1999). In these environments the soil organic carbon is concentrated in the upper five cm, and this horizon is fundamental for properties such as soil stability and fertility. When the organic horizon is destroyed, we observe the rapid transition to unstable sand. In the research area, this process was often observed in sites with high recreational use.

In the study area the effect of short term land use change can be immediate not only for soils and geomorphic dynamics but also in terms of biotic processes and spatial fragmentation. For example, in the areas subjected to high recreational use there is a clear decrease of microbiotical crust (NRCS, 1997; Álvarez-Rogel et al., 2007), formed by the agglutinating effect of fungal mycelia on the particles, which have very important ecological functions (enrichment of the soil in organic matter, aggregates stability, atmospheric nitrogen fixation, stimulation of microbial activity, etc.). These crusts are particularly developed in areas with low anthropic impact and recreational use. For that concern spatial fragmentation, the high recreational use causes an increase in the number of marginal areas, and consequently a decrease in the ecosystem connection by the creation of ecological islands (Reed et al., 1996).

This work demonstrated how wrong past management decisions have resulted in observable recoils on state and pedogenetic evolution of the studied soils. Particularly, the following actions represent

the most dangerous threats for these dune soils: massive use of allochthonous species (mostly conifers), lack of careful forestry management actions subsequent to the reforestation phase and main land use destinations.

The influence of human activity was further confirmed by the presence of buried Ab horizons, with a higher organic matter content than the actual epipedon, that can be considered as relict evidence of the dune system state (Álvarez-Rogel et al., 2007) before the reforestation. Particularly, these horizons can be related to a dense ancient vegetation cover, which was probably destroyed to facilitate the reforestation with allochthonous species. This management practice contributed to the burial of the old soils due to the lack of vegetation cover against wind erosion.

CONCLUSIONS

The natural conditions in Sardinia coastal areas are characterized by a fragile environment very sensitive to human pressure. Land use change can exert a great influence on soil, landscape and environment. For example forest overgrazing and brushwood clear-cutting practices in limestone areas can result in significant soil degradation by declining organic carbon, nitrogen, loss of structure and increase of erosion phenomena. Also in coastal sand dunes ecosystems the high human pressure, increased in the last thirty years due to intensive urban development for tourism purposes, can lead to soil degradation with consequences in terms of geomorphic dynamics, biotic processes and spatial fragmentation. These kinds of environments are widely spread in Sardinia and they represent an important environmental and economic resource. For such reasons it is necessary to preserve the function and sustainability of these natural systems with the application of best management practices. From this point of view, since the end of 2007, two areas are subjected to long-term controls using the methodology briefly described above. In each site eight plots were realized with the following features: site 1) four fenced and four open plots (5 m x 5 m in size) in grazed and clear-cutted areas, with the aim to understand the effects of grazing and brushwood clear-cutting on vegetation dynamics and soil characteristics; site 2) four plots in areas with high visitor use and the other four subjected to a lower use (8 m length x 1 m wide). In each site the observations about the plants community (overall

percentage cover, overall average height, relative percentage cover of each species, species richness, species diversity, etc.) and some selected soil characteristics (organic carbon, total nitrogen, humic and fulvic acids, etc.) will be recorded for each season in the next three years.

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DESERTIFICATION AND RESILIENCE IN THE DENSELY POPULATED AND SEMI-ARID HIGHLANDS OF NORTHERN ETHIOPIA – EVIDENCE FROM PHOTO MONITORING WITH 140 YEARS INTERVAL

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INTRODUCTION

Semi-arid areas of the world (UNEP, 1994) are often marginalized in terms of investments in natural resource management and agricultural production (Reij and Steeds, 2003). “It is like pouring water on a stone” is a popular saying in the better endowed parts of the country when talking about Ethiopia’s peripheral drylands. The overall productivity of such areas is often perceived to be so dramatically damaged by human impact that recovery is deemed impossible (Rasmussen et al., 2001; Thomas, 1993). However, several impact studies have demonstrated that investments in drylands do pay off in economic terms (Boyd and Turton, 2000; Holden et al., 2005; Reij and Steeds, 2003).

These case studies are often limited in space, time and scope; they may include better endowed regions (Holden et al., 2005) and/or high-investment and nearby-monitored NGO-type of interventions. One might therefore question to what extent these reports on recovery are representative of wider areas. Admittedly, such impact studies typically do not include detailed botanical, hydrological and geomorphological components either (Rohde and Hilhorst, 2001). Here, we present some outputs of a project that has made a multi-scale assessment of the results of 20 years of environmental

rehabilitation of a whole region in one of the world's most degraded areas: the Tigray highlands in northern Ethiopia (Fig. 1).

Despite the catastrophic impact of dry years on the degraded environment (Casenave and Valentin, 1992; Valentin, 1996), no tendency of decreasing rainfall can be observed in the Ethiopian highlands (Conway, 2000; Hulme, 1992), nor for the rainfall station of Mekelle, located in the centre of the study area. Causes of current land degradation by sheet, rill and gully erosion are to be found in the unsustainable use of natural resources and in changing land use and land cover, which result from human impact on the environment (Nyssen et al., 2004).

There is geomorphological and palynological evidence that deforestation and the associated soil erosion in the Ethiopian highlands is at least 3000 years old (Bonnefille and Hamilton, 1986; Hurni, 1985; Moeyersons et al., 2006; Nyssen et al., 2004). However, modern population growth is assumed to have accelerated soil erosion due to a progressive change in land cover with the main purpose of increasing food production within a subsistence farming system (Kebrom Tekle and Hedlund, 2000; Wøien, 1995). As land resources are pushed to their limits, ruptures in the fragile equilibrium contribute to catastrophes such as the 1984 famine.

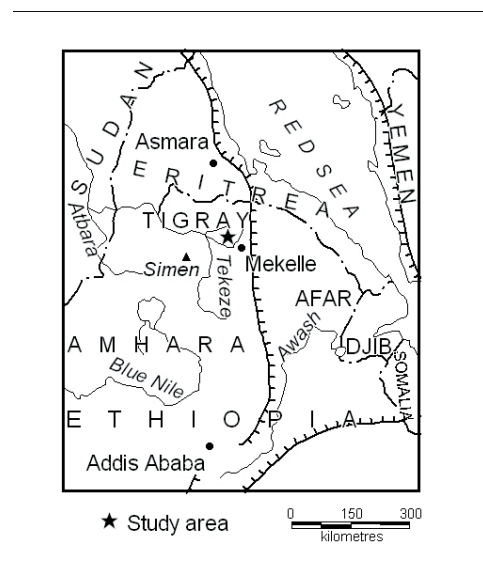


Figure 1. Location of the project area

As a response to such situations, huge efforts have been made in Tigray (northern Ethiopia) at a regional scale (105 km²) to control soil erosion, for instance through the construction of stone bunds and the rehabilitation of steep slopes (Descheemaeker et al., 2006a; Descheemaeker et al., 2006b; Nyssen et al., 2007d).

Research cooperation between Mekelle University, the academic heart of Tigray region, and Belgian partners on soil erosion and soil and water conservation started in 1994 through an MSc study of the University of Liège. Subsequently, fundamental research was carried out by FWO (Fund for Scientific Research, Flanders, Belgium) from 1998 to 2001 and concerned especially soil erosion processes, rates and assessment of human vs. natural causes of land degradation, and several VLIR projects were initiated by Ghent University and K.U.Leuven. The Zala-Daget project (VLIR, Flemish Inter-University Council, 2001-2007) was a joint project between Mekelle University, the Relief Society of Tigray, the K.U.Leuven and the Africamuseum in Tervuren (Belgium). The Tigrinya words zala and daget stand for physical and biological soil and water conservation technology. This research project focuses on the evaluation of various soil and water conservation techniques used in Tigray, impact of soil erosion at catchment scale and two-way transfer of knowledge on soil conservation between land users and researchers.

The project has published dozens of theses, congress presentations and scientific papers, out of which about thirty in high-level international scientific journals. At the end of project lifetime, two initiatives have been taken: the development of extension manuals, both in English (Nyssen et al., 2007a) and in the local Tigrinya language (Nyssen et al., 2007b). In addition, a region-wide photo-monitoring study was carried out through which the impacts of the sustained SWC efforts could be monitored.

THE ZALA-DAGET EXTENSION MANUALS

The extension manuals concentrate the gathered knowledge in a single volume directed towards experts in soil and water conservation and natural resources management. The Tigrinya manual (Fig. 2) has been simplified to the extent that it became accessible to a fraction of the smallholder farmers. Given that the manuals are about research progress, they have their own limitations. They are not full

scope of the manuals. Interested readers were provided with references of the articles on which that section was based.

LANDSCAPE CHANGES INDUCED BY CONSERVATION ACTIVITIES IN NORTHERN ETHIOPIA

The repeat photography study (Nyssen et al., 2007c) assesses changes in environmental conditions in the Ethiopian highlands based on a combination of more than ten years of field research (on-farm and at catchment scale) and observations deduced from the comparison of 51 historical photographs taken in 1975 (Hunting Technical Services, 1976; Virgo and Munro, 1978) with the current status. The combination of a variety of methods allowed for a holistic analysis of observed environmental changes in Tigray between 1975 and 2006 incorporating details on the effectiveness of conservation measures in this marginal semi-arid area, representative of mountain dryland environments elsewhere (Fig. 3).

The recent active intervention by authorities and farmers to conserve the natural resources in Tigray has led to demonstrated significant improvements in terms of soil conservation, infiltration, crop yield, biomass production, groundwater recharge and preven-

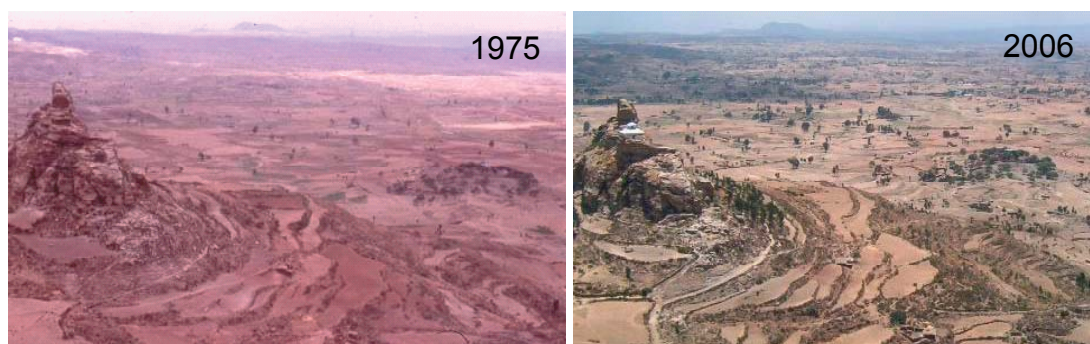


Figure 3. Excerpt of the repeat photography study, showing the most common type of change in the landscape. When the 1975 image (left; photo R.N. Munro) was taken, the ancient agricultural terraces that utilize sandstone benches in Makhano near Senkata were largely free of woody vegetation (photo J. Nyssen). In 2006 (right) the terraces have been rehabilitated, and vegetation has established on the risers. Many farmsteads have shelter belts, but the key feature is the lack of change in the church woodland (centre right of the picture). This set of repeat photographs acted as a control that demonstrates that changes on the surrounding plains and slopes are not related to increased rainfall after a drought but to land husbandry. This contributed to reject the hypothesis that the improvement is solely caused by better rainfall; if higher rainfall were the cause, the woodland would have improved too, because people do not cut down trees in such areas. The full study and photographs is available at http://www.geoweb.ugent.be/download/TLP_3_Photomonitoring.pdf

tion of flood hazard. These results from detailed in situ studies are corroborated by analyses of landscape changes, which show that the status of natural resources has improved (and locally strongly improved) since 1975. The rehabilitation is due both to improved vegetation cover and to the implementation of physical conservation structures.

Exceptional degradation is still ongoing around Des'a forest and some other remnant forests. Like elsewhere in Tigray, conservation of vegetation cover should be strongly implemented here. A system for sustainable forest exploitation must be established.

Our study invalidates hypotheses on irreversibility of land degradation in Tigray and a fortiori in less marginal semi-arid areas, and on futility of SWC programmes. The study furthermore demonstrates that (a) land management has become an inherent part of the farming system in Tigray, (b) it is possible to reverse environmental degradation in semi-arid areas through an active, farmer-centred SWC policy (Stocking, 2003), (c) keeping small-scale farmers on their land by providing adequate levels of subsidies (Robertson and Swinton, 2005) is an effective way to sustain the agricultural system of semi-arid areas in the long term and to provide ecosystem services to the society, and (d) the 'More People Less Erosion' hypothesis (Tiffen et al., 1994) is also valid in other, semi-arid areas. In a highly degraded environment, with high pressure on the land, no alternatives are left open but to improve land husbandry.

A new study has been started whereby photographs dating back to 1868 are compared to the current situation (Fig. 4). Qualitative analysis tends to indicate a slightly improved situation nowadays, as compared to 140 years ago, when population density was an order of magnitude smaller. Working hypothesis is that land degradation has continued until the late 1970s when the first region-wide conservation measures were taken (Munro et al., 2008).

CONCLUSIONS

The positive changes in ecosystem service supply that result from such changing land cover and management (Schroter et al., 2005) are an issue of global concern. Yet, the challenges to be met are numerous and require (a) in situ SWC of farmland (Nyssen et al., 2006), (b) shifting to stall feeding of livestock and ecologically sound grazing management of the rangelands, (c) involving local commu-

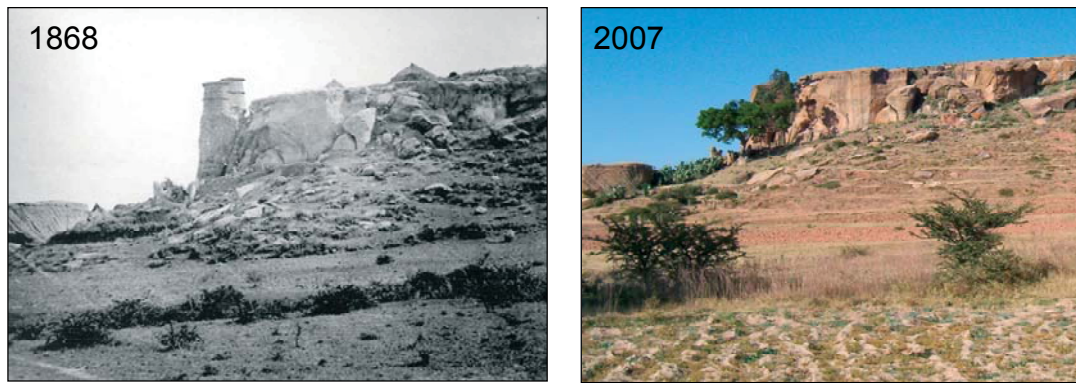


Figure 4. Ruins of the Adabaga 'brick' fortress are still present. On top of the cliff, there is an abandoned village which had a church and at least 8 big houses, all situated in a semi-circle around the tower (some of them are visible in the 1868 photograph). The apparent rock fall which is better visible (more fresh) on the 1868 photograph might be related to building stone quarrying activities. Most striking is the regrowth of an indigenous Ficus tree and grass cover on the footslope in 2007. Though narrower, the gully was already there in 1868 and seems stabilised in both cases.

nities in decision making about resource management (Robertson and Swinton, 2005; Segers et al., 2008) and (d) active development of a policy for sustainable urban energy consumption.

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DEVELOPMENT OF A WEB-BASED GEOGRAPHIC INFORMATION SYSTEM FOR MONITORING AEOLIAN SOIL EROSION IN ARAL SEA

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INTRODUCTION

The research is carried in the three largest Central Asian States – Kazakhstan, Uzbekistan and Turkmenistan, which refer to a specific geopolitical region having much in common: the physical environment, similar traditions in agriculture, similar culture and religion, and economic heritage (Saiko and Zonn, 2000). The Newly Independent States inherited the problem of desertification from the past. Large-scale irrigation development led to the ecological catastrophe in the Aral region. The environmental and economic situation was aggravated after the Soviet Union collapse in 1991. During the project, several working groups dealing with land use change, aeolian erosion, sand and dust storms and reclamation with phyto-ameliorative measures studied these processes within central Asia in general and specifically at the surroundings of the Aral Sea area.

The Aral Sea, a completely enclosed sea, is located in the semi-arid and desert areas of Central Asia (Peneva et al., 2004). This large continental water body, the fourth largest in the world, it has been fed by two major perennial rivers, the Amudarya and the Syrdarya (Boomer et al., 2000). The production of rice and especially the heavily irrigated cotton monocultures, resulted in significant

withdrawals of the Aral Sea tributaries, which combined with poor irrigation and drainage management led to the desiccation of the Aral Sea (Raskin et al., 1992), with significant falls of its level, area and volume and an important increase in its salinity creating one of the major ecological catastrophes of the 20th century as well as a socioeconomic tragedy (Glantz et al., 1993).

Beyond the deterioration of the lake and the loss of its fishing industry, there are other serious impacts (Crighton et al., 2003; Erdinger et al., 2004). The recession of the sea has created a huge area – about 30,000km² – that has been exposed and subjected to desertification (Fig. 1). Moreover, the salt of the former seabed which is deleterious to humans and toxic to crops is whipped up by the winds and carried over wide areas with the development of dust-salt storms (Jensen et al., 1997; Stulina and Sektimenko, 2004).

Aeolian processes manifested by sand and dust storms are natural events that occur world-widely in arid and semi-arid regions. The overall aim of this work is to develop the basis for a long-term ecologic research to investigate the temporal and spatial pattern of airborne salt-dust deposition across Central Asia, and model the current and future trends of aeolian processes in Aral Sea region. The nature of this phenomenon, the dispersion and different technical backgrounds of researchers that need to access information about dust-storms creates the need for the development of a unified geographic information system (GIS) system for data storage and analysis.

Geographic information systems are accepted as power full and integrated tools for storing, manipulating, visualizing and analy-

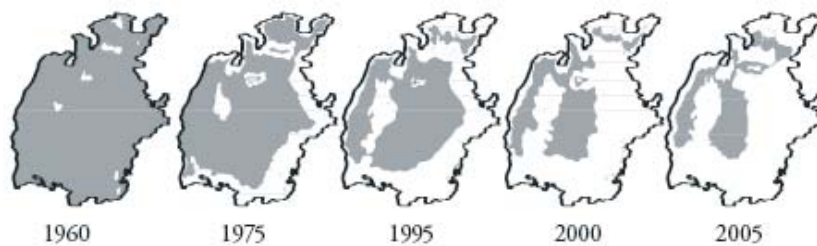


Figure 1. Evolution of the Aral Sea recession from satellite images

zing spatial data (Dragicevic, 2004). Like many other rapidly evolving technologies, the GIS has in part migrated to the World Wide Web and is commonly referred as WebGIS. This allows for a rapid dissemination of data, and sharing of maps between users in different locations (Diviacco, 2005; Frehner et al., 2006; Jesus et al., 2006).

Several types of WebGIS can be found in the literature, in some cases it was used for tracking the development of disease (Kelly and Tuxen, 2003; Guo-Jing et al., 2005), for ground water risk assessment (Lim et al., 2006), for land use monitoring (Mathiyalagan et al., 2005) and air quality monitoring (Bohler et al., 2002). The use of WebGIS makes geographic information available to larger audiences than conventional GIS packages or data files stored in a simple server it also enables the integration of geospatial datasets or other spatial information, this allows for real-time access to a high volume of data for all users that need it (Kraak, 2004).

Spatial planning requires a combination of software tools for geographic analysis and presentation. This article presents an approach that integrates various software tools which were originally developed independently and it describes how the web-based geographic information system for monitoring aeolian soil erosion in Aral Sea was developed, implemented and used.

THE SYSTEM FRAMEWORK

The overall monitoring information system is multi-scale, multi-source, flexible and geographically organized. It uses an Internet-based GIS ("WebGIS") technology, and has obtained information about soil erosion in Aral Sea area through four methods: using high temporal resolution remote sensing imagery concurrent with ground data collection and analysis; land use and land cover change using Envisat and MERIS data; use of model and real wind data to assess volume of sand/dust transportation; data fusion of the three results.

The aeolian soil erosion monitoring information system is dynamic, interactive and was developed based on Open-Source licensing. The back-end database uses Linux distribution Suse 10.0 as operating system running an APACHE server for HTTP requests to store spatial data in an integrative and relational database manage-

ment system (Fig. 2). The programming and access call to MapServer were based on PHP functions (MapScript).

All monitoring attribute data including rainfall data which obtained from the meteorological stations are stored in tables. This Linux-Apache-PHP-Mapserver connection is flexible and stable, allowing the users to retrieve several types of data like raster satellite images, meteorological data or geographically positioned sample data.

The system framework is composed of three parts: data management, middle connector and Web application. Data management means database management system within the internal network which is also called Intranet that composed of many service terminals connected with database server, with responsibilities for data uploading, data updating and data maintenance. Middle connector means the connectivity between Web server and WebGIS Application server. Web application means client browsers on the Internet through which the Internet user communicate with the website.

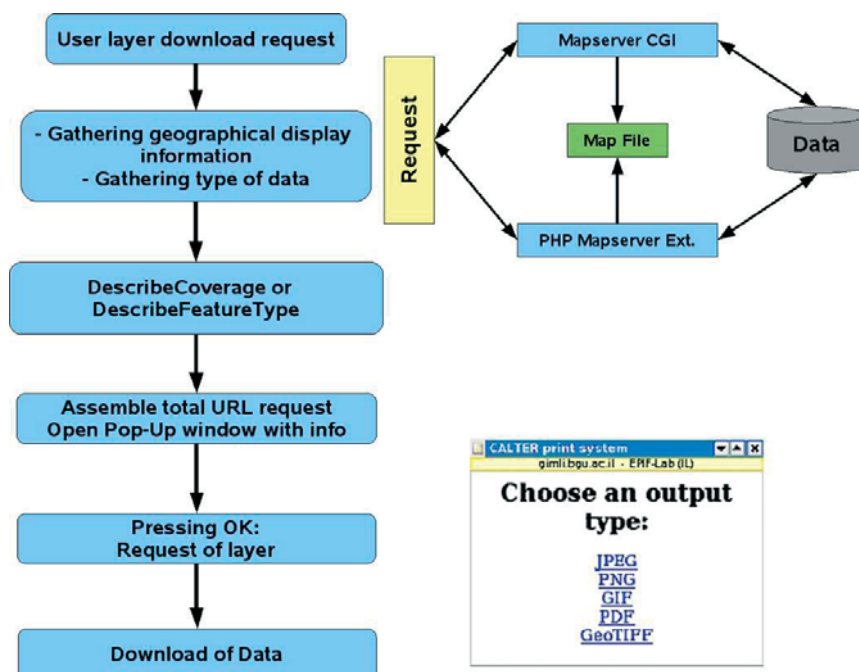


Figure 2. The system framework of soil erosion monitoring information and the model used for data download and print

The WebGIS implemented is based on WxS requests and data transactions implemented as AJAX operations inside the Ka-maps libraries. The WebGIS's download model uses WCS and WFS as services, the first one to transfer georeferenced images and the second for shapefile-point data. The image/download standard adopted is GeoTIFF using a geographic coordinate system based on WGS84.

DATABASE AND FUNCTION DESIGN

A GIS database was created. Data types and sources include: 1:50000 topographic map, DEM, slope map, aspect map, land use map, soil type, TM images, rainfall map etc. All data provide the real-time and accurate information related to soil erosion. In order to capitalize on differences in the signal of the different vegetation cover types, Landsat5 TM scenes were used. The images were georeferenced and calibrated. All images were acquired with a cell size of 30m.

Figure 3 shows the WebGIS initial display with background the NASA's SRTM images that contain the elevation values of the pla-

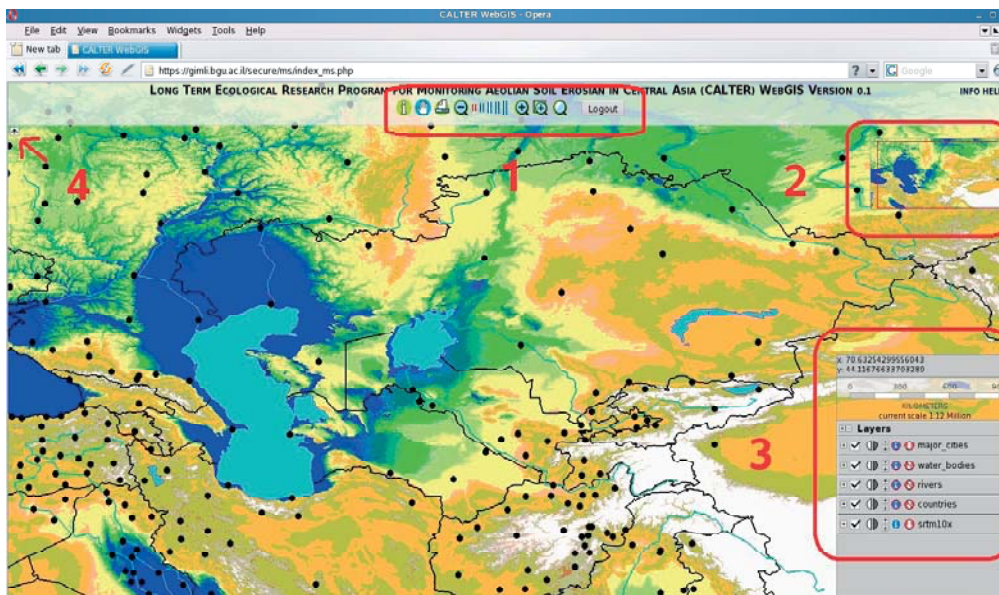


Figure 3. The WebGIS initial display with background the NASA's SRTM images (1: Docking tools like pan, print, zoom and logout; 2: The keymap indicates the current view extent relative to the total and can also be used to navigate through the WebGIS; 3: Legend docking panel showing the current cursor position in degrees of lat/long, the scale and layers; 4: Toggle button that activates the view).

net. Several layers are also displayed: countries, rivers, water bodies and major cities. All selected data can be downloaded.

Although the query and analysis of the soil erosion map is the most important function of the system, the common GIS function: zoom in, zoom out, pan, query, measure etc. can be found in the monitoring information system. The user can turn on and off data layers and the WebGIS responds to the selections by updating the map. The monitoring information system allows users to query the data spatially through the map interface using select by point, line, rectangle or polygon tools. The attribute data can be queried using a query tool that allows Boolean logic to be applied to each of the data fields within the attribute table.

CONCLUSIONS

WebGIS and remote sensing are new and useful methods of aeolian soil erosion monitoring. The web-based monitoring application have involved at the online presentation of acquired monitoring results. However, there is progress to be made in soil erosion monitoring by combining WebGIS, remote sensing, and access through the Internet. The present WebGIS decrease research operational cost and provide map and data services for all scientific community. The soil erosion results can be accessed and analyzed by researchers and decision-making officers. As the spatial technologies, WebGIS and remote sensing improve in the near future, it is possible to obtain soil erosion data and to manage the information about erosion more efficiently.

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ANALYZING THE EFFECTS OF PARTICLE-SIZE DISTRIBUTION CHANGES ASSOCIATED WITH CARBONATES ON THE PREDICTED SOIL-WATER RETENTION CURVE

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INTRODUCTION

Numerical models for simulating water flow and solute transport in unsaturated–saturated soil systems are enjoying considerable popularity as a tool for soil survey interpretations. Their success and reliability, however, are critically dependent on accurate information of soil hydraulic properties. The most important properties are the soil-water retention curve (SWRC) and hydraulic conductivity characteristics. Direct measurement of soil hydraulic properties is difficult, tedious to accomplish and expensive by currently available methods. When such data are not available, pedotransfer functions (PTFs) (Bouma, 1989) which utilize physical or empirical relations between soil hydraulic properties and other easily and cheaply measured properties can be used as alternative method. In this context, particle-size distribution (PSD) is the most important key predictor to most soil hydraulic PTFs. Precise and accurate determination of PSD is, therefore, needed and required to provide good representation of soil hydraulic properties. Differences in the methodologies are removal or non removal of cementing materials such as calcium carbonate. The use of PSD as the first and most basic input parameter raises the question of how different pre-treatments affect the prediction quality of PTFs. The objective of this study was to investigate the influence of pre-treatment on sand, silt, and clay fractions of calcareous soils.

MATERIALS AND METHODS

68 soil samples have been collected from most of the agro-climatic zones of Syria (Fig. 1). It includes the Kurd Dagħ block mountains in the northwest, the gently undulating plains in the central part and alluvial-colluvial plains and basalt plateaux with the Salt Lake 'Jabboul' in the southeast.

The samples' SWRC was determined at nine matric potentials. This was done with the sand box apparatus (Eijkelkamp Agrisearch Equipment, Giesbeek, the Netherlands) for matric potentials between -1 and -10 kPa, and with pressure chambers (Soilmoisture Equipment, Santa Barbara, CA) for matric potentials between -20 and -1500 kPa. Organic matter was determined by means of the Walkley and Black (1934) method. The sieve-pipette method (Gee and Bauder, 1986) which is the standard analytical method (ISO 11277) was used to determine the particle fractions. Two procedures were used differing in the pre-treatment process. In the widely used technique carbonates were removed by hydrochloric acid, while in the alternative one carbonates were not removed. The results of these two methods, which will be referred in this study as PSDS and PSDK methods, respectively, were used to predict the SWRC. In an earlier study of Cornelis et al. (2001) in which 9 PTFs were compared, it was shown that the PTF of Vereecken et al. (1989) was

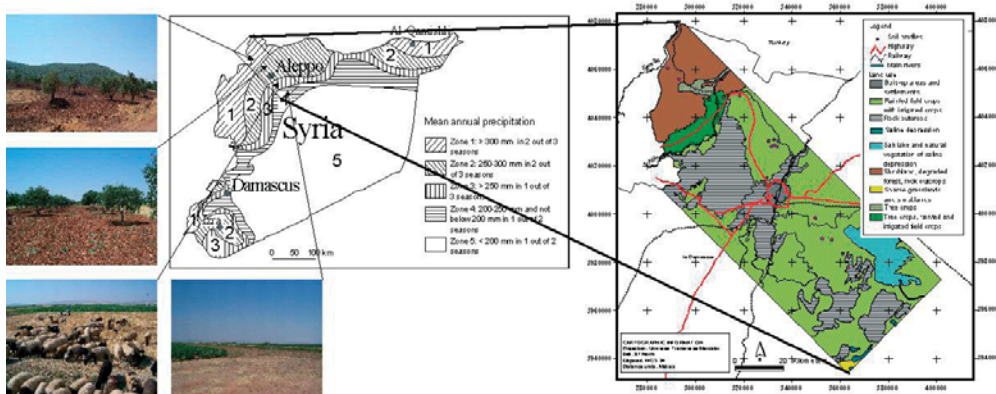


Figure 1. Map of study area showing the distribution of study sites

the most accurate one. Therefore this PTF was used to predict the parameters of the van Genuchten (1980) model:

$$\theta = \theta_r + (\theta_s - \theta_r) \left(\frac{1}{1 + (\alpha |\eta|)^n} \right)^{\left(1 - \frac{1}{n}\right)} \quad (1)$$

respectively, where θ_s is the saturated soil-water content, θ_r is the residual soil-water content, α and n are curve-fitting parameters related to the pore-size distribution.

In order to quantify the prediction accuracy of the two methods for a given soil, the estimated SWRCs were compared with the experimental ones using three complementary indices: the mean difference MD ($\text{m}^3 \text{m}^{-3}$), the root of the mean squared difference RMSD ($\text{m}^3 \text{m}^{-3}$) between the measured and estimated SWRC, and the Pearson correlation coefficient r . Assume the measured moisture retention function to be $\theta(\psi)_{mi}$ for soil i (i.e., a continuous van Genuchten curve was fitted to the discrete set of measured $\theta(\psi)$ values), and the predicted moisture retention function to be $\theta(\psi)_{pi}$ for soil i (i.e., a continuous van Genuchten curve as predicted by the Vereecken PTF), where $i = 1, 2, \dots, N$, with N the total number of soils in the evaluation data set. Consequently, the MD and the RMSD ($\text{m}^3 \text{m}^{-3}$) for soil i were calculated by:

$$\text{MD}_i = \frac{1}{b-a} \int_a^b [\theta(\psi)_{pi} - \theta(\psi)_{mi}] d\psi \quad (2)$$

$$\text{RMSD}_i = \sqrt{\frac{1}{b-a} \int_a^b [\theta(\psi)_{pi} - \theta(\psi)_{mi}]^2 d\psi} \quad (3)$$

where a and b are values defining the range of the experimental SWRC (in our case $a = \log 1 \text{ kPa}$ and $b = \log 1500 \text{ kPa}$ corresponding to the lowest and highest $|\psi|$ values applied in the experiment). In computing Eq. (2) and (3), $\log |\psi|$ was preferred over $|\psi|$ to avoid assigning too much weight to more negative soil water pressure heads (Tietje and Hennings, 1993). The use of the two indices is necessary because we are not comparing single values of water content but more values within a specific soil water pressure head range. MD indicates whether the PTFs overestimate or underestimate the measured data, while RMSD measures the absolute deviation from the measured data. The absolute value of MD should be as

small as possible. Nevertheless, the MD allows the overestimation (the positive difference) and the underestimation (the negative difference) to cancel out. Therefore, the MD was used in our case (with range from 1 to 4.18) only to indicate whether a PTF overestimates (MD>0) or underestimates (MD<0) the water content, while RMSD, which is always positive, can be viewed as the continuous analogue of the standard deviation over the whole MRC, providing therefore an absolute error index.

The Pearson correlation coefficient r (dimensionless) for soil i was calculated by:

$$r_i = \frac{\int_a^b [\theta(\psi)_{m_i} - \bar{\theta}_{m_i}] [\theta(\psi)_{p_i} - \bar{\theta}_{p_i}] d\psi}{\sqrt{\int_a^b [\theta(\psi)_{m_i} - \bar{\theta}_{m_i}]^2 d\psi \int_a^b [\theta(\psi)_{p_i} - \bar{\theta}_{p_i}]^2 d\psi}} \quad (4)$$

where $\bar{\theta}_{m_i}$ is the mean moisture content of the measured MRC for soil i , and $\bar{\theta}_{p_i}$ is the mean moisture content of the predicted MRC for soil i . The index r is an expression of the linearity between the measurements and predictions. Whenever the r value approaches 1, it indicates that measured and predicted data pairs are linearly located around the trend line with perfect agreement (or 1:1 line). The van Genuchten parameters in each of $\theta(\psi)_{p_i}$ were obtained in the same way as $\theta(\psi)_{m_i}$. Also here, $\log |\psi|$ was used rather than $|\psi|$ in calculating the moisture content.

RESULTS AND DISCUSSION

Figure 2 shows the textural distribution of the soil samples for the two methods of determining PSD. Great variability can be noticed in the sand, silt, and clay fractions. It is clear that carbonates content seems to be soil characteristic that has high influence in the results of PSD for calcareous soils.

As was mentioned above, the Vereecken et al. PTF was used to compare the prediction accuracy when using two different PSD inputs. Table 1 contains results of the different validation indices calculated for each PSD inputs. The PSDS method showed higher values of the mean of the absolute values of MD and the mean of RMSD values. When considering the mean of MDs, it can be noticed that the PSDS tend to underestimate the SWRC (Table 1 and Fig. 3). This underestimation occurs mainly at water content below -10 kPa.

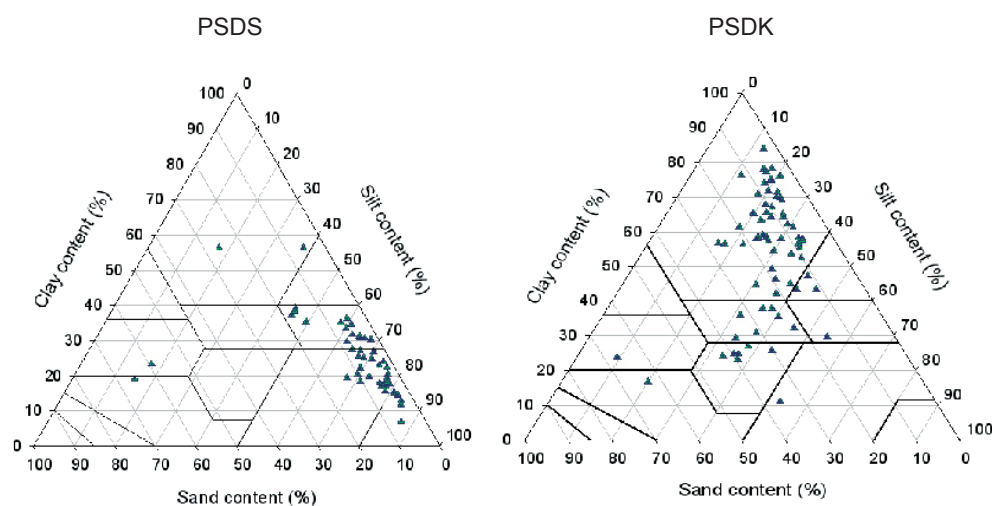


Figure 2. Variation of clay, silt and sand content in the dataset for the two PSD methods

Table I. Comparison of the validation indices of the predicted SWRC by the PTF of Vereecken et al. (1989) using two different PSD inputs.

PSD methods	mean MD $\text{m}^3 \text{m}^{-3}$	mean abs. MD $\text{m}^3 \text{m}^{-3}$	mean RMSD $\text{m}^3 \text{m}^{-3}$	mean r -	SD RMSD $\text{m}^3 \text{m}^{-3}$
PSDS	-0.0778	0.0949	0.1073	0.9742	0.0494
PSDK	-0.0400	0.0620	0.0698	0.9820	0.0574

The above findings are also supported by Fig. 4 in which measured water content values are plotted against predicted water content values at -1500 kPa matric potential. The PSDK method particularly performs very well at the dry end of the SWRCs ($y = -1500$ kPa). Finally, it can be concluded from this study that the PSDK method (without removal of carbonate) is more adequate to classify soil texture. The advantages associated with this method include decreasing the time and work and allowing accurate measurements of calcareous soils.

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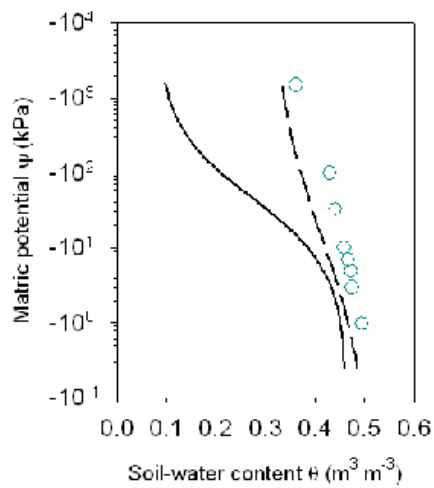


Figure 3. Measured and predicted soil-water retention curves for a calcareous soil

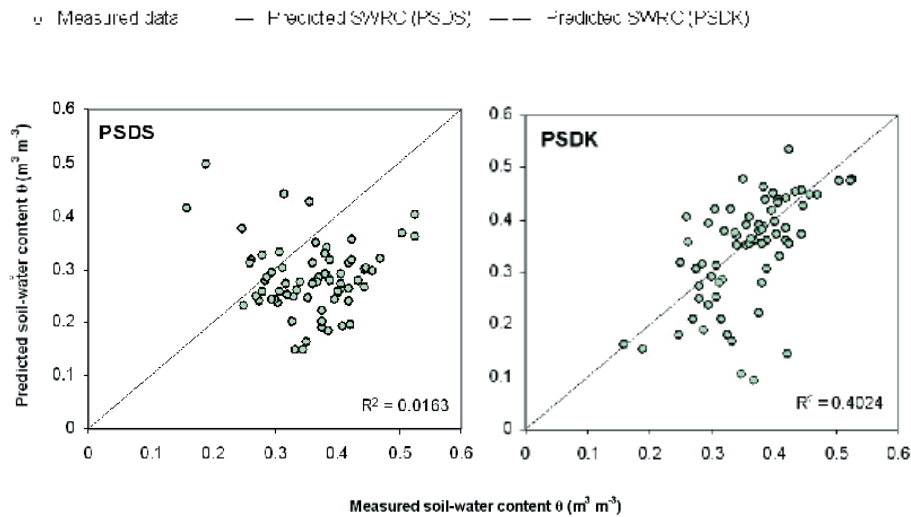


Figure 4. Measured vs. predicted soil-water contents at matric potential ψ of -1500 kPa for the two PSD methods

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CONCEPT OF A SINGLE DEVICE FOR SIMULTANEOUS SIMULATION OF WIND AND WATER EROSION IN THE FIELD

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INTRODUCTION

Soil degradation and desertification leads to a significant loss of soils capable of food production. The two major factors are water and wind erosion. Together they account for more than 85 % of the total amount of soil degradation in dryland areas (Middleton and Thomas, 1997). Both processes often occur simultaneously in time and space. For example heavy rainstorms are often associated with strong winds. For many years most soil erosion researchers have been studying both processes separately, although some researches in the last century demonstrated that wind and water erosion strongly interact (Disrud et al., 1969; Umback and Lemke, 1966; Mutchler and McGregor, 1979).

Natural erosion events are very complex and have a high spatial and temporal variability. Therefore laboratory as well as field wind tunnels and rainfall simulators are often used in soil erosion research to create controlled conditions and increase the amount of statistical data. Some laboratory facilities like the ones described by Lyles et al. (1969), de Lima et al. (1992) and Gabriels et al. (1997) have the capability to simulate rainfall and wind at the same time in order to study their interactions. Investigations using these facilities improved the knowledge about the influence of wind on shape, impact velocity and impact angle of raindrops fundamentally. For simultaneous in-situ field measurements of wind and water erosion Visser et al. (2004) suggest to use different standardised quantifi-

cation techniques to measure both processes both separately and together.

Keeping in mind the major advantages of rainfall and wind tunnel simulations, e.g. their good repeatability and controllability of boundary conditions, and the need for standardised field equipment, the main objective of this paper is to present a concept of a single device for simultaneous simulation of wind and water erosion in the field. For this purpose a nozzle type rainfall simulator has to be integrated into the existing portable wind tunnel. Additionally a combined sediment trap needs to be constructed, in which the detached material of both processes can be caught. Finally a standardised test procedure has to be developed.

METHODOLOGY

SMALL PORTABLE WIND TUNNEL

Main priority during development and construction of the wind tunnel was to achieve highest mobility with best possible approximation to the natural wind conditions. To increase the quantitative amount of data about relative wind erosion rates on different surfaces it is necessary to choose test sites not only according to their accessibility but because of their relevance to wind erosion. Leys et al. (2002) show that it is possible to characterize wind erosion rates from different surfaces with a "mini wind tunnel". Other wind tunnels with similar dimensions have been used successfully in erosion research (Gillette, 1978; Raupach and Leys, 1990).

This wind tunnel is based on earlier designs by Ries et al. (2000). The air-stream is generated by a 5.5 hp fan with 163 cm³. It has two vanes which can be variably adjusted to different angles to change wind velocity. Wind speed can be adjusted between 3 to 9 ms⁻¹ free stream. The rotating air-stream is caught by a 2 to 4 m long transition section which consists of strong PVC-foil with a thickness of 1 mm. Both the honeycomb and the wind tunnel are rectangular in shape and have a cross section of 0.7 x 0.7 m. The honeycomb structure is made of 0.15 m long and 0.04 m wide PVC tubes. The 3 m long tunnel itself consists of three separate 1 m long sections of aluminium and perspex sheets which can be folded up for transport. The sheets are stabilized and connected by three aluminium frames. Four steel bars each 1.5 m long, 0.15 m high, and 0.03 m thick are

attached to the side walls for connection with the ground. In order to avoid gaps, the bars are driven 5 cm into the ground. Thus the floor of the tunnel is open and creates a 2 m² test section which can be easily accessed by opening the Perspex sheets on one side of the tunnel. The detached sediment from the test area is caught by the sediment catching area which is made of commercial canvas cover (tarpaulin) with a base of 3 x 5 m and vertical boundaries of 1m at the sides and 1.5 m at the back. Figure 1 shows a dimensional sketch of the wind tunnel.

Calibration tests with a pietot tube, smoke gas tests and wind direction measurements indicate that the swirl from the rotating propeller has been eliminated by the honeycomb. Wind profile measurements show that a pre-shaped boundary layer of 10 to 15 cm, created by a tripping fence of 4 cm height, exists.

INTEGRATION OF RAINFALL SIMULATOR

For the simulation of rainfall four pressure nozzles will be installed into the roof of the tunnel. They will be positioned at 0.35 m, 1.1 m, 1.85 m and 2.6 m in flow direction of the tunnel. Aspired rainfall intensity range is 40 to 100 mm h⁻¹. Detailed characteristics of used field rainfall simulators and their general limitations are given in Hudson (1995) and Cerdà (1999). It seems obvious that because of the low fall height the drop velocity will not reach terminal velocity, but again limitations concerning the approximation of natural conditions have to be accepted in order to maintain aspired mobi-

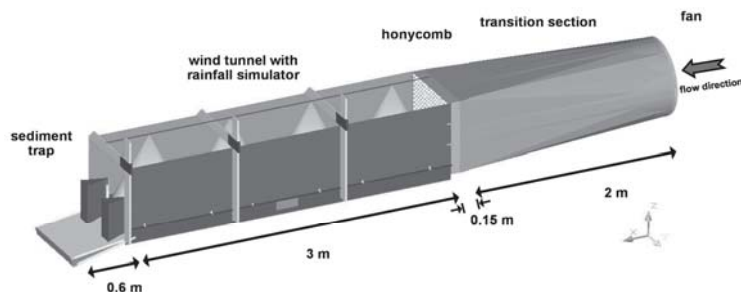


Figure 1. Dimensional sketch of combined wind and rainfall simulator. Please note that the sediment catching area is not shown. Instead the developed sediment trap is plotted. Roof of tunnel is left out for better display..

lity. Devoid of actual calibration results of drop sizes and fall velocities only estimations on the displacement of falling raindrops due to wind drag can be made. Erpul et al. (2003) calculated for their drop spectra an inclination angle from vertical of $53^\circ \pm 11.5^\circ$ at wind speeds of 6 m s^{-1} . Assuming that this simulator produces similar drop sizes, the displacement distance in our tunnel at 6 m s^{-1} would be about 0.9 m.

COMBINED SEDIMENT TRAP

A combined sediment catcher has been developed in order to collect as much transported material as possible. The runoff from the plot is caught by a gutter system made of aluminium (Fig. 2). The advantage of this material in comparison to wood or stainless steel is the low weight together with the stability. Due to its smooth surface collection of sediment and cleaning is easy. The trap is 0.6 m long, 0.7 m wide and its rear wall is 0.2 m high. In order to prevent an undercutting of the gutter by runoff water, a vertical sheet of 5 cm height is attached to the inlet which will be driven into the ground. The gutter is covered by a cover plate to keep drifting rain drops out. Additionally it is expected that a relevant proportion of the detached splash material will deposit on the cover plate. Erpul et al. (2004) calculated rainsplash distances of 0.6 to 0.75 m for a wind speed of 6 m s^{-1} . Visser et al. (2004) strongly suggest using splash cups and walls to measure the amount of wind driven splash. Nevertheless, in the described experimental setup, the created back pressure by a

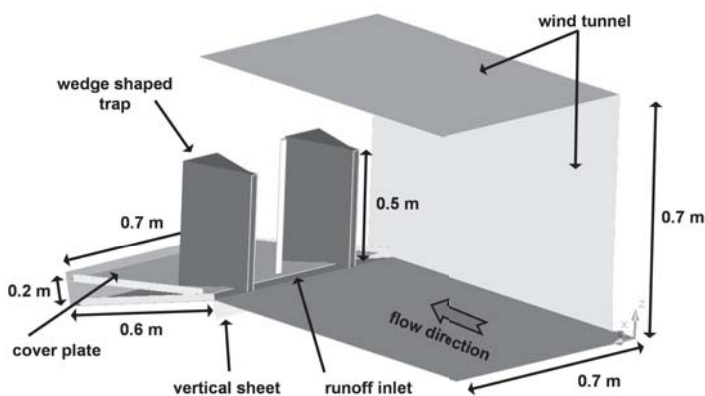


Figure 2. Dimensional sketch of combined sediment catcher. Please note that modified Wilson and Cook samplers are left out for better display. Bean shows actual position.

splash wall would cause too much interference with the air-stream inside the tunnel. Information on splash transport perpendicular to the wind flow can be approximated by the amount of sediment that is caught in the rinses that are attached to the side walls of the tunnel for collection of rundown water. One side of the gutter system is closed while the other side is partially open to enable material collection.

Two vertically integrating, wedge-shaped sediment traps and a beam with four modified Wilson and Cook samplers (MWAC; Wilson and Cooke, 1980) to catch the airborne material are attached to the gutter. Both sampler types are passive ones. Laboratory and field calibrations of the MWAC sampler by Goossens and Offer (2000) and Goossens et al. (2000) show very high trapping efficiencies of 75 to 125 % for dust particles as well as for sand particles. Very important for measurements at different wind speeds is the fact that the trapping efficiency of the MWAC shows almost no dependency on wind speed throughout the tested velocities (1 to 15 m s⁻¹). Although the Big Spring Number Eight sampler (Fryrear 1986) showed better continuity for dust, the higher efficiency together with its small size, light weight, easy handling, and low costs made the MWAC the best sampler for measuring vertical flux profiles in this setup.

The wedge-shaped traps are a combination of the ICE sampler (International Centre for Eremology; Cornelis and Gabriels, 2003) and the GTW sampler (Guelph-Trent Wedge; Nickling and McKenna-Neumann, 1997). The trap, constructed of a 1.5 mm thick aluminium sheet, is 0.5 m high, and has a rectangular sampling orifice extending 40 mm beyond the wedge. The opening width measures 20 mm and the internal inlet angle of the wedge is 32°. Instead of the mesh-covered back of the GTW trap, the developed trap has wind outlets on both sides. Size and position followed the calculations of Cornelis and Gabriels (2003) for the ICE sampler (Fig. 3). This design has the advantage of lower material loss through the mesh as well as the simplification of cleaning after the use with wetted material during rainfall simulations. In addition one side of the trap can be opened for cleaning. The covering of the openings consists of a stainless steel wire mesh (256 mesh) with 63 µm and 41 % porosity. Adjacent to the sampling orifice, the bottom of the sampler is lowered by 4 cm to create a barrier for preventing caught parti-

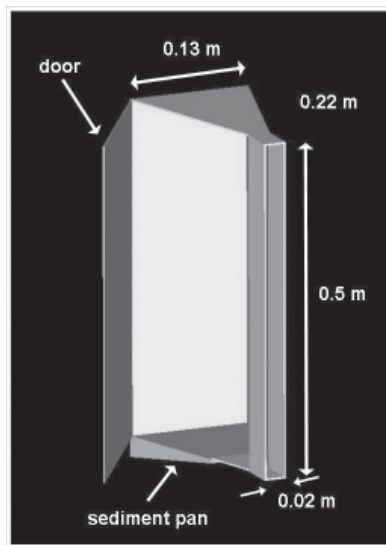


Figure 3. Dimensional sketch of wedge-shaped sediment trap (combination of GTW and ICE traps).

cles from being blown out of the trap. Both traps are easy to handle, lightweight, cheap, and have shown good calibration results (Cornelis and Gabriels, 2003; Nickling and McKenna-Neumann, 1997).

In order to protect the combined sediment trap against exterior influences, it is positioned about 10 to 15 cm into the wind tunnel.

TEST PROCEDURE IN THE FIELD

After build-up at the carefully chosen test site, certain plot characteristics including surface roughness, vegetation cover, soil moisture content (before & after test run) as well as soil crust thickness and type are recorded. A simulation of different soil surface treatments like rolling, ploughing or sheep trampling is possible before or during the wind tunnel tests by opening the side wall. Approximate duration of a test will be 30 min with measurement intervals of 5 min for surface runoff. The accumulated splash material from the cover plate of the gutter and from the sidewall rinses is collected once at the end of each test run. MWAC and wedge samplers are also emptied after the test run. Shear stress of air-stream onto the surface is measured with drag plates during a separate test run. Finally disturbed soil samples for further laboratory analysis of soil moisture content and soil texture are taken from the plot. Five different test run variations are possible:

- (1) single wind erosion test run,
- (2) single water erosion test run,

- (3) simultaneous wind and water test run with different wind speeds or rainfall intensities,
- (4) water erosion test run following wind erosion test run,
- (5) wind erosion test run following wetting of the surface with different water contents.

OUTLOOK

By means of this single device we expect to obtain quantitative information regarding the relative impact of wind and water erosion on soil degradation and desertification. Spatially, the focus will be on semi-arid and arid Mediterranean regions in Spain and Morocco, where the interactions of both processes are very intensive. The capability to carry out in-situ tests in remote areas, especially taking into account different soil surfaces or different soil treatments, is considered to be of great value for comparative soil erosion research.

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MEASURING SALTATION IMPACT WITH PIEZO-ELECTRIC AND ACOUSTIC SENSORS

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INTRODUCTION

Wind erosion can become a problem whenever the soil is loose, dry, bare or nearly bare (Fryear, 1985). Wind erosion is a serious problem in many parts of the world, especially in arid and semi-arid regions. In wind erosion research, roughly two different approach lines can be distinguished. Since the Dust Bowl crisis in the USA in the 1930s, a research line developed that focused on the control and prevention of wind erosion in agricultural areas (Winslow, 2004). In the Sahara Desert and Sahel wind erosion research was based on geomorphological landscape forming processes. Since the 1980s, these two lines merged and wind erosion research focused on understanding the process and quantification of soil losses and related agricultural damage (Sterk 2003).

Since the start of wind erosion research a wide variety of techniques to measure wind erosion related parameters were developed. However, so far no standardization of the measurements techniques exist (Visser, 2004; Visser, 2004)). To be able to compare published data there is a need for information on the accuracy and reliability of the different measurement techniques.

In planning methods, to reduce the hazard of wind erosion, threshold velocity and intensity of saltation transport are important parameters. So far 3 sensors are known which are capable of measuring these parameters; 1) The Saltiphone™ - (Eijkelkamp Agrisearch Equipment, Giesbeek, The Netherlands) 2) The Sensit™

Wind Eroding Mass Sensor - (Sensit Company, Portland ND, USA) and 3) The Safire™ – (Sabatech Smart Devices, Amsterdam, The Netherlands). So far little is known about the mutual correspondence of the mentioned devices. This research has been set up with the objective to measure and compare the efficiency and accuracy of 3 types of saltation sensors. The sensors are tested on the following subjects: 1) sensitivity for the intensity of wind blown mass transport, 2) the possibility of using the sensors to quantify sediment transport, 3) orientation of the sensor, and 4) sensitivity for influence of rain and noise.

MATERIALS AND METHODS

In this study 3 different sensors which use the output signals as a relative measure of saltation activity are tested in a windtunnel. The Saltiphone, the Sensit and the Safire. All sensors were attached to a CR10X datalogger (Campbell Scientific, Inc., Logan UT, USA), to record the output.

The Saltiphone (Fig. 1A) is an acoustic based sediment sensor developed by Spaan en van Abeele (1991). The Saltiphone consists of a microphone ($r = 5$ mm) installed in a stainless steel tube ($r = 25$ mm, length 130 mm) at 65 mm from the inlet. The frontal detection area is 78.5 mm^2 . At the backside of the tube 2 vanes were mounted to keep the tube perpendicular to the wind direction. The tube is mounted on a ball bearing, which is attached to a stainless steel pin (length 500 mm) that is pressed vertical in the soil. The tube can be moved on the pin to adjust the measuring height. The standard height (centre microphone – soil surface) is 100 mm. The microphone is connected with a filter, which amplifies the high frequent (8-9 Hz) impact of sand particles and filters the low frequent sound of wind and rain. Each hit of a sand particle causes a pulse that is cut off after 1 ms. Each time a pulse is generated, no other particle impact can be detected. Two versions of filters are in use; one with a digital output (SAL), and one revised version with both an analog and digital output (SALrev). Experiments have shown that the impact of dust particles is too low to be detected by the Saltiphone (Bakkum 1994).

The Sensit (Fig. 1B) is a cylindrical piezo-electric crystal ($r = 12$ mm, height 15 mm) which is mounted 55 mm under the top of

a stainless steel post. The frontal detection area is 370 mm². An anodized shield is laminated on to the outer surface of the crystal protecting it from impact damage. The total length of the sensor is 325 mm. The sensor can be mounted above or below soil surface. The digital output signals are 1) number of particle impacts and 2) kinetic energy (KE) in the form of pulse trains. The sensitivity is adjusted exclusively to the impact of saltating particles. This adjustment reduces the impact of vibration or electrostatic noise. Tests by Stout (1992) have shown that the crystal does not respond to particles with a momentum < 5.10-8 N s. Dust cannot achieve such high momentum, therefore the Sensit is a saltation sensor.

The Safire (Fig. 1C) is a cylindrical piëzo-electric crystal (r = 9 mm, height 15 mm) which is mounted 120 mm from the base of the tube. The frontal detection area is 280 mm². A rubber sheath is damped and shielded over the total length of the sensor to protect it from impact damage. A small protuberance in the rubber sheathing is the detection zone. Total length of the sensor is 330 mm. At the base a stainless steel pin (length 500 mm) can be attached to insert the sensor into the soil at a user specified measuring height. The sensor is equipped with a filter for noise (eg. raindrops) or jolts. The standard output is a digital signal in the form of a pulse train. Time

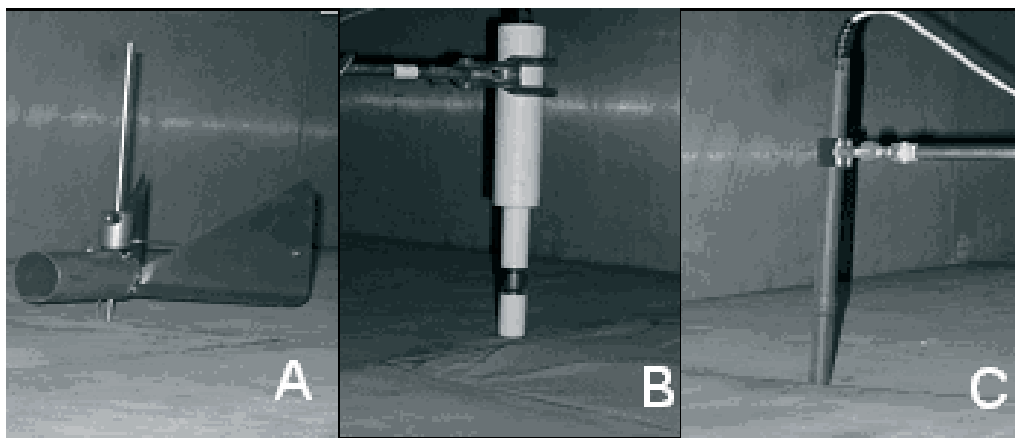


Figure 1 Saltation sensors A) SaltpHONE B) Sensit C) Safire

required to register saltating particle impact is 40 ms (Baas, 2003). The sensor is capable of measuring saltation impacts at a frequency of 20 Hz.

The sensors were tested in the wind tunnel of the International Centre for Eremology (ICE) of Ghent University, Belgium (Cornelis et al., 2004). The tunnel is a closed-circuit low-speed blowing type. The air flow is generated by an axial fan ($r = 0.75$ m) with adjustable blades. By changing the pitch-angle of the blades wind velocity can be controlled. The test area has a length of 12 m and a width of 1.2 m; the height is adjustable and in this research installed at 1.8 m. In the test area a rainfall simulation facility is installed. The box for sand feeding has the dimensions: width 0.4 m, length 1 m and depth 0.02 m and is filled with driftsand from Kootwijkerzand in The Netherlands (median 299μ). The sensors were placed in the centre of the wind tunnel at 6 m from entry, 0.6 m from the side wall directly behind the sand feeding box. Wind velocity was monitored with 16-mm vane probes (Testo, Lenzkirch, Germany) at 1.30 m behind the tested sensor at fixed heights (0.03, 0.12, 0.23, 0.47 and 1 m).

The three different sensors can be used for specific point measurements at fixed heights because of the small heights (10–15 mm) of the detection area. All the sensors were separately tested on their capacity to measure intensity of saltation transport with 3 wind speeds (7.5, 10 and 15 m s^{-1}), and tested at fixed height of 0.05 m. All runs had a duration of 5 minutes. A quantification test (relation mass flux density versus saltation flux) for each sensor was performed in combination with a Modified Wilson and Cooke (MWAC) sediment catcher at 0.05 m height behind the tested sensor (wind-speed 10 and 15 m s^{-1}) with the inlet orientated to the wind. Additional tests were sensitivity on orientation (Sensit and Safire), noise (windturbine) and rainfall. The in- and outlet of the sample bottles are glass tubes with an internal diameter of 7.5 mm, resulting in an opening of 44 mm^2 .

The main advantage of the mentioned sensors is that the moment of initiation and the moment of cessation can easily be recorded (Visser, 2005). The choice for windspeed (7.5, 10 and 15 m s^{-1}) is based on the field studies on Kootwijkerzand, The Netherlands (Riksen, 2006). Because of differences in frontal detection area and techniques, various response signals can be expected.

RESULTS AND DISCUSSION

During the tests none of the sensors experienced problems with installation or technical malfunction.

SENSITIVITY ON INTENSITY OF WINDBLOWN MASS TRANSPORT

Each sensor was tested on its affect to saltation impact under three wind speeds at 0.05 m height. Of the three sensors the Sensit had the highest response to saltation (Fig. 2A) Furthermore, the Sensit was sensitive for a higher intensity of windblown mass transport; which was reflected by higher numbers of impacts with an increased wind speed.

The Saltiphone response on saltation is at a lower level compared to the Sensit. The saltiphone seemed to react well to an increase in intensity in windblown mass transport with an increase in windspeed from 7.5 to 10 m s⁻¹. Increasing the windspeed from 10 to 15 m s⁻¹ had a minimal effect on the response. The difference in response with the standard and revised model is remarkable (Fig. 2A). The range of measured values with a specific windspeed is for the revised (SalRev) version larger compared with the original Saltiphone (Sal). This phenomenon is best shown at the highest windspeed, 15 m s⁻¹ (Fig. 2A). For the SalRev the measured range is 50 to 325 cts s⁻¹, whereas the measured range for the SAL is 50-200 cts s⁻¹.

The response on saltation of the Safire is a fraction of the other sensors. A slight increase in reaction with differences in intensities of wind-blown mass transport was measured (Fig. 2).

Signals induced by saltated sand particles have different response on the sensors. The frontal detection area of the sensors are different, ratio Sensit / Safire / Saltiphone is: 5 / 3 / 1. The Sensit with the largest frontal detection area surface (370 mm²) had the highest response values. Safire with the middle sized frontal area had the lowest response values. If the results are computed to cnts cm⁻² s⁻¹ the response of the sensors are different. The SalRev has the highest response followed by the Sal and Sensit. The Safire response is very low. This low response can be partly explained by the rubber sheath which is damped directly on the piëzo-electric crystal and can have some irregular setting which provide unequally distributed tension forces on the piëzo-electric crystal (Baas, 2003). The differences in response of the two Saltiphone models is related to differences in the

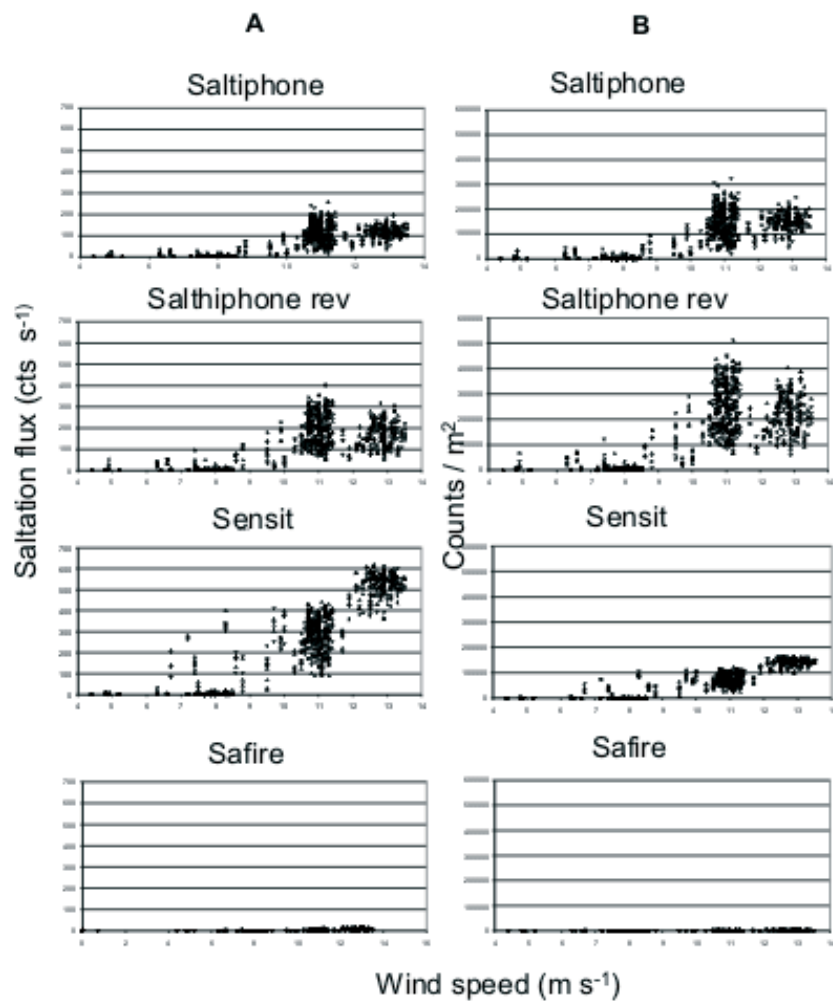


Figure 2 Sensor reaction to sediment transport at different windspeeds, A) sensor output in counts per second B) sensors output in counts per m2 per second

design of the filter electronics (analog versus analog/digital) which results in a level down of the saltation flux in the analog version.

The momentum threshold for the driftsand from Kootwijkerzand, the Netherlands is 4.8 m s^{-1} (measured with a saltiphone; Riksen, 2005). In this study all the sensors respond on the selected lowest wind speed of 7.5 m s^{-1} . The sensors were not tested on their sensitivity around the threshold velocity of the sediment in this research. It is likely that the sensors measure a different threshold velocity

related to their sensitivity. Van Pelt (2006) stated as a result of a test that the effects of different sensor impact areas, the Saltiphone and Sensit are approximately equally sensitive for larger particle diameters. The Safire was the least sensitive and most variable in all cases. Large variability among similar sensors limits their usefulness in determining and quantifying saltation intensity.

During this experiment no test on texture response is performed, but it is likely that the sensitivity of the three tested sensors on the Kootwijk driftsand is different. Only for the Sensit is the sensitivity mentioned in its specification (Stout, 1996).

As a result of this experiment it is important that the sensors are tested (in laboratory) to the specific texture range previously before a field experiment will be start.

MASS TRANSPORT

Mass flux density in relation to saltation flux is performed in a separate test. It showed a relation between mass transport and sensor response (Table 1). This test gives an indication if the sensors are useful for this purpose but one single test is too limited to make conclusions. Sensit and Saltiphone had a sensor dependent response. The revised version of the Saltiphone showed a divergent response compared to the old version. Safire showed a very low response and is not useful. Wind tunnel tests with the Saltiphone showed that

Table 1. Relationship between total mass transport $\text{gr } 3 \text{ min}^{-1}$ and average saltation counts. Mass transport is measured at 5 heights with MWAC sediment catcher.

Sensor	Windspeed m s^{-1}	Mass transport $\text{gr } 3 \text{ min}^{-1}$	AVG saltation cts s^{-1}
Sal*	10	0.00	415
Sal*	15	0.82	771
Salrev**	10	0.55	80
Salrev**	15	0.69	122
Sensit	10	0.67	492
Sensit	15	0.51	672
Safire	10	0.48	2
Safire	15	0.49	4

*Sal, original saltiphone,

** SAIRev, revised version of the saltiphone

the pulse count rate is lineary related to the measured mass flux at the same height (Sterk, 1998). Because of that test it is useful to check the suitability to measure mass transport. Calibration of mass transport can be performed by using a MWAC sediment catcher which is installed during the test. Previous research showed that the Saltiphone cannot be used to quantify the absolute amounts of particle flux during saltation (Goossens, 2000).

ORIENTATION

It is important that the detection area of the sensors is always perpendicular to the wind direction because grazing particles have a lower chance of being detected. The Saltiphone is constructed with two vanes at the backside which keeps the sensor always in the right position. The Sensit and Safire construction of the piëzo-electric crystal is a tube in which every wind direction is always perpendicular to the tube shape.

The omni-directional signal response of the Sensit and the Safire in different orientations (I, II, III and IV) is not constant in terms of magnitude (Fig. 3). The relation magnitude-direction within the Sensit can increase with factor 2, the Safire relation can increase with a factor 3. This phenomena within the Safire can be explained because of the correlation with the leads which slightly sticks out on the surface of the sensor. On the position of the leads is a higher

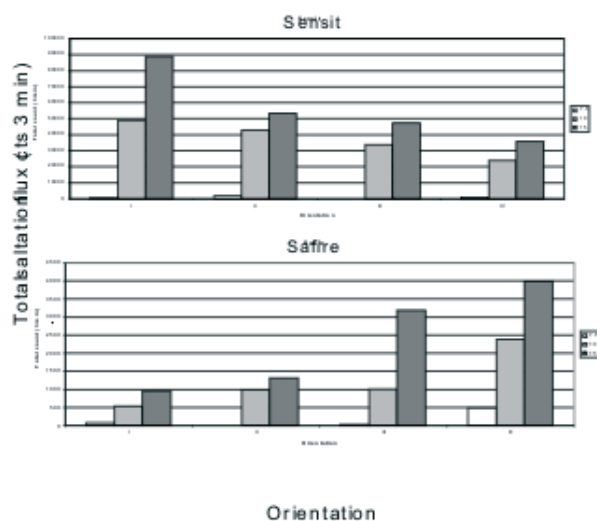


Figure 3. Response of saltation at 4 different orientations (positions) on piëzo-electric sensors with 3 wind speeds (7.5, 10 and 15 m s⁻¹)

response detected which suggest a better transmission to the piëzo-electric crystal inside. The leads are visibly recognizable at the Safire so can be positioned in the wind direction (Baas 2003). For the Sensit the leads are not visible and the device therefore needs to be tested on its most sensitive orientation before installation.

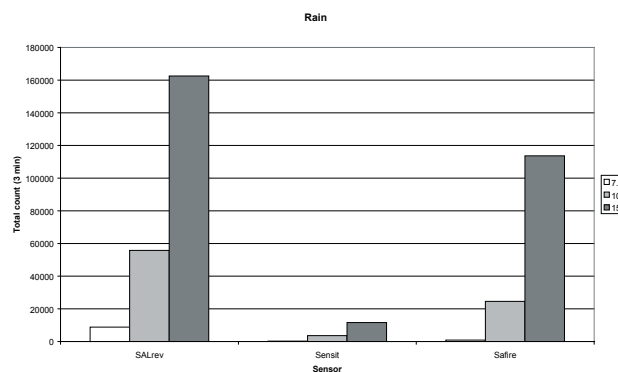
Because of this effect of the piëzo-electric sensors it is recommended to use these sensors in a field study where a prevailing wind direction is known and face the most sensitive part of the sensor in the wind direction. Saltiphones can be used under every wind direction scenario.

RAIN AND NOISE

Noise produced by the fan of the windtunnel is not measured in terms of frequency. The produced sound is not detected by the sensors and especially the design of the microphone electronics of the Saltiphone showed that fan sound is filtered.

Impact of raindrops on the detection part of the sensors is tested with 3 windspeeds with a rain intensity of $\sim 100 \text{ mm h}^{-1}$ (Fig. 4). The response of the Saltiphone and the Safire on raindrop impact is very high (give values); Sensit has a low response on raindrops compared to the other sensors (give values). The tested sensors are electronic equipped with filters for reducing impact of noise, raindrops and/or jolts. Within the Sensit the electronic filter is build for this type of specific frequencies and results in filtering of the impact of raindrops on the sensor. The high response of the Saltiphone is a result of the technique and construction of the sensor, it is functioning as a resonance-box. The response of the rain on the sensors is related to

Figure 4. Response of saltation sensors to wind driven rain (intensity of 100 mm h^{-1}) at three different wind speeds in a windtunnel



the windspeed. The horizontal wind accelerate the raindrops which produce higher impact on the sensor. The size of the raindrops (bigger than the sand particles) in combination with the windspeed produced a higher momentum and that causes the higher response.

To assure a measurement of windblown particle transport it is advisable to measure rainfall intensities with an automatic rain gauge (tipping-bucket) in field studies as well.

CONCLUSION

Use of saltation sensors is useful for moments of initiation and cessation and intensity of wind blown mass transport if the accuracy of the sensors is known. Current research showed that the Sensit is the most accurate sensor on the measurement of the intensity of saltating particles (counts s^{-1}) and less sensitive for rain impact.

But if the impact is translated to counts cm^{-2} the Salthiphone is the most sensitive. Furthermore it is clear that the Safire has the lowest response. This experiment was executed with one type of driftsand, as a result of this it is advisable to perform a sand sensitivity test before a experiment (lab or field) will be started.

Use of saltation sensors to measure mass transport (saltation flux) is possible with Salthiphone and Sensit but this test was limited to conclude this assumption. With the revised version of the Salthiphone (compared to the standard version) a higher measurement range will be covered. Calibration of mass transport can be performed by using a MWAC sediment catcher.

For accuracy on variable wind regimes the Salthiphone performed the best. Its construction based on a windvane is always perpendicular to the wind direction. Sensit and Safire showed at different positions of the sensor irregular response. As a result of this it is advisable to use these sensors in situations in which a prevailing wind direction is known.

Influence of the impact of raindrops on the sensors is the highest at the Salthiphone. Sensit had the lowest because of the built-in electronic filter. To assure saltation measurements it is recommended to measure simultaneous rainfall intensities with an automatic rain gauge (tipping-bucket).

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IMPACT OF DUST PROCESSES ON AIR QUALITY IN NIAMEY, NIGER, AND CONSEQUENCES ON HUMAN HEALTH

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INTRODUCTION

The Sahara largely contributes to the global injection of mineral dust into the northern hemisphere (Prospero et al., 2002; Washington et al., 2003). Yet it is estimated that the Sahara and its margins inject yearly amounts of dust into the atmosphere varying between 600 and 900 106 tons (D'Almeida, 1986; Marticorena et al., 1997; Callot et al., 2000), about half of the yearly global mineral dust production (Ginoux et al., 2004).

Over the last decade, mineral dust has become a major topic in environment studies. The increase of aeolian processes observed in most arid and semi-arid areas of the world over the last decades is thought to be a response to environmental stresses and global climate change (Tegen and Fung, 1995; Rosenfeld et al., 2001; Ozer, 2002).

In addition, there is a growing evidence that air pollution caused by increasing concentration of respirable particulates, that is those smaller than 10 μm (PM_{10}), have many local to global environmental and human-related consequences, most of which are adverse. In addition, wind-borne dust may transport bacteria and fungi (Kellogg et al., 2004; Prospero et al., 2005) and can be contaminated with pesticides (O'Hara et al., 2000) or even radioactive (Papastefanou et al., 2001).

Saharan dust is often transported far away to the sources (Middleton and Goudie, 2001). As a result, air quality deterioration

caused by high concentrations of respirable African mineral dust has been reported in various regions far away from the sources, such as the Canary Islands (Viana et al., 2002), Spain (Rodriguez et al., 2001; Salvador et al., 2004), the United Kingdom (Ryall et al., 2002), the Middle East (Alpert and Ganor, 2001), the West Indies (Rajkumar and Chang, 2000) and the south-eastern United States (Prospero, 1999). Such mineral particulate matter air pollution is a serious health threat in various regions of the world because it may promote respiratory infection, cardiovascular disease and other ailments (Biilders et al., 2001; Griffin and Kellogg, 2004; Ozer, 2008). High concentration in mineral PM_{10} are cause of morbidity and mortality. Yet, an augmentation of 7.66% of respiratory diseases (+1.12% per $10 \mu g m^{-3}$ increase in PM_{10}) and 4.92% of the total mortality (+0.72 per $10 \mu g m^{-3}$ increase in PM_{10}) during Mongolian dust outbreaks in Taipei, Taiwan has been recorded (Chen et al., 2004). As far as the Caribbean island of Trinidad, African dust clouds have been associated with increased pediatric asthma accident and emergency admissions (Gyan et al., 2005). Surprisingly, no measurement of ambient air pollution levels near the Saharan dust sources is available (WHO, 2000; Baldasano et al., 2003).

Based on horizontal visibility measurements reduced by mineral dust in the air, this paper estimates PM_{10} concentration levels at the synoptic station of Niamey-Airport, Niger, during year 2005 by using different relations found in the literature. Comparisons with air quality standards from various sources are realized and discussed.

DATA

The meteorological horizontal visibility is one of the elements world-widely identifying air mass characteristics. In synoptic stations, horizontal visibility is observed on a hourly basis and defined as the greatest horizontal distance at which a black object of suitable dimensions, located near the ground can be seen and recognized when observed against a background scattering of hydrometeors (rain, snow, fog, mist) or lithometeors (dust processes) (WMO 1992). At the synoptic station of Niamey-Airport, 18 targets (buildings, towers, mosques, etc.) with well measured distance to the point of observation are used to estimate horizontal visibility. The interna-

tional synoptic surface observation code (SYNOP code, WMO 1996) allowed the identification of four classes of dust-related conditions (see detailed information on dust related conditions used in the literature in Ozer, 2000):

1. dust being raised from the ground at the time of the observation (SYNOP codes 07 and 08) and reducing horizontal visibility to less than five kilometers (blowing dust);
2. dust storms, resulting of turbulent wind systems entraining particles of dust into the air, at various degrees of intensity (SYNOP codes 09 and 30 to 36) reducing horizontal visibility to below one kilometer;
3. dust suspended in the air but not being raised from the ground at the time of observation (SYNOP code 06), remnants of earlier deflation events reducing horizontal visibility to less than five kilometers. Dust deposition is noticed at the time of the observation; and
4. haze (SYNOP code 05, presumably caused by dust) reducing horizontal visibility to less than ten kilometers. In this case, no dust deposition is observed which suggests that the dust particles have been raised from the soil at a considerable distance away.

For this study, only dust processes reducing horizontal visibility to five kilometers and below were taken into account. Horizontal visibility were selected on a three-hourly basis, that is at 03:00, 06:00, 09:00, 12:00, 15:00, 18:00, 21:00, and 24:00 UTC.

METHODS

RELATION BETWEEN HORIZONTAL VISIBILITY AND PM₁₀

As far as today, only D'Almeida (1986) carried out an in deep study in West Africa on the relation between horizontal visibility and PM₁₀ levels of mineral dust mass concentration. Therefore, this paper will be based on the D'Almeida's (1986) correlation analysis linking observed aerosols turbidity, horizontal visibility and mineral dust mass concentration. This was developed on a turbidity network based on 11 stations set up in the Sahara, in the Sahelian belt and in the surrounding southern area during two years (1981 and 1982). Used visibilities range from 200 meters to 40 kilometers and the obtained relation is ($r^2 = 0.95$):

$$C = 914.06 VV^{-0.73} + 19.03$$

where C is the PM_{10} concentration in $\mu g\ m^{-3}$ and VV is the horizontal visibility in km.

Comparative suspended mineral dust concentration data for atmospheric dust processes linked with visibility measurements are very scarce in the literature. Reduced visibility to 1.9 km during a yellow sand storm in Kwangju, Korea, was associated with PM_{10} concentrations of $602\ \mu g\ m^{-3}$. (Kim et al., 2001). For this visibility reduction, D'Almeida's relation estimates a concentration in PM_{10} of $591\ \mu g\ m^{-3}$.

This relationship is applied to the visibility data of Niamey-Airport in order to retrieve PM_{10} estimates. Obtained results are presented at the daily and derived yearly scale.

AIR QUALITY REGULATIONS

Several guidelines and regulations have been adopted to define air quality levels. The US Environmental Protection Agency (EPA) defines the National Ambient Air Quality Standards (NAAQS), and the EU labels the Limits Values for Air Quality (LVAQ). A compilation of the air quality regulation status around the world shows that no such criteria exists in Africa (Baldasano et al., 2003).

For PM_{10} , the EU-LVAQ is the strictest limit with $50\ \mu g\ m^{-3}$ not to be exceeded 35 days per year and 7 days per year from 2010. Other 24-hour standard concentration range from 100 to $150\ \mu g\ m^{-3}$ (Baldasano et al., 2003). In the USA, the EPA-NAAQS established that the $150\ \mu g\ m^{-3}$ threshold can not be exceeded more than once per year, averaged over 3 years. In addition to these daily limits, the US EPA developed the Air Quality Index (AQI) as a tool to provide people with timely and easy-to-understand information on local air quality and whether it poses a health concern (US EPA, 1999). The AQI scale has been divided in six categories, each corresponding to a different level of health concern. The two first AQI categories (good and moderate, $< 155\ PM_{10}\ \mu g\ m^{-3}$) have likely no impact on health, while the last AQI category (hazardous, $> 424\ PM_{10}\ \mu g\ m^{-3}$) is associated with a serious risk of respiratory symptoms and aggravation of lung disease, such as asthma, for sensitive groups and with respiratory effects likely in general population. In between (PM_{10} ranging from 155 to $424\ \mu g\ m^{-3}$), three other categories consider air quality

as unhealthy to very unhealthy, especially for sensitive groups. Estimated PM_{10} concentrations will be systematically compared with threshold values established by US EPA-NAAQS and EU-LVAQ.

RESULTS

DAILY PM_{10} CONCENTRATIONS DUE TO SAHARAN DUST

Figure 1 shows the estimated profiles of mean daily PM_{10} concentrations due to mineral dust processes at Niamey-Airport during 2005. The major number of affected days by low air quality mainly occurred in January to March, with 58% and 73% of the yearly number of days above the 24-hour EU-LVAQ ($50 \mu g m^{-3}$) and US EPA-NAAQS PM_{10} regulations ($150 \mu g m^{-3}$), respectively. Two days with extremely high density of particulate matter are observed on January 6 and 7 with PM_{10} concentrations of 1217 and $1514 \mu g m^{-3}$, respectively. During these two days, horizontal visibility ranged between 0.3 and 1 km due to dust storm activity.

Such very high concentrations are not uncommon during very dense dust storms. Chung and colleagues (2003) recorded a $1779 \mu g m^{-3}$ concentration in Chongwon-Chongju, Korea. In Beijing, PM_{10} concentrations above $1000 \mu g m^{-3}$ were reported during dust storms (Fang et al., 2003). In Kuwait, Draxler and colleagues (2001) measured PM_{10} air concentration exceeding $1800 \mu g m^{-3}$ during severe

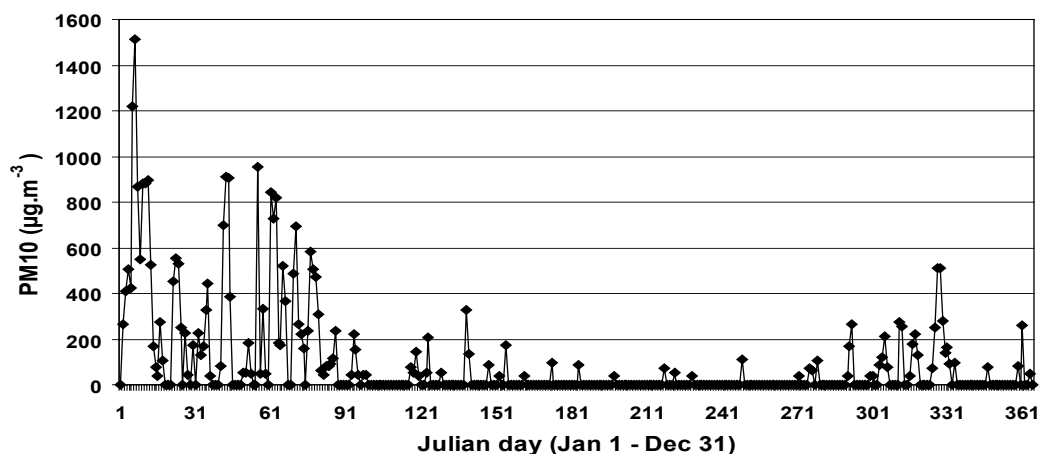


Figure 1. Estimated daily mean concentrations of PM_{10} ($\mu g m^{-3}$) due to Saharan dust events at Niamey in 2005.

dust storms. In Mauritania, daily PM_{10} concentrations up to $3000 \mu g m^{-3}$ were estimated in 2004 during huge dust storms (Ozer, 2008) and PM_{10} concentrations above $1000 \mu g m^{-3}$ were also estimated in 2000 (Ozer et al., 2007).

Frequency distribution of estimated daily PM_{10} concentration at Niamey-Airport is shown in Fig. 2. Results suggest that 71.8% of the days were free of mineral dust ($<50 \mu g m^{-3}$). Air quality is deteriorated all other 103 days, with 36 days in the $50-150 \mu g m^{-3}$ range. Compared with threshold daily PM_{10} concentrations established by the EU-LVAQ, the number of polluted days is about three times above the permitted number of days with $>50 \mu g m^{-3}$, and 15 times higher than the legislation on air quality to enter into force by 2010. For what regards the comparison with the US EPA-NAAQS, 67 days exceed the $150 \mu g m^{-3}$ limit value.

Compared with the US EPA-AQI, 24 days (6.6%) may be considered as unhealthy for sensitive groups, 15 days (4.1%) as unhealthy to very unhealthy and 28 other days (7.7%) may be qualified as hazardous. A total of 18.4% of the days was therefore likely to impact human health in Niamey during 2005 because of the high frequency of mineral dust processes.

YEARLY PM_{10} VALUES DUE TO SAHARAN DUST

The annual mean PM_{10} concentration presents a value of $92 \mu g m^{-3}$ in 2005. This figure is far above the norms adopted in developed countries as it is twice the threshold value established by the US

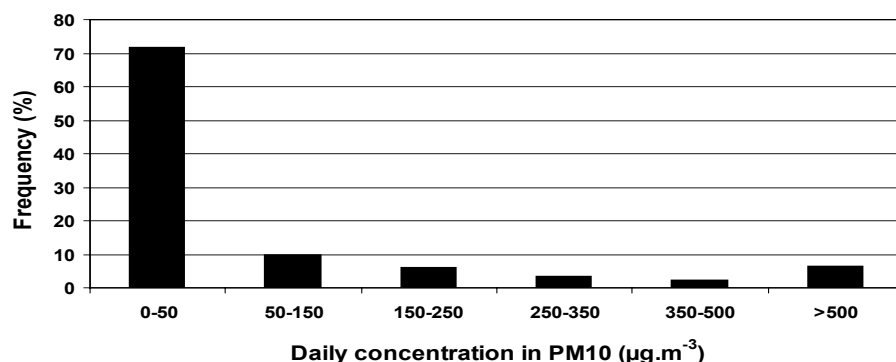


Figure 2. Distribution of the number of days with selected PM_{10} pollution gradients ($\mu g m^{-3}$)

EPA-NAAQS ($50 \mu\text{g m}^{-3}$) and about five times higher than the limit of the EU-LVAQ yearly mean PM_{10} concentration ($20 \mu\text{g m}^{-3}$) to enter into force by 2010. Estimated annual mean PM_{10} concentration from visibility impairments in Niamey was of $67 \mu\text{g m}^{-3}$ in 2003 (Ozer, 2005) and of $108 \mu\text{g m}^{-3}$ in Nouakchott, Mauritania, in 2000 (Ozer et al., 2007). No comparison can be made with other African data as no measurements nor estimations are available in the recent compilation of air quality data realized by Baldasano et al. (2003). However, according to other annual mean PM_{10} concentration reported by these authors, only the city of Tegucigalpa, Honduras, exceeds the Niamey value with $157 \mu\text{g m}^{-3}$. It is worth mentioning here that no records of PM_{10} concentration are available in arid regions from developing countries.

Such values do not estimate the urban air pollution of the city of Niamey where the activities of a rapidly growing urban population (907,000 inhabitants in 2008 against 392,000 in 1988, WWWW1) do produce large quantities of particulate matter. This urban air pollution mainly results from increasing traffic of old and badly maintained vehicles on sandy roads, and from individual fires for cooking purposes.

CONCLUSIONS

The results presented in this study give a estimation of the impact of mineral dust resulting from aeolian processes on air quality degradation in Niamey, Niger, during 2005. A mean annual PM_{10} concentration of $92 \mu\text{g m}^{-3}$ which dramatically exceeds all various norms established in developed countries is alarming. Daily PM_{10} concentrations exceeded twice $1000 \mu\text{g m}^{-3}$ in 2005. The EU-LVAQ limit 24-hour PM_{10} concentration ($>50 \mu\text{g m}^{-3}$) was exceeded 103 days, about 15 times the legislation on air quality to enter into force by 2010. The $150 \mu\text{g m}^{-3}$ limit value established by the US EPA-NAAQS was exceeded 67 times, with 28 days that may be qualified as hazardous according to the US EPA-AQI.

Developed countries are building up strategies in order to reduce air pollution. On the contrary, most African countries have no air quality regulations, neither the tools to monitor air pollution. It is known that acute respiratory infections among children is one of the major cause of mortality in developing countries, especially in Africa

(Black et al., 2003; Ozer, 2008; Romieu et al., 2002; Smith et al., 1999). However, no study of the impact of mineral dust on human health in West Africa was carried out due to the lack of air quality data. Estimations of PM₁₀ concentrations derived from horizontal visibility observations could be a first approach to realize such studies.

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DUNE REHABILITATION USING A MECHANICAL FIXATION TECHNIQUE: EFFECT ON SEDIMENT FLUXES AND ON THE QUANTITATIVE AND QUALITATIVE RECOVERY OF THE HERBACEOUS SOIL COVER

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INTRODUCTION

Thirty percent of the strongly degraded soils of the world are in the Sahel, where wind erosion is a major contributor to the soil degradation process. In the Manga area (Department of Gouré, Eastern Niger) desertification is reflected by the re-activation of formerly fixed dunes and the replacement of the trees by shrubs (Karimoune, 1994; Tidjani, 2006). Thus the surface occupied by active dunes has increased from 0 ha in 1975 to 10.000 ha in 1985, and to 30.000 ha in 2005 (Toudjani and Guero, 2006). Most of these dunes are situated near villages and interdune depressions with high agro-pastoral potential where the anthropic pressure is the strongest.

In Niger, the most commonly used technique for dune fixation is windbreaks made of rows of natural vegetation or perennial herbaceous, shrubs or trees plantations (Biielders et al., 2004) or dead tree branches or artificial material. These windbreaks aim first to reduce the wind speed at the soil surface. The limit of the protection zone is conventionally defined as being the distance up to which the wind speed is reduced for more than 20 %. A windbreak of 40% porosity and of height H reduces wind erosion by 50% up to a distance of 6 times H upwind and 22 times H downwind (Skidmore and Hagen, 1977). Roose (1994) reported a reduction by more than 20 % of the wind speed over a distance of 10 and 12 times the height of the windbreak upwind and downwind, respectively. In Niger, 2-m high windbreaks of *Bauhinia rufescens* reduced aeolian soil fluxes

by, respectively, 47 to 77 % at a distance of 14 m upwind and 10 m downwind. For *Andropogon gayanus*, this reduction was 6 and 55 % (Buerkert and Lamers, 1999). Five meter wide herbaceous vegetation strips made of *Galago senegalensis* and *Andropogon gayannus* reduced eolian sediments fluxes from 53 to 70% when the spacing between the bands was reduced from 20 to 6 m (Buerkert et al., 1996).

The above examples indicate that windbreaks have a strong potential for reducing wind erosion. However, when dead fencing material is used, the lifespan of the windbreak is generally limited to 2-3 years at best. Recolonisation of the space between windbreaks by herbaceous vegetation may in such cases be an essential contribution to the overall sediment flux reduction efficiency of the windbreak system. Although related to a somewhat different agro-climatic setting, it has been shown that a 20-m wide grass vegetation band is able to retain almost 90% of incoming sediment (Biielders et al., 2002).

To be effective in terms of dune fixation, the recovery of the herbaceous vegetation would have to occur rapidly in order to take over from the physical barriers after just one or two years. Yet, little is known about the effectiveness of wind barriers in promoting grass cover recovery and the effect of combined windbreak-grass cover on sediment fluxes. Besides, although the recovery of the ground cover is quintessential from the point of view of wind erosion control, the diversity of the recovering herbaceous vegetation is also worthy of investigation because it is an indicator of the ecological restoration and may possibly be exploited as a source of feed for livestock. In China, dune fixation in the center of Mongolia induced a very diverse vegetation recolonisation after 46 years of soil protection but the speed of this recovery was not studied (Li et al., 2004). The objective of this study was therefore to evaluate the short-term effectiveness of a mechanical windbreak on aeolian sediment fluxes and the quantitative and qualitative recovery of the natural herbaceous cover in a context of dune re-activation in Eastern Niger.

MATERIALS ET METHODS

The experimental site (Fig. 1) is an active dune at Tchago (Lat. 14°02' 39 " N, Length. 10°03' 52 " E), 240 m long in the NNW-SSE direction

and approximately 100 m wide, oriented perpendicular to the dominant Harmattan wind. Wind speed and direction were measured at 2 m height by means of a wind vane and an anemometer. Daily rainfall amount was measured with an automatic rain gauge.

The reactivated dune was protected by means of a checkerboard pattern of windbreaks, covering an area of 200 m by 40 m over the entire length of the dune (Fig. 1) and subdivided into 40 plots of 20 m by 10 m each. Thirty plots were located on bare soil and 6 plots on a naturally vegetated area at the South-Eastern end of the dune. The remaining 4 plots formed a transition zone and will not be analysed here. The windbreaks (average height of 1.8 m) were made of *Leptadenia pyrotechnica* branches. Average windbreak porosity at the start of the experiment was $9.0 \pm 7\%$ ($n = 30$).

MWAC ("Modified Wilson And Cooke") sediment traps were aligned along 8 transects running parallel to the Harmattan winds through the middle of 8 degraded plots. On each transect, a MWAC mast is placed at 3 m upwind and at 2 m, 5 m, 9 m and 18 m downwind of the first windbreak row facing the Harmattan winds (Fig. 2). Traps were placed at 0.05, 0.15, 0.4 and 0.6 m and 1 m height on each mast. Equation 1 was fitted to the observed sediment mass flux density profiles and integrated up to 1 m to yield total flux.

$$q(z) = q_0 \left(\frac{z}{\sigma} + 1 \right)^{-p} \quad (1)$$

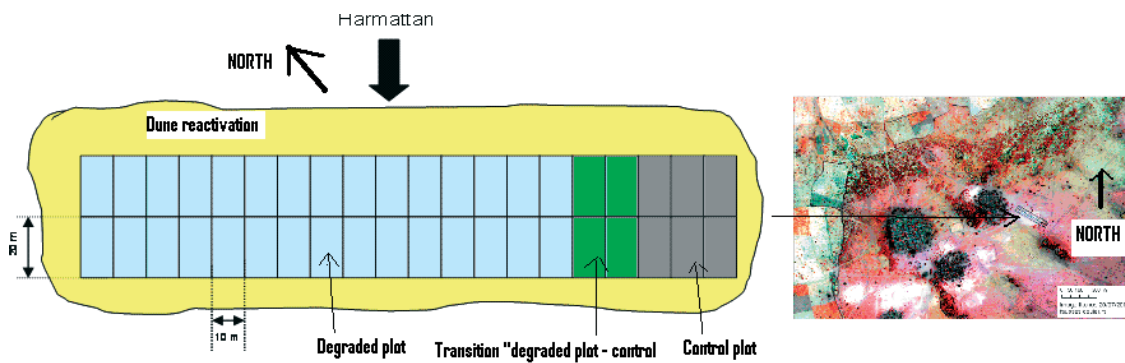


Figure 1. Aerial view of the study zone (Tidjani, 2006) : (a) experimental site, (b) dune reactivation, (c) village.

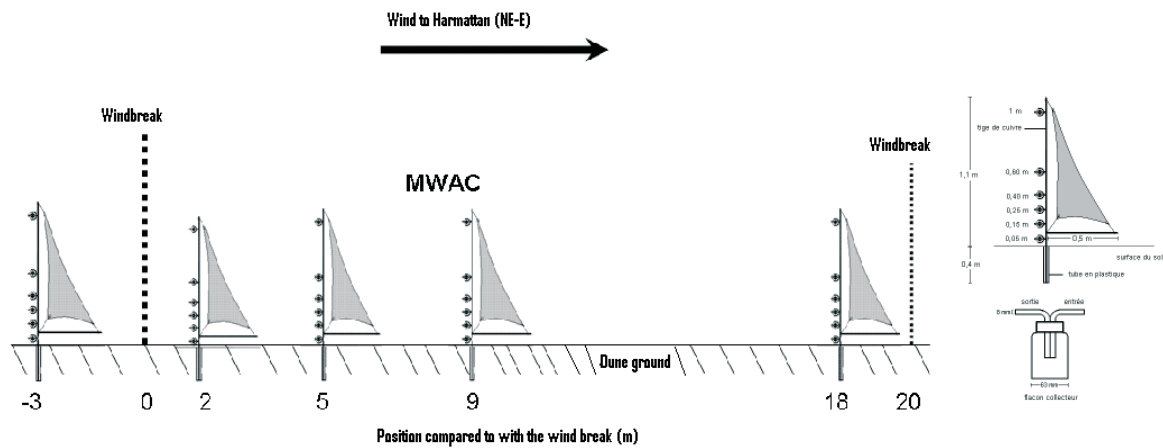


Figure 2. Diagram of MWAC catchers installed perpendicularly to windbreaks on a transect at Tchago

where $q(z)$ and q_0 are the mass flux density at height $z = z$ (m) and $z = 0$, respectively ($\text{kg m}^{-2} \text{s}^{-1}$); p and σ are coefficients (-). Sterk and Raats (1996) estimate that $\sigma = 1$ m.

For each transects, graduated stakes were placed at 4 and 1 m upwind and at 1, 4, 9 and 17 m downwind of the windbreak to monitor changes in surface topography. Measurements were repeated each month between 11th November 2005 and 15th April 2006

The inventory of the herbaceous vegetation was carried out in 2005, 2006 and 2007 in 6 bands running parallel to the windbreak: 0-5 m (1A), 5-15 m (1B) and 15-20 m (1C) away from the first windbreak row facing Harmattan winds and 0-5 m (2A), 5-15 m (2B), 15-20 m (2C) away from the second windbreak. The inventory was also done in the undegraded part of the dune. Grass dry matter was quantified on ten 0.5 m^2 subplots randomly distributed in each band. Measurements of biomass and observations of species diversity (De Fabregues, 1979) were made at the end of the rainy season when the growth of the grasses had stopped.

RESULTS AND DISCUSSIONS

The winds observed on the experimental site showed a very clear seasonal trend. From November to March, the wind came from the North-East (Harmattan), whereas from May to September, it came from the South-West to West (monsoon). April and October are typically transition months. Between November and March, wind

speeds ranging between 6 and 10 m s⁻¹ represented more than 99% of the wind speeds higher than 6 m s⁻¹, the latter corresponding to the threshold wind speed for saltation.

The analysis of the sediment fluxes collected at 3 m upwind of the windbreak exposed to Harmattan winds showed an important spatiotemporal variation of sediment mobilization (Fig. 3). However, these sediment fluxes were probably underestimated owing to the fact that these MWAC sand catchers were in the zone of influence of the windbreak.

Figure 4 shows the sediment fluxes measured at 2, 5, 9 and 18 m downwind of the first windbreak for the period from 15th February to 15th March in 2005, 2006 and 2007. In 2005 (year of installation of the windbreak) the wind fluxes measured at 2 m, 5 m, 8 m and 16 m downwind of the first windbreak represent respectively 5 %, 1.2 %, 1.3 % and 1.3 % of the flux measured at 3 m upwind of the windbreak. One year later, no fluxes were recorded downwind of the windbreak.

Between 11th November 2005 and 15th April 2006, the study site was subject to sediment deposits. The deposits are most important immediately upwind of the windbreak as well as over a short distance downwind of the windbreak (Fig. 4). This situation reflects the effectiveness at reducing sediment fluxes of the first windbreak row exposed to the Harmattan wind. The sediment deposits are enriched in coarse particles upwind and in fine particles, organic

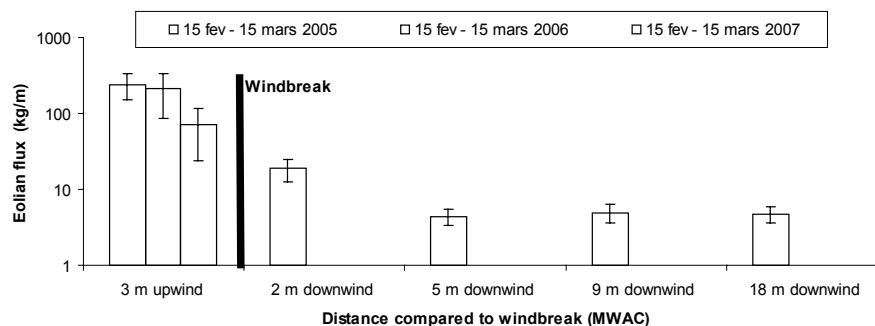


Figure 3. Average sediment fluxes as a function of the distance from the windbreak between February 15 and March 15 in 2005, 2006 and 2007. Error bar is the standard deviation ($n = 8$).

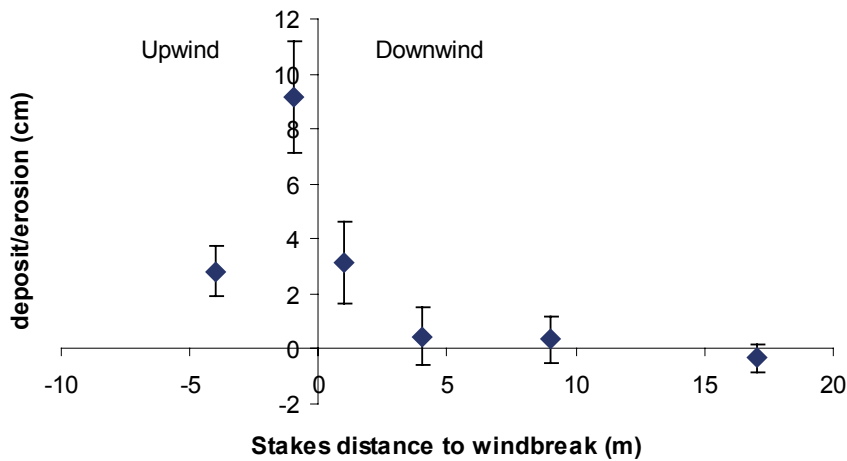


Figure 4. Change in surface topography upwind and downwind of the windbreak exposed to the Harmattan wind on an active dune at Tchago for the period from 11th November 2005 to 15th April 2006; the y-axis represent the position of the windbreak. Error bars are standard deviations ($n = 8$).

carbon and total N downwind of the windbreak (not shown). The enrichment in C and N could result from both the enrichment in fine particles (clay-OC complexes) and added OC following the recovery of the herbaceous vegetation. Available P content in sediment deposits remained very low upwind and downwind of the wind break.

The herbaceous vegetation recovered in the first year after the installation of the windbreak system. Overall, differences in herbaceous biomass production between years were not significant, except in the control zone where the higher biomass production in 2007 may be attributed to higher rainfall (Fig. 5). In the 4 central bands, biomass production remained modest compared to the control, despite the absence of measurable sediment fluxes during the last two years. On the contrary, the herbaceous biomass production tended to be significantly higher immediately downwind of the windbreak row facing the Harmattan as well as downwind of the row facing the Monsoon winds (Fig. 5). This corresponds to zones with important sediment deposition (Fig. 4), which occurred during the Harmattan period for band 1A and the monsoon period for band 2C. These deposits are enriched in fine particles, which may have enhanced both the chemical and physical soil fertility. It may also be that the deposits have a greater seedbank potential. It is unlikely that the

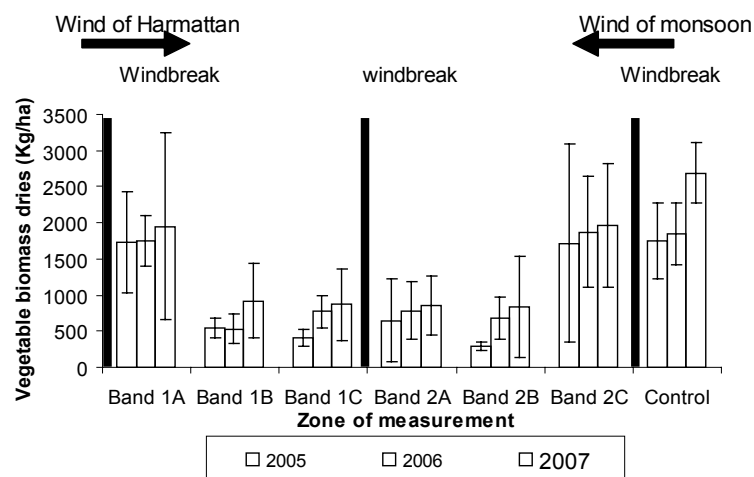


Figure 5. Herbaceous biomass production within the windbreak system and in the control area on an active dune at Tchago from 2005 till 2007. Error bars are standard deviations (n=10).

higher growth in bands 1A and 2C compared to the central bands resulted from more favourable microclimatic conditions. Indeed, during the rainy season winds are dominated by monsoon winds, hence one would expect the greatest sheltering effect in bands 2C and 1C rather than 2C and 1A. Hence it appears that, although the reduction in sand fluxes and grazing control favour the recovery of the grass vegetation as observed in the central bands, the trapping of sediment enriched in fine particles strongly enhances the restoration allowing these bands to reach productivity levels similar to the control.

Within the experimental site, the number of species and the number of families to which they belong increased considerably year by year, both on the degraded and undegraded zones of the dune.

Table I. Recovery of the herbaceous cover on an active dune equipped with a wind-break system between 2005 and 2007

Localization	Number of species		
	2005	2006	2007
Band 1A to 2C	13 (8 families)	29 (18 families)	59 (20 familles)
Control	11 (8 families)	33 (18 families)	71 (23 familles)

Overall, the dominant family was that of graminaceae with mainly *Aristida adscensionis* and *Cenchrus biflorus*. Given that the increase in diversity affects both the degraded and undegraded areas, it may be that grazing control plays a major role in this process.

CONCLUSIONS

Windbreaks made of branches of *Leptadenia pyrotechnica* appeared very effective at reducing sediment fluxes on an active dune at Tch-ago, Damagaram East (East of Niger). This is likely the result of both the windbreak itself and the recovery of the grass vegetation, which take place in the first year following the installation of the windbreak system. Consequently, during the second and third year of measurement, no measurable sediment fluxes were observed in the windbreak system. Sediments accumulated downwind and close to the outer windbreaks appear to play a key role in the promoting grass biomass development. Wind erosion control and grazing control resulted in a gradual increase in species diversity in the windbreak system over the years. The produced dry herbaceous biomass exceeds by place 200 g m⁻² in 2007, which may allow for selective and careful harvesting. This technique of dune fixing is thus effective provided that the site is protected against grazing.

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DESERTIFICATION AND CHANGES IN RIVER REGIME IN CENTRAL AFRICA: POSSIBLE WAYS TO PREVENTION AND REMEDIATION

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INTRODUCTION

Oral and geological evidence show a remarkable change in the hydrological behaviour of rivers in big portions of the African continent (Moeyersons, 2000). The change started some hundreds to some tens of years ago. Rivers which were perennial some generations ago, become gradually seasonal. The peak floods are higher than before and follow shorter after the rains. The low stages are lower than before (Fig. 1). This phenomenon evidences the change which took place in the alimentation mechanism of rivers. Rivers, mainly spring-fed, became gradually increasingly runoff-fed. This can only be explained in terms of declining soil infiltration capacity in the spring catchments (Fig. 2), what leads to a reduction in soil humidity. But decreasing soil infiltration capacity contributes to land degradation in several other ways (Moeyersons et al., 2006):

1. The general increase in runoff makes that spring catchments on the topographic threshold graph for gullying (Montgomery and Dietrich, 1994) are shifting from gully free conditions to gully prone conditions. The danger for badland development increases.
2. The development of gullies in a formerly gully free landscape contributes to a reduction in the water storage capacity of the soil and, hence, will also contribute to a dryer environment.
3. Gullies are highways for the quick evacuation of soil materials eroded from the water divide areas and thus favour soil degradation.

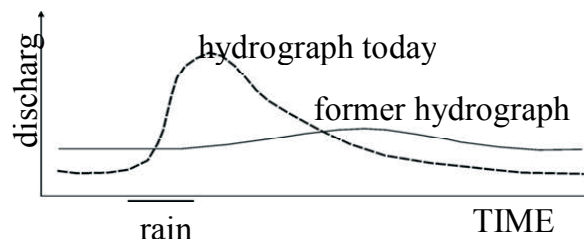


Figure 1. Evolution of the hydrographs

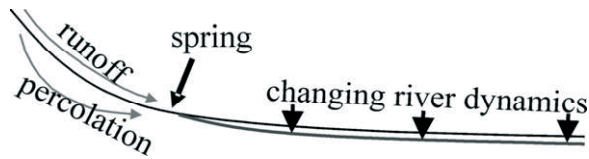


Figure 2. Evolution to more runoff

4. gullies can incise deep enough to become unstable and provoke mass movements.

The river beds, downslope of the springs, adapt to the new hydraulic conditions created by the occurrence of stream floods and flash floods. In flat areas, flash floods lead to widening of the stream channels and installation of braided river systems. Lateral erosion goes hand in hand with strong accumulation in the riffles. In steep areas, flash floods contribute to active vertical incision, which leads most of the time also to slope instabilities and mass movements.

The explained change in river regime is a frequently forthcoming phenomenon in Africa. Fig. 3 shows the regions where the phenomenon has been observed by one of the authors since the last 30 years and where, as a consequence, land degradation and desertification



Figure 3. Changing river dynamics in Africa

are in progress. In a general way it concerns a belt in the savannas around the tropical rain forests. But also inside the tropical belt, big clearings and towns are affected.

It is known that forest clearing, overgrazing and agricultural intensification lead to decreased spring discharges and increasing runoff coefficients. But increasing rainfall variability as can be expected as a result of global climate change (Hulme et al., 2001; Dore, 2005) is also believed to play a role.

This article wants to stress this type of situations as they occur along the Albertine Rift in Eastern D.R. of Congo, in Rwanda and Burundi. Firstly it aims to report on the material damage and even loss of lives, going hand in hand with the changes in hydrological behaviour of the landscape. Further, the article reports on geomorphological investigations, carried out in Rwanda in order to study the influence of soil use on the hydrological behaviour of slopes in Rwanda. Finally, this article will also explicitly mention the existing methods of soil and water conservation management which can contribute to 'normalisation' of the hydrological behaviour of slopes in the East D.R.Congo, Rwanda and Burundi.

EXAMPLES OF DAMAGE BY NATURAL RISKS: THE GRAVITY OF THE SITUATION

The Kivu-Rwanda-Burundi region seldom comes into the news as a result of environmental hazards. The only hazard, mentioned is of volcanic (Nyiragongo, 2002) or seismic (Bukavu, 02/2008) nature. Nevertheless, the whole region is currently affected by natural hazards, increasing in number and intensity every year. Included are sudden severe farmland erosion, river flash floods and inundations, deep gully incision, landslides and other mass wasting. Year after year the economic infrastructure of roads, buildings, bridges, farmland becomes increasingly damaged and losses of livestock, agricultural lands and food crops grow. Several dozens of people are yearly killed. In Bigogwe, Northern Rwanda some 20 people were killed by the inundations during the night of 12-13 September 2007. Flash floods in Uvira killed some 40 people in February 2002. Also unexpected variations in the water tables and lake levels are at stake. So it appears from remote sensing information that the Tanganyika and Kivu lakes and the swampy areas in northern Rwanda know a

lower water stage today than in the 50's. Recently, the hydro-electric plants in Northern Rwanda and on the Rusizi river became in difficulties. Furthermore, gullying becomes an increasing problem in towns and especially in their extension zones: houses and road infrastructure are threaten by gully incisions and the accompanying bank instabilities. Towns like Kigali, Butembo, Bukavu, Uvira, Cyangugu, Bujumbura are typical examples. Although never reported, we are aware of numerous inundations, landslides and sudden gully incisions over the entire territory of Rwanda, Burundi and Kivu, occurring at least since the seventies. Without any doubt, several dozens of people did die. We are not aware of calculations of the total cost of these small and big disasters, but there is no doubt that they hamper the sustainable development of the whole region.

It is also a fact that these natural disasters increase in frequency and intensity since the last two or three decades. The reason is unclear. Many of these 'geomorphological events' occur during or shortly after meteorological conditions, extreme in intensity and/or duration. Maybe climatic change is at stake (Muhigwa, 1999). But some landslides at Uvira and Bukavu have been proven to have a seismic origin (Moeyersons et al., 2004). Finally, the increasing hydrograph irregularities of rivers could be the consequence of changes in land use, which lead to a change in hydrological response of the landscape, rivers becoming increasingly runoff sensitive instead of spring discharge sensitive like it was some time ago. In this respect, the importance of deforestation on the low river stage has been shown over a period of 20 years along a few forested areas in Rwanda (Rwilima, Faugère, 1981). This evolution reflects the general decrease of the soil infiltration capacity.

As part of the research programme 'Study and mapping of natural hazards along the Albertine Rift' by the division of 'Geomorphology and Remote Sensing' of the RMCA, an inventory of all types of erosion processes, taking the size of a 'hazard' have been inventoried in Rwanda and counter-measures have been identified. More recently, studies have been done in Bukavu, Uvira, in the Bujumbura area, at Kigali, and problem regions have been visited like the Rusizi valley and the Kanyosha valley in northern Burundi. Research on gully development in the town of Butembo is also going on.

AIM

Since 1975, the geomorphology section of the RMCA is explicitly present in the area and field research has been done in Rwanda in order to study the influence of soil use on the hydrological behaviour of terrain on granite/gneiss and phyllite substrate. In the same time an inventory has been made for all types of erosion, triggered by runoff and percolating water. The role of soil use in these processes has been evaluated. Basic results are given by Moeyersons (1989; 2004).

MATERIAL AND METHODS

All hydrological and soil mechanical parameters have been measured with apparatuses belonging to the Laboratory of Experimental Geomorphology, KULeuven.

The infiltration capacity of the soils in Southern Rwanda has been measured by a portable rain simulator (Fig. 4), used to define infiltration envelopes (Smith, 1972).

The hydraulic conductivity has been measured in the field by a simple ring permeameter and in the laboratory by oedometer tests soil mechanical parameters like cohesion, shear resistance, have been defined by vane tests an/or mono-axial shear tests.

Measurements in the field of diffuse pluvial erosion have been done either in collector trenches below cultivated parcels (Fig. 5) or by means of erosion pins.

Creep measurements in the field have been executed by the measurement of displacement of tracers in so-called 'Young Pits' (Young, 1960).

The development of gullies was studied by qualitative and quantitative field observations.

Local soil and water conservation methods have been qualitatively evaluated in the field.

Teledetection methods, including aerial and satellite imagery analysis and mapping in GIS, are currently used to map landslides, deep gullies, inundation belts, severe farm erosion, river erosion.

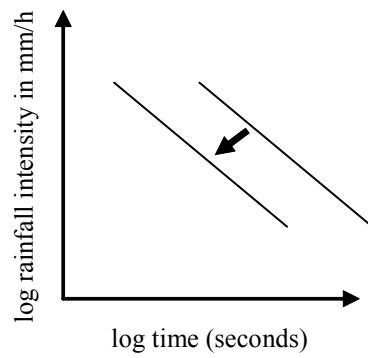


Figure 4. Rain simulator (left) and infiltration envelope. Lower infiltration capacity corresponds to shift of the envelope to the left



Figure 5. collector trench at Butare

RESULTS

A. THE INFILTRATION CAPACITY OF THE SOIL

The rain simulation experiments show that the infiltration capacity of the soil depends of at least the following variables:

- soil humidity: second runs on the same parcel, wetted already during the first test, show invariably a shift of the infiltration envelope to the left. This shows that the infiltration capacity will

be lowest at the end of the rain. Rains, showing a sudden increase of intensity near to the end of the storm should produce proportionally more runoff than rains with their peak shortly after the start of the rain. On the scale of a rainy season with increasing soil moisture content, rains near the end of the season should produce proportionally more runoff and should be more erosive.

- The state of the soil: It is generally believed that hoeing the soil and the creation of a raw surface of soil aggregates increases the infiltration capacity of the soil. The runs with the simulator confirm this effect but indicate also that the effect of hoeing is very temporary on most soils in the area because of rapid slaking of the top soil, shaping a nearly impervious sheet.
- The vegetation cover just above the surface: runs in a bean field show the importance of soil cover: once the cover is above 80%, runoff is minimal and disappears completely at 100% coverage. Also some grasses like *Eragrostis* sp. and *Cynodon dactylon* reduce or even annihilate runoff at a high soil coverage.

B. EROSION ON PASTURE, RANGELAND AND IN EUCALYPTUS PLANTATIONS

The erosion pin measurements over 4 years at Rwaza hill, Butare (Moeyersons, 1990) show that land use highly determines erosion intensity. Measurements along 3 cross-sections of the hill show:

- higher erosion within or just downslope of Eucalyptus plantations without undergrowth;
- low or no erosion on grassy surfaces, but high erosion when the grass cover is interrupted either by overgrazing or along cattle tracks;
- no erosion and even fixation of sediments arriving from upslope within a small belt of low bush, composed of *Pteridium* cfr. *Aquilinum*, *Echinops* sp., *Helichrysum* sp., *Senecio* sp., *Vernonia* sp. and others.

The erosion measurements in the collector trenches result in the following conclusions:

- erosion in the rangeland – pasture – Eucalyptus (RPE) zone shows a seasonal trend to decrease during the progress of the rainy season (Fig. 6). Taking into account that, according to the rain simulation tests, the runoff coefficient should grow in the course of the

season, the reduction in erosion has to be ascribed to an increasing soil protection by the grassy vegetation.

- Fig 7 shows the erosion dynamics 1981-1985 for the RPE area (trenches 1 to 4), compared to the dynamics of erosion in cultivated parcels (CP) (trenches 5 and 6). In spite of the seasonal trend of decrease during the course of the rainy seasons, the erosion in the RPE-area remains rather constant during measurements 1 to 18. Most spectacular are measurements 19 and 20 in the RPE belt, where erosion falls to less than one third of the level of former years after the zone had been declared by the owner as enclosure for free grazing cattle. This shows again the high protective potential of all vegetation close to the surface, in this case grasses, protected by trees.
- Fig. 7 shows also the erosion dynamics in cultivated fields. The erosion peaks in the cultivated fields (dashed lines 5 and 6) correspond to harvesting, weeding and all activities reducing crop cover or reworking the naked soil surface.

C. SLOPE STABILITY

New quantitative data have been collected that human activities not only can trigger diffuse and rill erosion but also important gully development (Moeyersons, 1991). It has also been shown that the

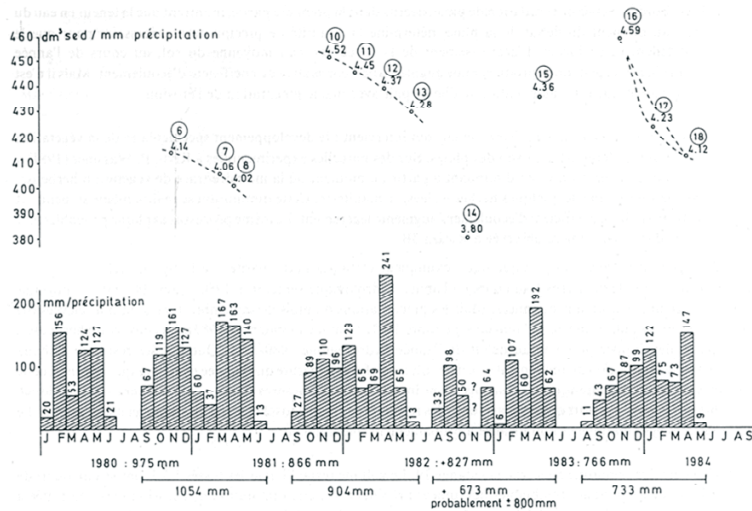


Figure 6. Volumetric determinations of sediment in collector trenches (dm^3) divided by mm of precipitation since former determination, measurements 4 to 18. Some precipitation data are missing for the hydrological year 1982-83.

making of collector trenches as part of a soil & water conservation technique is not efficient when applied on slopes steeper than 20° (Moeyersons, 2003). Calculations show that cultivated slopes steeper than 20° to 25° are only stable if infiltration is diffuse, not concentrated. In all cases, studied so far, it appears that human activities result in an increase in local runoff or local forced water infiltration in the soil by artificial concentration of runoff, or in an increase in slope over which runoff waters have to find their way. This change is depicted in the Montgomery and Dietrich (1994) topographic threshold condition (Fig. 8).

CONCLUSIONS

In the highlands of Kivu, Rwanda and Burundi, forests prove to be the best ecological system, absorbing even on steep slopes most of

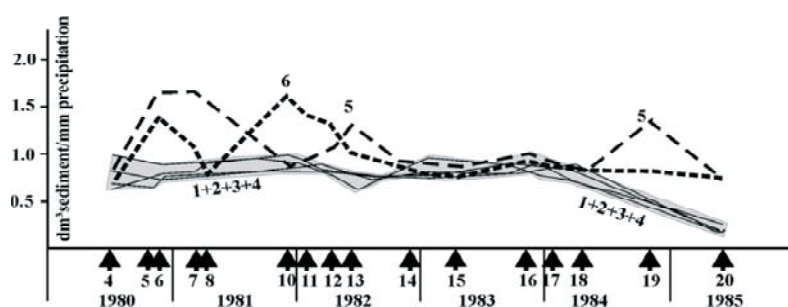
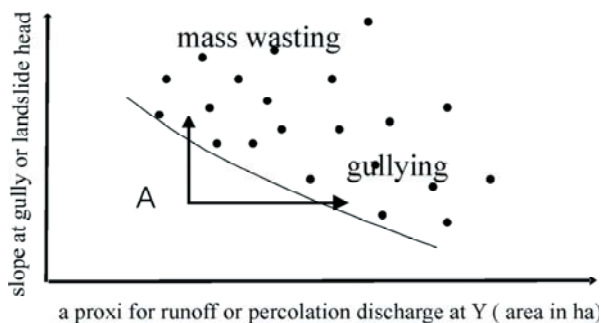


Figure 7. Volumetric determinations of sediment in collector trenches (dm^3) divided by mm of precipitation since former determination, measurements 4 to 20. Hatched belt contains measurements in rangeland - pasture - Eucalyptus belt (collector trenches 1 to 4).

Figure 8. Increase in slope angle or in runoff/percolation discharge can bring point A above the envelope of risk to gullying and landsliding



the runoff. The presence of still growing valley peat formations in the forest of Nyungwe is good evidence for the absence of sediment transport on the slopes and for a river regime without important peaks. The same is true for the Bigogwe area in northern Rwanda, where gullying, severe slope erosion and river floods, increasing in size and number only occur since recent forest clearing. The daily experience shows that even in the context of increasing extreme meteorological conditions, forests and savannas with not overgrazed undergrowth lead to nearly complete infiltration of water into the soil. Even on steep slopes this does never trigger mass wasting, probably because the infiltration is diffuse. Therefore, if forests have to be cut, we should replace them by ecological systems having the same hydrological response as forests, i.e. creating a diffuse precipitation water infiltration into the soil. The role of vegetation in protecting soil and improving the soil infiltration capacity is well known (Köning, 2002; Rishirumuhirwa, and Roose, 2002). According to our measurements and observations, we can forward several agricultural soil uses which reduce runoff to nearly zero, even on steep slopes:

- grassland, not over-grazed, with closed coverage;
- banana plantations with a soil covering undergrowth of legumes;
- coffee fields with good mulches;
- agro-forestry methods as mentioned by Ndayizigiye (1993), Ngenzi (1995), Köning (2002);
- tea plantations constitute a very nice and performing soil protective cover;
- reforestation and sustainable forest exploitation is also a possibility.

Soil-technical and biological mechanical methods for soil and water conservation are in use since a very long time. The first technique is called ‘progressive terracing’ and was introduced in the region after the second world war. It consists of the combined use of collector trenches and hays by pennisetum or another fixative plants. This system has been recommended only on slopes of less than 15°. If used on steeper slopes, it inevitably fails (Fig. 9) and even makes the situation worse by contributing to gullying (Moeyersons, 1989) and even landsliding (Moeyersons, 2004). The other technique is bench terracing, in Rwanda indicated as ‘terrassement radical’ (Fig. 10). Today, the technique is introduced in many plac-



Figure 9. On steep slopes, the pressure by sediments retained by the hays is too high. The hay is pushed forward and finally fails as happened in the foreground.



Figure 10. Bench terracing is in use in Rwanda since 1976. Never there have been reports on failures. The benches are slightly slope inward inclined and a 100 % infiltration is realised. This is absolutely necessary to prevent destruction of the whole slope by gullyng.

es in the area. It was launched in the seventies at the agricultural center of Kisaro.

The hydrological deregulation of the slopes in the study area finds its origin in deforestation and consequent over-cultivation and over-grazing and constitutes a natural risk. The increase of the local capacity of studying this natural risk and the consequences like inundations, mass wasting, gullyng, etc. is a first condition to combat

land degradation by better alleviation and prevention and for an environmentally sustainable development.

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DEFICIT IRRIGATION: MAXIMIZING THE OUTPUT OF EVERY DROP OF WATER IN DRY AREAS

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INTRODUCTION

In the very near future, agriculture needs to increase its production with a continuously decreasing fraction of the available fresh water (Howell, 2001). Therefore, sustainable methods of drought mitigation and production increase need to be adopted (Smith, 2000).

Within this context deficit irrigation (DI) is now widely been investigated as a valuable production strategy in dry regions (English and Raja, 1996; Kirda and Kanber, 1999; Pereira et al., 2002; Zhang, 2003). DI requires an important mental shift about agricultural water use. For many years, the main aim of agricultural research was to maximize total production. Now the focus lies on the most restrictive factor in production systems: the availability of either land or water. In the arid and semi-arid regions of the world, the restrictive factor for crop cultivation is water. This consequently asks for the maximization of the productivity per unit water. This paper reviews recent results of DI for the maximization of water productivity and offers a framework to evaluate the agronomic possibility of DI for certain crops.

CROP WATER PRODUCTIVITY

THE CONCEPT

Crop water productivity (WP) or water use efficiency (WUE), as reviewed by Molden (2003), is a key term in the evaluation of DI strategies. Crop water productivity (WP) with dimensions of Mg m^{-3} is in

this paper defined as the ratio of the mass of economically valuable yield (Y_a) to the volume of water consumed by the crop (ET_a):

$$WP = \frac{Y_a}{ET_a} \quad (1)$$

ET_a is the sum of water lost by soil evaporation and crop transpiration during the crop cycle. Since there is no easy way of distinguishing between the processes of soil evaporation and crop transpiration, they are generally combined in ET (Allen et al., 1998). In literature some confusion can exist when authors express the denominator as the amount of water applied (sum of rainfall and irrigation) or lost by crop transpiration (no unproductive soil evaporation considered).

Crops having a high WP should generally be preferred in regions with water scarcity, although this is not the only option. Crops that produce fruits or grains with a high energy content (e.g. high protein content) generally have a lower absolute WP value (Azam-Ali and Squire, 2002). Their yield is nevertheless of higher nutritional value which should be considered when assessing these crops for their possible use in drought prone areas.

THE CROP WATER PRODUCTION FUNCTION

The crop water production function (CWP function) expresses the relation between the total amount of water consumed (ET_a) and the obtained marketable yield (Y_a). The first order derivate of the function is the WP . In Fig. 1 a typical CWP function is presented. The axes of the CWP function are made dimensionless by plotting relative yield (ratio of actual, Y_a , to maximum possible yield under the given agronomic conditions, Y_m) versus the relative evapotranspiration (ratio of actual evapotranspiration, ET_a , to crop evapotranspiration under non-stressed standard conditions, ET_c). In general, different sections can be distinguished in the crop water production function (Fig. 1):

- Section a: When insufficient water is applied during the crop cycle, the crop will hardly develop and no significant yield can be produced. Further-on this yield can be of low quality (shriveled grains or fruits with low marketable value) or yield can be totally absent in this section (Yazar and Sezen, 2006; Geerts et al., 2008b).

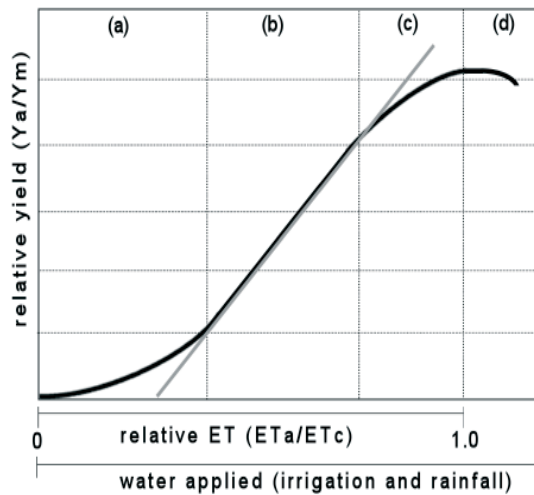


Figure 1. General shape of a crop water production (CWP) function

- Section b: Once a minimum amount of water is guaranteed by rainfall and or irrigation, the production function becomes linear. The slope of this linear section is related to the proportional factor between yield decline and water stress as given by the water stress factor K_y (Doorenbos and Kassam, 1979). A K_y factor of 1 relates to a linear section b with a slope of 1. These are stress-neutral crops: a decrease in ET provokes a proportional decrease in yield. A K_y factor smaller than 1 coincides with a linear section b with a mild slope. These are stress tolerant crops as a decrease of ET within the range of section b results in a less than a proportional increase in yield. A K_y factor larger than 1 matches with a section b with a steep slope and is a characteristic of the stress sensitive crops. An increase in ET within the range of section b results in a strong increase in yield. From Doorenbos and Kassam (1979) it is known that the linear section b generally has a lower ET limit of around 50 % relative ET , although this limit has not been defined for all crops.
- Section c: Once the relative ET is close to 1, the WP often decreases. The proportional gain in yield per unit increase in ET becomes gradually lower towards the upper limit of 100 % relative ET . This is observed for a lot of crops and the section c is sometimes rather stretched as for alfalfa or sugar beat (Doorenbos and

Kassam, 1979), wheat (Kang et al., 2002; Erdem et al., 2006; Sun et al., 2006) or cotton (Henggeler et al., 2002; Kanber et al., 2006; DeTar, 2007). For other crops such as maize, section c is almost absent (Kipkorir et al., 2002; Farré and Faci, 2006; Payero et al., 2006). Section c can be regarded as an inefficient section of the CWP function.

When the CWP function is expressed in terms of the amount of water applied by rainfall or irrigation, the function has a more pronounced S shaped curve (Fig. 1) and an additional section has to be considered:

- Section d: Applying more water than required by crop evapotranspiration, will not result in any increase in yield since the additionally supplied water is lost as (unproductive) soil evaporation and/or deep percolation. If too much water is applied, the yield might even drop as a result of nutrient leaching out of the root zone or as a result of water logging.

From Fig. 1 the following conclusions can be drawn with regard to maximizing the crop water productivity:

- In section a, applying irrigation water is always required if rainfall is insufficient. It guarantees the survival of the crop in the season;
- In the linear section b, the usefulness of applying irrigation water depends on the slope. The stronger the slope, the more the supply of irrigation water becomes beneficial in terms of water productivity. If the slope is weak, irrigation water can be saved since the decline in yield is small;
- In section c (if present) applying less irrigation water is always beneficial. This will increase the seasonal water productivity;
- In section d, applying irrigation water is generally not required, unless the root zone needs to be leached for salinity control.

If water shortage (resulting in a relative ET less than 1) is nicely distributed all over the crop season, the yield decline as a result of drought stress can be derived from the seasonal relative ET (Fig. 1 is for this case a seasonal function). However for a lot of crops, the drought tolerance varies strongly between growth stages. For these cases the CWP functions for the individual growth stages will differ in shape from the seasonal CWP function. In drought sensitive stages (often flowering and fruit setting) the slope in section b

is steep, while in drought tolerant stages (generally the vegetative stages and the late ripening period) the slope is mild.

DEFICIT IRRIGATION: DELIBERATELY PROVOKING WATER STRESS

Deficit irrigation (DI) is an optimization strategy in which irrigation water is applied during drought sensitive growth stages of a crop. Outside these periods, irrigation is limited or can even be absent if rainfall guarantees a minimum supply of water. The periods with water shortage are restricted to drought tolerant phenological stages, often the vegetative stages and the late ripening period. The total irrigation application is hence not proportional to the irrigation water requirement throughout the crop cycle. Because crop water requirements are not fully covered throughout the crop cycle, this inevitably results in plant water stress and consequently in production loss. However, although a certain yield reduction is tolerated, the productivity of water, which is the restrictive factor, is maximized by deficit irrigation (Rockström et al., 2003; Oweis et al., 2006). In this way, DI aims at obtaining maximum WP and at stabilizing yields rather than at obtaining maximum yields (Zhang and Oweis, 1999).

In literature, both the terms supplemental irrigation and deficit irrigation (DI) are used. The first term generally refers to a rainfed crop that receives additional irrigation during the whole season or specific sensitive growth stages, whereas DI refers mostly to crops that are normally fully irrigated but from which water is withheld during certain tolerant growth stages. Both names are nevertheless used conjunctively and may cause confusion. Due to ambiguities in their definitions, “deficit irrigation” is used as the only denomination throughout this review.

Since drought tolerance varies considerably by genotype and phenological stage, DI requires a precise knowledge of the crop response to water stress for each of the growth stages (Kirda et al., 1999; Ragab, 1996; Varlev et al., 1996). In addition, an adequate knowledge of the economic impact of yield reduction as a result of water stress is required for the correct application of DI (English et al., 1990; English and Raja, 1996; Sepaskhah and Akbari, 2005; Sepaskhah et al., 2006). In areas where water is the most restrictive factor, maximizing WP can be economically more profitable for the

farmer than maximizing yields. A combination of CWP functions (and revenue functions having the same shape) and cost functions (linear) can be used to derive the optimum water use and the range of water use in which the DI practice would be more profitable than full irrigation (FI) (English, 1990). Appropriate irrigation schedules for DI can be derived on the basis of extensive field trials (e.g. Oweis et al., 1998) or validated simulation models (e.g. Zairi, et al., 2000; Kipkorir et al., 2001; Lobell and Ortiz-Monasterio, 2006; Benli et al., 2007; Heng et al., 2007; Lorite et al., 2007).

Water saved by DI can be used to irrigate more land (on the same farm or on land of the water user's community). This often compensates largely for the economic loss due to yield reduction due to the high opportunity cost of water (Kipkorir et al., 2001; Ali et al., 2007). Even water transfers from water rich to water poor areas are possible as demonstrated recently in California by using DI for alfalfa (Hanson et al., 2007). In general, DI requires a far more integrated vision on water policy in agriculture.

FIELD EXPERIENCES WITH DEFICIT IRRIGATION OF DIFFERENT CROPS

In recent years, a lot of experience was gained on the determination of optimal DI strategies for common (e.g. Zhang, 2003) and less utilized (e.g. Fabeiro et al., 2003) or horticultural (e.g. Fabeiro et al., 2002) crops, supposing water is the limiting factor. In evaluating such research, the reader could follow the guidelines of the general framework of Fig. 1 to assess the results of different authors regarding the usefulness of applying DI in stead of rainfed cultivation and/or in stead of full irrigation in a certain location for a certain crop. In a lot of cases DI is beneficial as compared to rainfed cultivation, or its positive effect depends on how much rain is available to fulfill the necessary minimum ET for a certain crop and the behavior of the CWP function for small amounts of ET. Only in a few cases, DI is not better than FI from an agronomic point of view of producing "more crop per drop".

Recent findings confirm that DI of wheat can result in increasing WP without causing extreme yield reductions. In a four year field study (1998-2002) on winter wheat in Turkey, it was proven that well-planned irrigation caused a yield increase of 65 %, com-

pared to rain-fed crops, and doubled WP in comparison with the rainfed and fully-irrigated crops (Ilbeyi et al., 2006). The positive effect of DI on the WP of wheat was confirmed in other experiments in Turkey (Yazar and Sezen, 2006), in China in the Loess plateau region (Kang et al., 2002), in Syria (Zhang and Oweis, 1999; Oweis and Hachum, 2003) and in Bangladesh (Ali et al., 2007). The latter authors report that DI caused an average increase in yield of 1.6 Mg ha⁻¹ over the different experimental years in comparison with the rainfed treatments. From a pure WP point of view, DI is not always worthwhile to apply, as can be explained from the general shape of the CWP function. Kar et al. (2006), mention for example that highest WP was reached for the highest irrigation levels for maize, groundnut, sunflower and potato. This was confirmed for sweet corn by Oktem et al. (2003).

As a case study, results of experiments on DI of the under-utilized crop quinoa, conducted during the last 4 years in the Bolivian highlands are presented (Fig. 2.). From controlled experiments, the establishment, flowering and early grain filling stage of quinoa came out as the stages the most sensitive to drought stress (Garcia, 2003; Geerts et al., 2006a). Following regional guidelines of Geerts et al. (2006b) on the potential benefit of DI in quinoa in Bolivia, field experiments were conducted in the Central (semi-arid) and Southern (arid) Bolivian Altiplano. During the growing seasons 2005-2006 and 2006-2007, the water productivity of quinoa under rain fed cultivation, DI and FI was assessed. The DI strategy was also optimized by testing the additional advantage of pre-flowering irrigation and by only applying additional irrigation during the establishment stage of the crop. It was found that by applying DI, quinoa yields in semi-arid regions can be stabilized at 1.6 Mg ha⁻¹ with excellent grain size (Geerts et al., 2008a) (Fig. 2). This can be achieved by applying only half of the irrigation water required for FI. Irrigation only needs to be applied during plant establishment, flowering and grain filling. Geerts et al. (2008b) point out that in the very arid regions such as the Southern Bolivian Altiplano, more boundary conditions appear for the DI of quinoa: seasonal crop water requirements need to be covered by at least 55% to guarantee a significant beneficial effect of DI and due attention should be paid to the risk of salinization. As additional beneficial effect of DI for quinoa, the farmer has a better

control on the timing of flowering and harvest, allowing a better planning of agricultural activities throughout the season (Geerts, S., 2008; unpublished data).

DISCUSSION

ADVANTAGES OF DEFICIT IRRIGATION

The correct application of DI for a certain crop:

- causes a maximization of the productivity of water without reduction in harvest quality;
- allows better economic planning and stable income for the farmer due to a stabilization of the harvest;
- creates a less humid environment for the crop, decreasing the risk of certain diseases (e.g. fungi);
- reduces the loss of nutrients due to a reduction in leaching of the root zone, which results in a better quality of the ground water table (Ünlü et al., 2006, and a lower need for fertilizer application on the field;

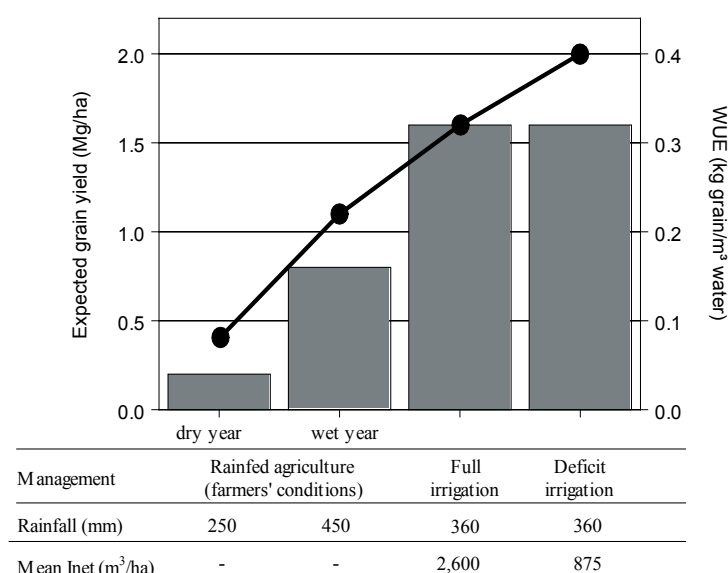


Figure 2. Expected grain yield and water productivity (WUE) for quinoa in the Bolivian Altiplano under different water management conditions (source: Geerts et al., 2008a)

- allows controlling the sowing date by irrigation and therefore the planning of agricultural practices (Oweis and Hachum, 2001);
- allows a better control of the length of the cropping cycle as under rainfed cultivation.

CONSTRAINTS FOR THE SUCCESSFUL APPLICATION OF DEFICIT IRRIGATION

Apart from all the advantages, DI requires:

- a precise knowledge of the crop response to water stress (Kirda, 2002). An economic risk is related to the optimal irrigation applications, for CWP functions with a steep optimum WP , occurring over a small optimum range of ET . As the plateau of this curve is often rather large, the risk should not be exaggerated (English, 1990; English and Raja, 1996; Zhang, 2003);
- that irrigators have free and full access to irrigation water in the crop's sensitive growing phases. This is not always the case in large block designs (Zhang, 2003);
- that a certain minimum quantity of irrigation water can always be applied (Geerts et al., 2008b; Kang et al., 2002; Zhang and Oweis, 1999). This is not always possible in extremely dry regions with low availability of irrigation water.

Additionally, DI can only be successful if:

- the small scale farmer considers the larger benefit for the total water users community, when facing a below maximum yield;
- actions are taken to avoid the risk of salinization as a result of insufficient leaching of the rootzone when irrigating with poor quality water (Ragab, 1996; Sarwar and Bastiaanssen, 2001; Kaman et al., 2006; Geerts et al., 2008b)

CONCLUSION

As shown in this conceptual review on the agronomic principles of deficit irrigation, a lot of field experiments were already conducted with deficit irrigation of common and less utilized crops. The shape of the relation between crop evapotranspiration and yield is proposed as a general framework for the evaluation of the drought sensitivity of a certain crop or growth stage. Although these crop water production functions vary per crop, and often per genotype and location, they give an idea about the agronomic usefulness of applying deficit irrigation in a specific situation.

Considering water as the limiting factor in agriculture in the future, its productivity becomes the general issue. In this way, it is clear that in water poor regions of the world, deficit irrigation will be a very important strategy of agricultural water management in the future. Sustainable dry-land agriculture on basis of deficit irrigation maximizes the output of each drop of water and is a way to prevent dry regions from being abandoned.

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PRACTICALITIES OF PARTICIPATION: COMPARISON OF INSTITUTIONAL CONDITIONS FOR PARTICIPATORY SOIL AND WATER CONSERVATION RESEARCH BETWEEN CHINA AND BOTSWANA

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INTRODUCTION

In the past two decades increased emphasis has been put on participatory methods to be used in projects focussed on agricultural research for development and natural resource management. Multiple theories on participation have been established and a range of approaches are being used at grassroots level to increase involvement of rural inhabitants. The idea is that research has more relevance when the main beneficiaries of the research participate within the whole process (Sutherland, 1998). A move was made from a supply to a more demand driven research agenda. Nowadays, most funding agencies within the development arena insist on stakeholder participation as a prerequisite for obtaining funding. It is safe to say that “stakeholder participation” is the mode of the day. However, there is also a large stream of literature that criticizes present-day participation. Often keywords like “participation” and “empowerment” are used to legitimise interventions and appropriation of nice-sounding words is used to dress up “business as usual” (Cornwall and Brock, 2005). The question then is to what extent “stakeholder participation” is also the practice of the day?

This paper reflects field research conducted in China and Botswana within the framework of DESIRE, a global EU initiative to combat desertification which started in 2006. Two study site teams (SST) from the two countries were analyzed using the SWOT analysis tool. Within this short paper, the reader will get acquainted with

these two SSTs and how they attempt to adopt a participatory approach within the project. Through the analysis it will become clear that doing so is easier said than done.

DESIRE PROGRAM

DESIRE stands for 'desertification, mitigation and remediation of land'. It is a global initiative which is reflected by its 28 partners from 18 'hotspots' from around the globe (see Fig. 1).

The DESIRE project attempts to establish promising alternative land use and management strategies based on close collaboration of scientists with local stakeholder groups (DESIRE 2008).

THE RESEARCH

This study covers the two SSTs from China and Botswana and was executed in 2007. The objective was to gain insight in the practicalities in using stakeholder participatory approaches as required by the DESIRE program that started February 2007. An outline of both teams is presented in Table 1.

Upon arriving at the study sites, the project activities had not yet started. Only few preparations had been made so far. To solve

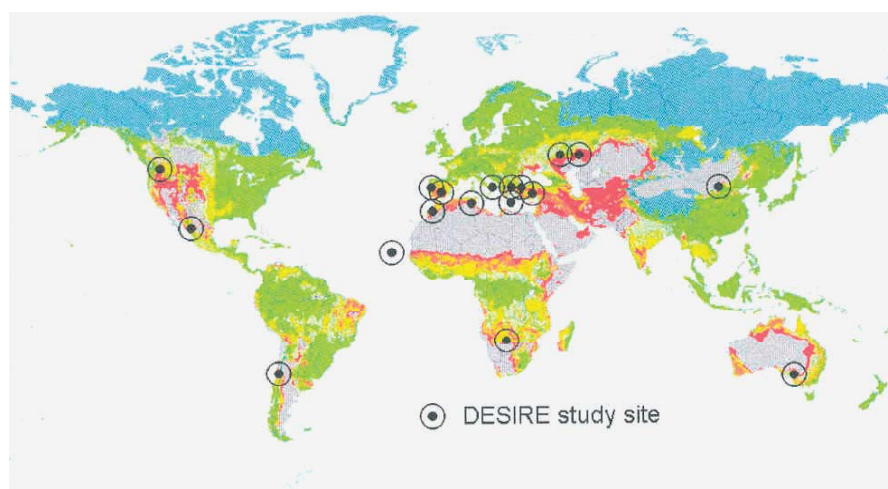


Figure 1. Map of the 18 DESIRE 'hotspots' / study sites; source: http://www.desire-project.eu/index.php?option=com_content&task=view&id=15&Itemid=34

Table I. Outline of the two research teams from China and Botswana

	China team	Botswana team
Institution	Institute for Soil and Water Conservation (ISWC)	University of Botswana (UB)
Place	Yangling	Gaborone
Composition	Members mainly specialized in physical aspects of land	Multidisciplinary team
No. of members	6	6
Time for project	1/3	1/3

this issue, in China workshops were prepared for the DESIRE team which focused on potential stakeholders. Observing the team during these workshops provided insight in both the internal strengths and weaknesses and external opportunities and threats for using a stakeholder participatory approach. In Botswana the main focus was on the external environment whereby a household survey was conducted. To gain insight in possible internal strengths and weaknesses, a questionnaire was handed out to all the team members. The study findings were discussed with the team members either during feedback sessions or through the e-mail.

SWOT ANALYSIS

The SWOT analysis tool was used to analyze the collected, mainly qualitative data. SWOT is the abbreviation of Strengths, Weaknesses, Opportunities and Threats. The model dates back to the 1960's when it was created by Andrews and his colleagues as core of the emerging 'design' school (Learned et al., 1965, in Mintzberg et al., 1998). The main idea behind the SWOT analysis tool is that it assists in the generation of strategic options and addresses their suitability from knowledge of an organisations strategic position. The SWOT analysis itself consists of a defined list of internal strengths and weaknesses and external opportunities and threats of an organisation. The main assumption of the strategy is that its success is determined by the relation between the positive and negative attributes of an organisation in relation to its external environment.

Through the use of the TOWS matrix (see Fig. 2), options can be identified that address a different combination of the internal factors (strengths & weaknesses) and the external factors (opportunities &

Internal External	Strengths	Weaknesses
	SO	WO
Threats	ST	WT

Figure 2. TOWS matrix

threats). Before conducting such an analysis and developing strategic options, it is essential that one understands the organisations environment and its resource capacities (Johnson et al., 2005).

The SWOT analysis process consists of three main steps. Table 2 presents these steps in a chronological order.

As stated in Table 2, the last step is to design a list of strategic action plans. Four different strategies can be identified by combining the internal and external factors: these are SO, WO, ST and WT strategy. Table 3 presents an outline of the four strategies.

Table 2. Steps to be taken using the SWOT analysis tool

Steps	Action
1	A list should be made of maximum five internal strengths and weaknesses;
2	A list should be made of maximum five external opportunities and threats; These are potential future strengths, respectively weaknesses for the team
3	Design a list of strategic action plans using data obtained in step 1 and 2

Table 3. Outline of the four strategies

Strategy	Action
SO	A maximum of three options are generated whereby strengths are used to take advantage of opportunities
WO	A maximum of three options are generated whereby advantage is taken over opportunities to overcome weaknesses
ST	A maximum of three options are generated whereby strengths are used to avoid threats
WT	A maximum of three options are generated whereby weaknesses are minimized and threats avoided

MAIN RESULTS

For the research five strengths, weaknesses, opportunities and threats were identified. However, for this brief paper only two of these are presented that illustrate best the different dimensions and factors that influence the practical application of a participatory approach. The identified strategic action plans will not be dealt with in this paper because it is of less relevance for the main conclusions. In the following the main findings within the two countries are listed.

CHINA:

Strengths (within the DESIRE-SST)

Past experience: as the ISWC has done an extensive amount of research in the Yanhe watershed, a lot of data is already available and a number of stakeholders in the area are acquainted with members of the SST.

Flexibility: the working hours at the ISWC are flexible and working in the weekend is common. This makes that the research team can adapt to the time schedules of farmers, which are uncertain and weather dependent. The adaptation of the team to the farmers' time schedule potentially increases farmers' attendance during participatory activities.

Weaknesses (within the DESIRE-SST)

Interdisciplinary: the study-site-team consisting of six members are specialized in the fields of; impact assessment of erosion and soil and water conservation, land use and land management, soil erosion modelling, vegetation restoration, forestry and ecology, remote sensing, geo-information systems and data management. Missing in this list of specializations are experts in the fields of the social and economic sciences who are crucial for conducting integrated stakeholder participatory research.

Ownership: all members of the SST are occupied with many other activities next to the DESIRE program. The team has not yet had the time to develop a full sense of ownership for the DESIRE program.

Opportunities (outside the DESIRE-SST)

Governmental will: there are numerous past attempts by the government to remediate desertification effects in the Loess Plateau. One of the methods used is the introduction of local soil and water conservation laws, rules and regulations that communities must abide to. These rules and regulations were made according to research results and public needs. Secondly, the government makes a lot of investments in the area.

Public concern: an increasing public concern on environmental degradation can be recognised within the younger generations. According to the SST there was a strong link between this increase in concern and increase in living standards of the Chinese. Next to increased awareness, it is also recognised that many more private investments are being made for the sake of the environment.

Threats (outside the DESIRE-SST)

Loss of labour: the 21st century has shown a shift towards increasing migration to the urban area, mainly by the youth. This has resulted in a vital loss of manpower and local knowledge within the rural areas. Often, however, young men also cannot earn enough in the cities creating many psychological problems and the increased distance between parents and their children creates emotional burdens.

Dependency: as the government finances most of the rural projects that focuses on remediation of degraded lands, the continuation of these projects has become highly dependent on these inputs. Although external incentives like 'grain for green' have shown to be very effective, many examples of farmers who suddenly were unwilling and/or unable to maintain the introduced measures when the 'tap was closed' can be seen in recent reports (WOCAT, 2003).

BOTSWANA:

Strengths (within the DESIRE-SST)

Interdisciplinary: the SST consists of a mix of the soft and hard sciences, integrating social, economic and natural sciences.

Past experience: the choice of the study site is based upon the idea that the DESIRE research will build on previous research done in the same area. As such, the team has experience with and knowledge on the area.

Weaknesses (within the DESIRE-SST)

Flexibility: most of the SST members have fixed working hours at the University of Botswana.

Ownership: the members of the SST are occupied with other activities next to the DESIRE program. The team has not yet had the time to develop a full sense of ownership for the DESIRE program.

Opportunities (outside the DESIRE-SST)

Local institutions: multiple local institutions exist within the study site that can assist in activities related to environmental rehabilitation.

Government will: launched in 2007, the National Action Program to Combat Desertification indicates that the Botswana government acknowledges the desertification threat and is willing to invest in actions to sustain the environment.

Threats (outside the DESIRE-SST)

Absence of key stakeholders (knowledge drain): firstly, information concerning livestock keeping and its impacts on the environment lies mainly within the hands of the men who are difficult to reach because they live outside the villages for most of the time. Secondly, HIV/AIDS has its toll on those within the working class who make up a significant part of knowledgeable stakeholders. Thirdly, the younger generations are reluctant to stay in the study site. Although those coming back are willing to participate, they are less knowledgeable on the natural resources.

Fatalistic dependency: although respondents mention they are willing to participate, few take on the responsibility for their lives and their environment due to an existing dependency upon government support and a strong reliance on (religious) fate.

DISCUSSION

Considering the two study-site-teams and their internal strengths and weaknesses, both similarities and differences can be identified. Looking at the similarities, both teams had past experiences within the study-sites. Here this is analyzed as a strength whereby knowledge can be built on these past experiences. One must be careful however in concluding that past experience is always a strength. In another case this may be analyzed as a weakness when the relation

between a team and local stakeholders is worsened due to past experiences. The second similarity was the point made on ownership. Only one-third of the members' time can be spent on the DESIRE project. As other activities required their attention, both teams have not yet had enough time to develop a full sense of ownership for the project.

Differences can be identified when analyzing flexibility and interdisciplinary. First of all, in the China case, the flexibility of the team in terms of their working hours and possibilities for long term field visits is a strong point. This same point is analyzed as weakness of the Botswana team. On the other hand, the Botswana SST consisted of members from both the Beta and the Gamma disciplines while the China team mainly consisted of Beta specialised members. Analyzing this difference, a certain degree of logic can be observed which can be brought in relation to the different types of institutions in which the two teams operate; whereas the SST in China falls within the framework of a research institute, the SST in Botswana falls within the framework of a university. The members of the China team are mainly responsible for increasing the knowledge base while members of the Botswana team also have a responsibility towards their students. This latter responsibility results in a decrease in flexibility. As for the difference in interdisciplinary of the two teams, while the University of Botswana teaches multiple disciplines, the ISWC mainly focuses on the physical aspects of land management.

As for the external environment, whereas one might expect large differences between these two local settings seeing as they are literally worlds apart, interesting similarities could be identified. In both countries, the government recognizes the importance of the participation of local stakeholders within policy making. However, the main constraint is the lack of capacity to undertake actions to do so. Nevertheless, government will is present which can be analyzed as an opportunity. Another similarity is the government dependency which in Botswana partly resulted in a kind of fatalistic dependency among local stakeholders. This was analyzed as threat, as was the migration issue. In both countries, mainly the young migrated to urban areas to find work.

A key difference between the two study sites was the presence of local institutions. Whereas in Botswana multiple committees were

present to assist in future activities within DESIRE, in China only government officials are available to assist in the execution of activities.

CONCLUSIONS

Comparing the two research cases from China and Botswana, some interesting differences but even more interesting similarities could be analyzed in terms of strengths, weaknesses, opportunities and threats for using stakeholder participatory approaches. This paper has shown how institutional conditions affect the ability of a research team to adopt such approaches and how the complex environment in which stakeholders live affects their ability and willingness to participate. Research for development initiatives around the world attempt to adopt participatory approaches as we speak. This paper has shown that doing so is easier said than done.

RECOMMENDATIONS

To say that a participatory approach will be adopted is one thing, to actually do it is another. Before the planning stage it is thus important for a research team to be self-critical and first analyze ones own strengths and weaknesses in actually adopting a participatory approach. Once this insight is created, actions can be planned to 'fill the gaps' where necessary.

Secondly, from field experience in Botswana, it was interesting to see how team members originating from Botswana sought solutions in line with local developments while foreign members saw local developments as part of the complex desertification problem and sought solutions in line with new developments like tourism. From this experience it is advised not to romanticize local solutions but to also consider alternative solutions.

Lastly, using the term 'project' indirectly assumes that it has a beginning and an end. Past experiences have shown however that, more than often when projects focused on soil and water conservation come to an end, within a few years conservation activities are no longer adopted by local farmers. It is thus important to incorporate policies during the project that deal with follow-up issues. Maybe even do away with the term 'project' and rather speak in terms of 'programs' that combine desertification mitigation with opportunities to improve the local livelihood.

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GREEN BELT OF NOUAKCHOTT - REHABILITATION AND EXTENSION SUPPORT PROJECT

PH. BLEROT, CH. BERTE AND G. COSTER

The Walloon Region of Belgium – the Government of Mauritania
– FAO – PAM

PROJECT'S BACKGROUND

Given the persistent problem of the capital's infrastructure's invasion by sand, the first reforestation work around Nouakchott began in 1975 with the help of an international NGO, the Lutheran World Federation (LWF), and continued until 1992. All in all, close to 1,270 hectares were stabilised and afforested mainly with *Prosopis juliflora*, *Euphorbia balsamifera*, *Leptadenia pyrotechnica*, *Acacia senegal*, and *Balanites aegyptiaca*, and seeded with grasses such as *Aristida pungens* and *Panicum turgidum*.

Unfortunately, the initial site selection for this green barrier around Nouakchott did not take account of the population's rapid growth – the population is currently approaching one million – and the considerable pressure that has been exerted on the urban and peri-urban areas over the past thirty years.

Based on this assessment and in order to kick off a realistic plantation rehabilitation and extension process that would be better planned and integrated in the development dynamics of the capital and its outlying neighbourhoods, in 1999 the Government of the Islamic Republic of Mauritania requested, with the help of His Royal Highness Prince Laurent of Belgium, assistance from the Government of the Walloon Region of Belgium to participate in this programme to protect Nouakchott's socio-economic infrastructure from the encroaching sands. This support took the shape of the Nouakchott green belt rehabilitation and extension support project (*Appui*

à la réhabilitation et à l'extension de la ceinture verte de Nouakchott - GCPR/MAU/022/BEL), which ran from February 2000 to the end of December 2007.

Over this period, the Government of the Walloon Region's contribution totalled US\$ 1,628,600 and the project's execution was entrusted to the United Nations' Food and Agriculture Organization (FAO). The World Food Program was in charge of the food-for-work family rations that were given to the field personnel.

PROJECT'S OBJECTIVES

DEVELOPMENT OBJECTIVE

To step up the fight against the encroaching sands by protecting Nouakchott's socio-economic infrastructure whilst ensuring the permanence, expansion, and sustainable management of the capital's urban and peri-urban settlements with the participation of co-operatives, associations, NGOs, and workers' and trade organizations in close co-operation with the administrative, municipal, and technical authorities.

IMMEDIATE OBJECTIVES

As defined in the project document, these objectives were:

- to guarantee the continuity and renewal of the tree cover already set up;
- to prepare, organize, and maintain the participation of the population and authorities in order to safeguard, maintain, and extend the forest plantations;
- to design medium- and long-term urban and peri-urban forestry programmes for the city of Nouakchott; and
- to adapt and test coastal dune fixation schemes on a small scale.

RESULTS OF THE WORK DONE TO DATE

SURVEY OF THE FOREST AND TRUCK GARDEN AREAS IN THE PROJECT'S AREA OF INTERVENTION

The project surveyed and mapped the existing forest areas: 1,270 hectares at Toujounine, Dar Naim, and Tavragh-Zeina, plus their extension during the 2000 to 2007 planting seasons, i.e., 800 hectares at Toujounine, 7 hectares along the coastal sand ridge at Nouakchott, and 50 hectares in Trarza Region (30 at Tiguint and

20 at Tendghaidsat). The main truck garden areas, that is, 150 hectares on the edge of the capital, were also surveyed and mapped.

To protect the tree plantings done in Nouakchott's green belt and given their importance in protecting and safeguarding the city's socio-economic infrastructure from the encroaching sand and the physical and financial efforts made by the Mauritanian government and development partners to carry them out, all of the reforestation areas located in and around the capital were integrated by decree in the city of Nouakchott's 2000-2010 and 2010-2020 urbanisation plans.

METEOROLOGICAL DATA PROCESSING

– Nouakchott airport weather station

This station is located some five kilometres from the Toujounine site. The weather data (temperature, precipitation, relative humidity, evaporation, hours of sunshine, and wind speed readings) were collected from 1946 to 2007, for a 62-year observation period, and computerised.

– Tiguint weather station, Trarza Region

The precipitation readings and number of days of rain began in 2002, which was the year that the project began working at Tiguint and Tendghaidsat in Trarza Region.

TREE NURSERIES

A. TEN SOUEILIM NURSERY, DAR NAIM DEPARTMENT, NOUAKCHOTT DISTRICT

Emphasis was placed throughout the project on constant practical training of the staff and the production of healthy sets with good ligneous development and orthotropic root systems with an abundance of secondary roots.

The propagation methods were direct sowing in polyethylene bags (25 x 12.5 cm when flat for a volume of 1,256 cm³), bagged cuttings, and, experimentally, bare-root seedlings in bench terraces 10 metres long, 1.5 metre wide, and 0.30 metre high.

For the 2000 and 2000 to 2007 growing years, the total output stood at 401,200 sets, for an annual mean of 57,315 sets, mainly of *Prosopis juliflora*, *Acacia raddiana*, *Acacia senegal*, *Leptadenia py-*

rotechnica, *Aristida pungens*, *Panicum turgidum*, *Nitraria retusa*, and *Tamarix aphylla*.

Of this total, 50,000 sets were selected and distributed in the course of various national reforestation events such as *Tree Week* and the *World Day to Combat Desertification*, as well as to national NGOs and local communities.

B. TENDGHAIDSAT, NURSERY, TRARZA REGION

The area's rural community set up this nursery in 2006 with the help of and monitoring by the project's technicians.

It produced 22,750 sets in the 2006 and 2007 growing years. The species were the same as for the Ten Soueilim nursery.

MECHANICAL STABILISATION OF DUNES

The entire intervention site at Toujounine, that is, 1,225 hectares, of which 800 had been set up by the GCPR/MAU/022/BEL project and 425 by the WLF project, was surveyed and mapped at the scale of 1/40,000. The same was done for the coastal dune site – 7 hectares – at Nouakchott and for the sites in Trarza Region, that is, 30 hectares at Tiguint and 20 hectares at Tendghaidsat.

The criss-crossing wattles technique was chosen for these four sites, given the complex dune model. On average, 250-300 linear metres of fencing (perimeter fences and fences against the counter-dunes running perpendicular to the prevailing wind direction) and internal wattles were laid down per hectare.

The project opted to use unwoven branches of *leptadenia* and mainly *prosopis* as the stabilising materials.

This material was put down on the previously staked installation site in the form of a hedge in a trench. This barrier has 30-40% permeability, enabling it to slow down the wind speeds and avoid whirlwind formation. The fences erected in this way were 1 to 1.25 metre high.

For this activity, two to three 20-man teams (1 team foreman and 19 workers) a day cut, transported, and set up the fences of vegetation. Each man placed 6 to 8 metres of fencing per day, depending on the distance from the supply point.

Mechanical stabilisation work by site for the run of the project is given in Table 1.

Table I. Mechanical stabilisation work by site for the run of the GCPR/MAU/022/BEL project

Sites	Toujounine Continental dunes	Tiguint	Tendghaidsat	Nouakchott Coastal dunes	Total
Acreage (ha.)	800	30	20	7	857
Perimeter and counter-dune fences (l.m.)	108,474	2,350	2,700	1,625	115,149
Wattles (l.m.)	108,250	605	0	300	109,155
Total (l.m.)	216,724	2,955	2,700	1,925	224,304
Maintenance (l.m.)	9,925	100	0	3,840	13,865

l.m = linear metres of fencing

BIOLOGICAL FIXATION OF DUNES

Once the dunes were stabilised, it became possible to anchor them definitively by establishing trees and perennial grasses on and around them.

On the continental dunes, *Prosopis juliflora* (the only ligneous species to have given good results in practice on this type of terrain to date) and *Aristida pungens* were set up on the highly mobile dune ridges. The deflationary areas were planted with *Leptadenia pyrotechnica*, *Aristida pungens*, and *Panicum turgidum*. The other woody species – mainly *Acacia raddiana* and *Acacia senegal* – were set up in the more stable areas. When it comes to the sowing methods, broad casting (local herbaceous species) and dibbling (*Colocynthus vulgaris*, a Cucurbitaceae) were tested beginning in 2006, but the take rate depends on rainfall.

Halophytic woody species such as *Nitraria retusa*, *Tamarix aphylla*, and *Tamarix senegalensis* were planted on the coastal dunes.

During the 2000, 2002, and 2003 plantings, the planting interval for the woody and herbaceous species was 5 x 5 metres in a square arrangement (for a planting density of 400 sets per hectare). To boost the grass cover's development and avoid competition between trees in this low-rainfall ecosystem, the planting interval for all these species was increased to 7 x 7 metres in a staggered arrangement (density of 235 sets per hectare) in 2004 and 2005 and

10 x 10 metres, also staggered (density of 115 sets per hectare), in 2006 and 2007. The last density was, however, increased on highly mobile dunes.

The individual sets of each woody and herbaceous species for transplanting in the field were selected at the nursery. The bags were removed at the time of planting, recovered, and destroyed.

When rainfall was insufficient, which was often the case in the course of the various growing years, each set was given 20 to 30 litres of water at the time of planting in order to allow the root system to reach the soil's layer of residual humidity more quickly.

Overplanting was done each year in the areas of high mortality.

The 35% mortality rate observed for the woody species is explained by the rather unfavourable climatic conditions that marked the 2002, 2003, 2004, and 2007 growing seasons, with rainfall below 50 mm and desiccating sand-laden winds from December to the end of April.

Major natural regeneration of the grass cover involving mainly *Aristida pungens*, *Panicum turgidum*, *Cyperus rotundus*, *Elionorus elegans* and *Eragrostis* sp. was observed over the entire Toujounine and Tiguint sites two years after the project activities began. This development is worth pointing out as it had not occurred previously.

Planting and overplanting statistics by site for the run of the project are given in Table 2.

A total of 220,205 sets (75% of the programme's total) were planted in the four areas of the project's intervention in 2000 and 2002-2007.

From 2002 to 2007 these areas were overplanted with 72,650 sets (25% of the project's total).

Table 2. Planting and overplanting statistics by site for the run of the GCPR/MAU/022/BEL project

Site	Toujounine	Coastal dunes	Tiguint	Tendghaid-sat	Total
Acreage (ha)	800	7	30	20	857
Number of sets					
1st plantings	194,730	2,375	9,200	13,900	220,205
Fill plantings	55,330	5,120	9,800	2,400	72,650
Total	250,060	7,495	19,000	16,300	292,855

To ensure the permanence of the existing forest engineering works and their extensions, the project regularly held meetings and field visits with the local authorities, technical departments of the Ministry of Rural Development and Environment (MDRE), next with the State Secretariat of the Environment (SEE), and finally with the Ministry of the Environment (now under the name of *Ministère Délégué à l'Environnement auprès du Premier Ministre de l'Environnement* (MDAPMCE)), as well as with the localities and communities directly affected by the encroaching sands north-east of Nouakchott at Toujounine and Dar Naim and at Tiguint and Tendghaidsat in Trarza Region.

DEVELOPMENT OF THE FOREST STANDS IN NOUAKCHOTT'S GREEN BELT

The main aim of the reforestation work done around Nouakchott by the WLF from 1975 to 1992 and by project GCPR/MAU/022/BEL from 2000 to 2007 was to stabilise and fix by biological means the dunes that threatened the capital's socio-economic infrastructure.

The aim of improvements made in these stands was to regulate their use to maintain the beneficial effects of the curative control measures, especially those of the dunes' fixation, whilst preserving in a sustainable way the forest resources that had been set up.

In the case of Nouakchott's green belt, a simple engineering and management plan for the planted sites had been developed from the project's very beginning. The activities in the stands of *Prosopis juliflora* that had grown to maturity at Toujounine and Dar Naim were considered to be conventional silvicultural operations, i.e., maintenance cutting, thinning, and sanitation cutting.

The logging work done in these stands primarily made it possible to:

- gather and place the plant material necessary to set up the fences (perimeter and counter-dune fences) and internal wattles on the current site (800 hectares) of Toujounine and the coastal dune site (7 hectares) at Nouakchott; and
- harvest poles.

A total of six observation plots were worked in 2003, four at Tou-

jounine and two at Dar Naim. Each plot covered an area of 2,500 m². The harvesting operation consisted in pruning from each *prosopis* all of the poles to a height of 1.5 m. As most of the trees produced an abundance of new shoots, this technique was selected for use in all of the workable stands.

That same year, a 2,500 m² plot of 12-year-old *Prosopis juliflora* at Toujounine was clear-cut in order to estimate the annual production per hectare. This production figure stood at 766 kg ha⁻¹ year⁻¹ for timber that was intended mainly for use as firewood and to obtain poles. The clear-cutting technique was abandoned since not a single stump on the entire plot gave off new shoots.

RETRAINING THE TECHNICIANS AND GIVING BASIC TRAINING TO THE WORKSITE PERSONNEL

Two technicians who had been assigned to the project in 2002 were given intensive practical training by the national co-ordinator and co-ordinator of the work regarding the various facets of combating the drifting sands and utilisation of pastoral and forestry options as well as the production of sets, mechanical dune stabilisation, and biological dune stabilisation techniques. These technicians then trained and guided the worksite personnel and wardens in charge of protecting the forest sites in turn.

CONTACTS AND PROJECT SUPPORT ACTIVITIES

From the time of its launch in February 2000, the project carried out a policy of working with the national institutions (MDRE, DEAR, Nouakchott and Trarza Regional Delegations of the MDRE from 2000 to June 2006; SSE and its Nouakchott and Trarza Regional Offices from July 2006 to March 2007; and MDE as of April 2007), national NGOs, i.e., mainly CANPE (friends of nature and the environment) and Nedwa (communications for educational development), AMBSEM (*Association mauritanienne pour le bien-être et le secours de l'enfant et de la mère* – Mauritanian association for child and maternal welfare and relief) and ADD (*Association pour le développement durable – sustainable development*), international NGOs WLF and OSS (Sahara and Sahel Observatory), United Nations agencies such as UNDP, FAO, WFP, and UNFPA; and the projects directly concerned by desertification control and environmental protection,

conservation, and sustainable management, i.e., Oasis Development Project, Community Rural Development Programme, livestock development projects, and Programme of Integrated Development of Irrigated Agriculture in Mauritania).

GENERAL CONCLUSIONS

Despite rather unfavourable climatic conditions and limited manpower and logistic means, the outcome of the Nouakchott green belt rehabilitation and extension support project is considered to be very positive.

The project made it possible to retrigger the process of extending the green belt around the capital and rehabilitate the existing forest stands using appropriate, reliable techniques that Mauritania's technical services and urban, peri-urban, and rural populations could easily adopt. The same thing was achieved at Tiguint and Tendghaidsat in Trarza Region. As for the coastal dune site, the sand's movement was quickly controlled through mechanical stabilisation work and the formation of a major counter-dune to raise and add substance to the coastal sand ridge fronting the ocean.

In line with its objectives, the project made it possible to produce 423,950 nursery sets (401,200 at Ten Soueilim and 22,750 at Tendghaidsat), to stabilise 857 hectares mechanically by erecting 224.3 kilometres of fences and planting 220,205 selected seedlings (not including fill planting) on the intervention sites from 2000 to 2007, with emphasis placed on local woody and herbaceous species since 2003. The project also distributed 50,000 sets to support the annual national reforestation campaigns, towns and villages, and national NGOs.

To ensure the permanence of the existing engineering works and plantings at Toujounine, Dar Naim, Tiguint, and Tendghaidsat, the project attaches great importance to involving the administrative and municipal authorities that are concerned, forestry technical services, NGOs, and populations affected directly by the encroaching sands.

A simple methodology for setting up and managing the urban and peri-urban predominantly *Prosopis juliflora* forests based on the experiences and logging studies of projects conducted in Mauritania makes it possible to preserve and ensure the permanence of

the capital that has been created whilst providing the indispensable plant material for stabilising the dunes.

The project's success was made possible by the team spirit and effective collaboration of all the partners in the various years, that is, the Government of Mauritania, Walloon Region of Belgium, FAO, WFP, forestry engineers and technicians, all of the field personnel, national and international NGOs, and all the co-operatives and other groups motivated by actions to combat the desert's advance and protect the environment.

RECOMMENDATIONS

INSTITUTIONAL RECOMMENDATIONS

It is recommended to:

- take the necessary measures in searching for development partners to continue and develop, without discontinuity, the activities taken by the Nouakchott green belt rehabilitation and extension support project from 2000 to 2007, given the importance of these activities and the environmental and socio-economic benefits that they generate for the capital;
- implement, in the medium and long term, both a policy and a legislative framework for the development and participatory management of urban and peri-urban tree formations under public and private ownership;
- define the respective roles, rights, and duties of the various players in the country's urban and peri-urban forest systems whilst specifying the ways and organizational and legislative frameworks for implementing a participatory approach in the consolidation, extension, and sound management of these systems;
- encourage the sustainable development of urban and peri-urban forestry in and around the capital and nationally. This development should generate jobs and income for the informal sector;
- co-ordinate the planning and execution of development and environmental policies in ways that get all of the players – national authorities, technical services, municipalities and communities, national and international NGOs, and so on – involved in the preparation, implementation, and management of the regional programmes; and

- reinforce the current forestry service’s human and material resources on the national, central, and regional level in line with the annual programmes that are adopted to control desertification more effectively and protect the environment, as well as to manage existing and future forest assets sustainably.

TECHNICAL RECOMMENDATIONS

Recommendations for future plantings:

- to give priority to diversifying the local woody and herbaceous species that are adapted to local conditions, insisting on the provenance of the seeds and cuttings to acquire;
- in the nurseries, to emphasise the quality of the planting material (sets) to produce;
- to maintain and to raise as soon as necessary the network of criss-crossing wattles during the first years of their installation to contain the dunes’ changing profiles as well as possible;
- to guarantee an optimal planting take rate by ensuring good field crew organization, sufficient logistic support, and constant monitoring of the activities (selection of sets leaving the nursery, protection of sets during transport, planting per se with or without watering, and security guards);
- to search for the ideal scheme to enable the people, NGOs, local authorities, and technical services to participate in the sustainable planting and maintenance of the country’s forest formations by increased awareness, unfaltering sensitisation, and an organization allowing the transfer of activities and exercise of responsibility.

To this end, the relevant national offices should opt:

- first, to have the State’s technical services take direct charge of the improvements’ management during the projects’ performance in conjunction with the municipalities, co-operatives, and national NGOs;
- second, to have the State transfer the management of the stands that are set up to the identified communities under the technical supervision of the current Ministry of Environment (MDAPMCE) and its Regional Offices;

- to maintain effective surveillance of the plantations in all the intervention areas, doing so in ways that involve the neighbouring communities, national and international NGOs, etc., directly, with the support of the relevant technical services;
- to analyse the costs of each activity (production of sets, mechanical stabilisation, biological fixation, security services, logging and other forest uses, and various training schemes) in order to design programmes and strategies that the national authorities will implement in order to achieve their development objectives;
- to develop a database system that will enable Mauritania and the entire sub-region to disseminate the techniques that are used and their outcomes widely.

ISRAELI DESERT AQUACULTURE - A WINDOW FOR GLOBAL AQUACULTURE OPPORTUNITIES

SAMUEL APPELBAUM

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BACKGROUND

World demand for fish and other seafood products has been increasing steadily due to population growth and the growing awareness of fish being a healthy food. Natural resources do not cover the global demand for fish, on the contrary, world wild catch is stagnating and there is evidence of decline in the catch of some marine species. Aquaculture as a consequence is developing worldwide as fast as 11% annually, making it the fastest growing food production sector. However, associated with this rapid, welcome development, especially in the intensive monoculture species (Finfish and shrimp), are concerns about the environmental, economic and social impacts and acceptability of such practices.

Inland aquaculture in Israel began in the 1940s. Today aquaculture is practiced in 73 farms located mostly in the northern and central parts of the country. The total annual production of these farms including the catch in the sea of Galilea amounts to ca 25,000 tons mainly of tilapia, carp, mullet and trout reared in earthen ponds and reservoirs filled with spring and rain water, plus ca 3000 tons of sea bream and sea bass reared in net-pens in the open sea in the bay of Eilat.

The total annual consumption of fish in Israel has reached over 71,000 tons (~11 kg per capita). About one third of this comes from local production and local catch, two thirds from imports. Consumption forecasts for the years 2010 and 2020 are 86,000 tons and over

100,000 tons respectively demanding an increase in production and imports.

Thus, Israel must continue developing and expanding aquaculture to meet its increasing domestic demand for fish.

ISRAEL'S FRESHWATER PROBLEM

Chronic fresh-water shortage, accompanied by high water costs, urbanisation and rising land prices along the Israeli coastal belt where fish farms have been traditionally operating, highlight the urgent need for alternatives in terms of water resources and suitable sites for aquaculture operations. Additionally, growing public pressure is forcing the termination of fish culture in the bay of Eilat as one factor causing destruction of the coral reefs. The Mediterranean Israeli coastline as an alternative site for net-pen fish culture is also ruled out because of destructive winter storms.

The Israeli Negev Desert comprises ca 2/3 (~13,000 km²) of the country (~21,000 km²) but only receive an annual rainfall of between 60-100 mm.

In the late fifties, through drilling at depths up to 1000 m, the discovery was made of the "Nubian Sand Stone" (300 m and below) and the "lower Cenomanian Turonian" (800-1000 m) aquifers, containing huge reserves (billions of cubic meters) of unpolluted, brackish geothermal water. This water, with a salinity ranging from 1800-4000 TDS has been found most suitable for fish culture and is currently in use for aquaculture in the Israeli desert. As a further benefit water effluent from the fish, rich in organic waste, is used for irrigating agricultural crops. Thus aquaculture and agriculture form an efficient integrated system

This "Desert Water", though situated deeply underground (500-1000 m) is easily accessible as it rises by artesian pressure to the sea level and has just to be raised from an average suction depth of about 270 meters (Fig. 1).

The fact that this warm water, around 40 °C when reaching the surface, is available all year round provides an excellent and realistic potential for the expanding national fish farming industry.

DESALINATION

Desalination of sea water or brackish water is one of the major steps towards combating the severe water shortage in Israel (Fig. 2). Brine



Figure 1. Brackish water exists in abundant quantities underneath the Israeli deserts

resulting from desalination of seawater is returned to the sea, brine from desalinization of inland water however, has to be disposed of, i.e. into evaporation ponds. This brine can be used for aquaculture, being particularly suitable for the reproduction of aquatic species that only breed in water of higher salinity such as seawater.

RESEARCH

Experiments towards the use of brackish water for agricultural irrigation began in the 1940s. Constant research has led to widespread



Figure 2. Desalination plant

use of the drip irrigation system and to the current use of saline water in greenhouses. The use of saline water for commercial production of wheat, cotton and fodder began in 1972. Since then, tomatoes, cucumbers and alfalfa are also being produced. Brackish water is currently being used for irrigation of olive trees and on an experimental basis, in vineyards, pomegranate, jojoba and almonds.

In indoor and outdoor research programs which have been carried out at our “Bengis Centre for Desert Aquaculture” it has been proved that due to its moderate salinity, (osmoregulatory advantage), constant warmth, purity, and availability regardless of weather conditions, the “desert water” with its lower price compared with the fresh water in the country, is most advantageous for culture of warm water aquatic species.

PRESENT

OPERATION OF DESERT FISH FARMS

In the Negev Highland district there are at present 8 combined wells (600-1000 m deep) supplying 7 million m³ of brackish (2000-3500 TDS) geothermal (38-40 °C) water per annum to the farms of four major settlements in a district of ~400,000 ha and a population of about 4,500.

Currently 15 commercial fish farms are operating in the Israeli desert producing edible and ornamental fish as well as crustaceans (Figs. 3-4). All edible fish that are produced are sold on the domestic market while most of the ornamental fish produced are exported.

Edible fish species currently being cultured in the desert farms in Israel: Tilapia (*Oreochromis niloticus*), Barramundi (*Lates calcarifer*), Bass (*Morone* sp.), Red drum (*Sciaenops ocellatus*), Catfish (*Clarias gariepinus*)

ORNAMENTAL FISH IN THE DESERT FARMS

This sector of fisheries and aquaculture industry has gained an enormous popularity worldwide during the last few decades and further interest appears to be continuously growing making it potentially a very profitable global component of international trade worth in excess of US\$10 billion annually..

The culture of ornamental and tropical aquarium fish in Israel started more than three decades ago and reflecting a high demand, culture facilities for ornamental fish have expanded.



Figure 3. Negev desert fish farms: outdoor fish pools and structures



Figure 4. Negev desert fish farms: indoor pools showing mechanical aerators – and fish harvesting

Today there are about 20 tropical fish farms, most of which are located in the Israeli desert area. The size of the farms is typically between 0.1-0.3 hectares, each farm operates in separate hot-houses being isolated from the others, with no common water system.

Ornamental fish cultured in the desert farms in Israel: Guppy (*Poecilia reticulata*), Platyfish (*Xiphophorus maculatus*), Swordtail (*Xiphophorus helleri*)

FUTURE

Israel has to continue developing and expanding aquaculture to meet her increasing domestic demand for fish and to take advantage of increasing export opportunities.

In order to expand its aquaculture activities Israel is being forced to increase the use of available marginal water i.e., existing desert brackish water as well as desalinated sea and brackish water.

Adapting and developing technologies for intensive fish culture with minimal use of fresh water, maximum water reuse and use of marginal water such as the “desert water” are crucial for Israel’s aquaculture industry development and for remaining competitive in the lucrative world export market.

Intensive utilization of the treasure of brackish geothermal water of the Israeli desert for integrated agriculture/aquaculture would enable the continued expansion of Israel’s aquaculture industry while significantly easing the pressure on Israel’s scarce fresh water resources (Fig. 5).

Based on the above, it is obvious that further development of Israeli aquaculture will have to go hand in hand with a rapid expansion in the already existing domestic arid land aquaculture. Aquaculture in the Israeli Negev Desert will hold an increasingly dominant position in the country’s aquaculture development.

SUMMARY OF THE ADVANTAGES OF DESERT AQUACULTURE

The existence of large amounts of accessible subsurface unpolluted brackish geothermal water, the so called “Desert water”, is most suitable for fish culture.

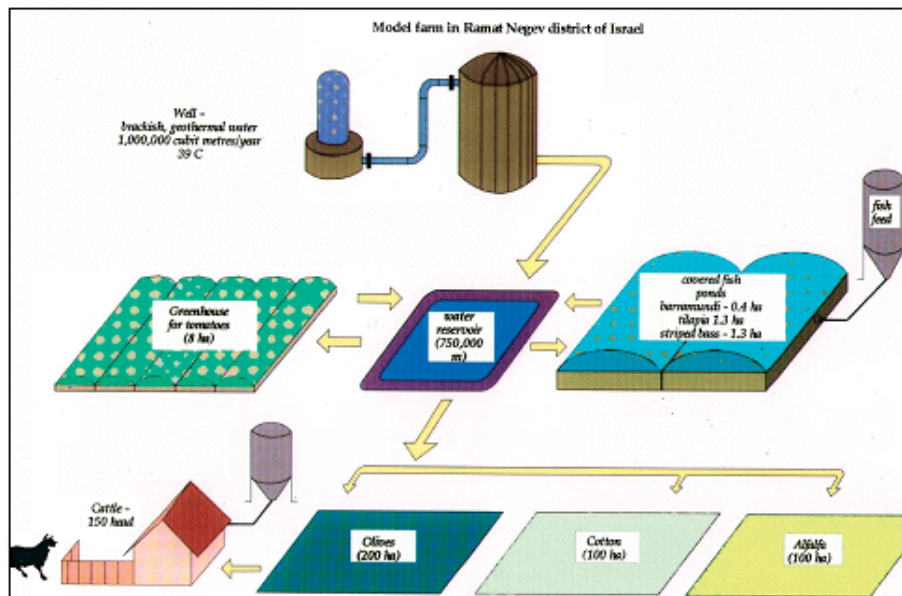


Figure 5. Layout of Integrated Desert Aqua/agriculture Operation

The cost of the “Desert water” is lower than that of fresh water for the country. There is no shortage of land in the desert and its price is much lower than in other regions of the country. The pollutant free “desert water” allows a high quality fish product for the customers.

CONCLUSION

Arid land aquaculture is not a technological revolution; it is simply an innovative approach that differs from conventional fish farming. Arid or semi-arid lands with subsurface water resources have huge potential for developing and sustaining Aqua/ Agricultural products. Technologies applied in arid lands should minimize negative impact on the valuable unspoiled environment and maximize the preservation of the land’s use such as, the integration of aquaculture with agriculture to conserve water both by reuse and expansion of the chain of users of the same water.

The potentials of a growing consumer market for aquaculture products and an accessible reservoir of unpolluted subsurface brackish geothermal water in the Israeli desert combined together with continued technological research and innovation should make the production of many thousands tons of fish and other aquatic organisms in the desert a not too distant reality.

Deserts worldwide should obtain better attention for their potential in use for developing aquaculture and agriculture preferably integrated.

MARGINE, THE OLIVE MILLS WASTE WATER AS AN ORGANIC AMENDMENT FOR CONTROLLING WIND EROSION IN SOUTHERN TUNISIA BY IMPROVING THE SOIL SURFACE STRUCTURE

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INTRODUCTION

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.

Increasing the organic matter content in sandy soils can increase the aggregate formation and stability and reduce the susceptibility to erosion.

The quantities of margine, the olive mills waste water, accumulating each year and dumped in open reservoirs and lakes, constitute also a real environmental problem in Tunisia. They could be valorized instead and used as an organic amendment for improving soil physical properties (Mellouli, 1996).

The objectives of this study were to evaluate the impact of 10 years of successive margine sprays on the surface properties of sandy soils in olive orchards in southern Tunisia. This work is a joint venture of the Institut de l'Olivier, Zarzis, Tunisia, the Institut des Régions Arides, Médenine, Tunisia and the Unesco Chair on Eremology, Ghent University, Belgium, the Soil Erosion Research Group and the Soil Physics Research Group of the Department of Soil Management, Ghent University, Belgium.

MATERIALS, RESULTS AND DISCUSSION

MARGININE

Margine is obtained after grinding of olives. The chemical composition of margine can be found in Taamallah (2007) and Mellouli (1996). Among the important characteristics are: liquid content: 87.9 %; pH(water): 5.5; ECe: 18.6 mS cm⁻¹; organic substances: 107 g l⁻¹.

FIELD APPLICATIONS

The margine was applied at the Chammakh-Zarzis olive orchard, which 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 margine was pumped from a pit cistern in a tank and brought by tractor to the field (Fig. 1). It was then sprayed homogeneously on the soil surface, previously tilled to a 10-15 cm depth (Fig. 2).

From 1995 until 2006, margine was sprayed during December-January at yearly rates of 0 m³ ha⁻¹ (control) , 50 m³ ha⁻¹ (treatment 1), 100 m³ ha⁻¹ (treatment 2), and 200 m³ ha⁻¹ (treatment 3). The four 1 ha parcels were selected as shown in Fig. 1, each containing 16 olive trees between 60 and 70 years old, planted at intervals of 25 meter. The parcels were separated by two non-treated olive tree rows (50 m distance).



Figure 1. Margine spray from tank and tractor



Figure 2. Margine treated fields

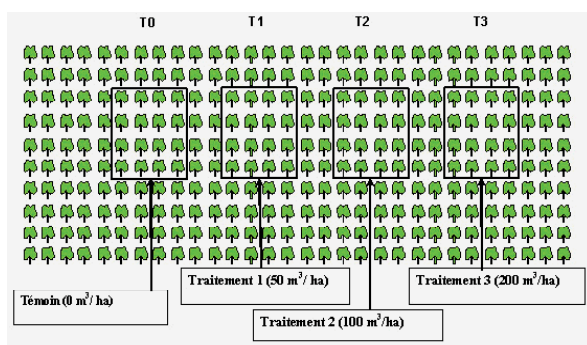


Figure 3. Schematic lay out of the Chammack-Zarzis experimental field.

EFFECT OF MARGINE ON ORGANIC MATTER CONTENT

Soil samples for organic matter content determination were taken in 2006 on each parcel and this after 10 years of 'margine' application. The organic matter content determined by the Walkley and Black method is listed in Table 1.

Table 1. Organic matter content of the upper sandy soil layer after 10 years of *margine* application

Rate ($\text{m}^3 \text{ha}^{-1}$)	Organic matter content (%)
0 (control)	0.06
50	0.41
100	0.71
200	1.27

EFFECT OF MARGINE ON AGGREGATE FORMATION AND STABILITY

Disturbed surface samples were taken and brought to the laboratory, air dried and sieved for dry aggregate distribution. Only at rates of $200 \text{ m}^3 \text{ ha}^{-1}$ differences in aggregate formation were significant compared to the other treatments and the control. At application rates of 50 and $100 \text{ m}^3 \text{ ha}^{-1}$ only 10 % of the aggregates had diameters larger than 2 mm, whereas at the $200 \text{ m}^3 \text{ ha}^{-1}$ rate this increased to 35 %.

The same samples were then subjected to an under water sieving test and allowed to break down. Once more the $200 \text{ m}^3 \text{ ha}^{-1}$ rate showed marked differences compared to the lower application rates, where now only 5% of the aggregates had diameters larger than 2 mm. The $200 \text{ m}^3 \text{ ha}^{-1}$ application rate still resulted in 25 % of aggregates with diameters larger than 2 mm, reflecting a higher aggregate stability.

EFFECT OF MARGINE ON THRESHOLD FRICTION VELOCITY FOR INITIATING PARTICLE MOVEMENT

Bulk samples of the upper sandy soil layers were shipped to the International Center for Eremology (ICE), Ghent University, Belgium to be tested in its wind tunnel. 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 et al., 2004). The samples were placed in $0.95 \times 0.40 \times 0.02 \text{ m}$ 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 were introduced in the test area and wind velocities were monitored at a 1-Hz frequency with 13 mm diameter vane probes mounted at heights of 0.05m, 0.10m, 0.15 m, 0.20 m, 0.30 m, 0.40 m, 0.50 m, 0.60 m and 0.70 m. The shear velocity u_* of the sand surface could be calculated from the windprofile and the roughness length z_0 , taking a von Karman constant k of 0.4. The experiments were conducted in 4 replicates per treatment.

The initiation of particle movement was determined by continuously recording particle transport with a saltiphone. The saltiphone, described by Spaan and van den Abeele (1991), 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 method described by Cornelis and Gabriels (2003) was used. A Bagnold (1941) type of transport equation was fitted to observed particle transport rates recorded at four different wind speeds. Table 2 illustrates the threshold friction velocity values for the different treatments with margine. It can be observed that margines substantially increased the threshold shear velocity. Compared to the control, an application rate of $100 \text{ m}^3 \text{ ha}^{-1}$, increased u_{*t} with 18%, whereas a rate of $200 \text{ m}^3 \text{ ha}^{-1}$ increased u_{*t} by 43%, which implies that the soil becomes much less sensitive to erosion by wind.

Table 2. Threshold friction velocities for initiating particle movement after 10 year of margine application

Rate ($\text{m}^3 \text{ ha}^{-1}$)	Threshold friction velocity u_{*t} (m s^{-1})
0 (control)	0.44
50	0.45
100	0.52
200	0.60

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