United Nations
Convention to Combat Desertification

UNCCD SPI Science - Policy Interface

A Report of the Science-Policy Interface

The Land-Drought Nexus

Enhancing the role of land-based interventions in drought mitigation and risk management

United Nations
Convention to Combat Desertification

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How to cite this document:
A. Reichhuber, N. Gerber, A. Mirzabaev, M. Svoboda, A. López Santos, V. Graw, R. Stefanski, J. Davies, A. Vuković, M.A. Fernández García, C. Fiati and X. Jia. 2019. The Land-Drought Nexus: Enhancing the Role of Land-Based Interventions in Drought Mitigation and Risk Management. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.

Published in 2019 by United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany
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UNCCD-SPI Technical Series No. 05

ISBN 978-92-95117-21-1 (hard copy)
ISBN 978-92-95117-27-3 (electronic copy)

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This publication is printed on 100% FSC recycled paper.

Supported by the UNCCD, the European Union, and the Changwon Initiative from the Korea Forest Service

European Commission

THE CHANGWON INITIATIVE

A Report of the Science-Policy Interface

The Land-Drought Nexus

Enhancing the role of land-based interventions in drought mitigation and risk management

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"The Land-Drought Nexus: Enhancing the Role of Land-based Interventions in Drought Mitigation and Risk Management" was prepared in accordance with the rules and procedures established by the UNCCD Conference of the Parties (COP), by which any scientific output prepared under the supervision of the Science-Policy Interface (SPI) should undergo an international, independent review process (decision 19/COP.12).

This report was prepared by an author team of 5 lead authors and 7 contributing authors. In October 2018, following a competitive public tender, the UNIQUE forestry and land use GmbH was commissioned to prepare this report in association with the SPI. A scoping meeting was held in October 2018 in Bonn, Germany. SPI members and observers, representatives of UNIQUE GmbH, and external experts in drought management, land governance, Land Degradation Neutrality (LDN) Target Setting Programme implementation, and sustainable land management participated in this meeting, followed by three authors' meetings in 25–27 February in Bonn and on 26 April and 7 May 2019 by skype call.

Following an intensive assessment of the technical documents and peer-reviewed scientific literature, a draft report produced by the authors underwent a two-step peer review process, including an internal review and, an independent external scientific review. For the latter, five external reviewers (individual experts) from the different UNCCD regions, and one representative of international organization, which are relevant to the UNCCD process on LDN were selected. The lead authors ensured that all peer review comments received appropriate consideration. A summary of the report was reviewed by the Bureau of the Conference of the Parties of the UNCCD.

Foreword

While healthy soils provide a buffer in times of drought, degraded land amplifies water scarcity and threatens the food and ecosystems that support a global population rapidly approaching 10 billion people. It is within our power to either mitigate or exacerbate those threats. That's why this report draws on the latest research and experience to provide guidance on land-based techniques, which can improve both the availability of water and the quality of life for those who depend on it.

With about 4 billion people, representing nearly two-thirds of the world population, already experiencing severe water scarcity for at least part of the year, we must use every tool at our disposal to prevent that figure from doubling by 2050. The reality however is that although the role of land in exacerbating droughts is well understood, most mitigation policies and practices have yet to exploit its true potential for generating positive, long-term impacts. To help close that gap, the report's authors analyze well designed land-based interventions that not only mitigate and manage drought risks, but also strengthen the resilience of communities and ecosystems.

As the report demonstrates, practices that simultaneously tackle land degradation, drought and water scarcity, can also generate high social, environmental and economic returns. Therefore, the authors introduce the concept of Drought-smart land management practices and identify the enablers for those. Drought-smart land management practices reduce vulnerability to water shortages and multiply the opportunities to expand sustainable development. For example, as well as exploring the connections between land degradation and related issues, such as biodiversity loss or climate change, the report shares detailed practical experience with techniques such as tillage, mulching, weed management, counter hedgerows and stone bunds. This includes precision levelling techniques that cut irrigation for grain production by up to 30% in the United States; legume-based crop rotations that improve water infiltration by up to 238% in Malawi, Mozambique, Zambia and Zimbabwe; ecological data sensors that provide early warning of forest fires in China; and customized fertility techniques that multiply crop yields in Kenya, Senegal, Bolivia, Belgium and the United States when implemented over several years.

I can't recommend this report strongly enough for anyone tackling desertification and land degradation, climate change or biodiversity loss. It sends a strong message to policy makers and other stakeholders that drought management provides some incredible opportunities to collaborate on practical and mutually beneficial solutions.

Ibrahim Thiaw
Executive Secretary
United Nations Convention to Combat Desertification

Executive Summary

Drought is one of the major drivers of global food and water insecurity, affecting agricultural production and access to food and water. Drought can, in extreme cases, force people to abandon their land, resorting to migration as their last livelihood strategy[1] making the prospect of ending hunger and malnutrition by 2030 more difficult.

Land management offers opportunities for mitigating the effects of drought and, more generally, refocusing actions on "proactive drought management". It also increases the resilience of people and ecosystems to drought.

By relevant decisions, the thirteen session of the Conference of the Parties of the United Nations Convention to Combat Desertification (UNCCD) requested the Science-Policy Interface (SPI), as objective 2 of its work programme for the biennium 2018–2019, to provide technical guidance to Parties to support the adoption and implementation of land-based interventions for drought management and mitigation.

Overall objective

The objective of the technical report is to provide a comprehensive review of existing synthesis reports and primary literature in order to: (a) highlight the potential of land-based interventions to mitigate the effects of drought by increasing the resilience of ecosystems and the socioeconomic well-being of populations; and (b) provide guidance to support the adoption and implementation of land-based interventions for drought management and mitigation in the context of LDN. This is a planned contribution to the Work Program 2018-2019 of the UNCCD's Science-Policy Interface (SPI).

Following an extensive scientific review, the SPI, conducted an assessment of 14 categories of sustainable land management measures in four land use types (crop, grazing, forests and woodlands, and mixed land use), which builds on existing United Nations Convention to Combat Desertification initiatives in the context of land degradation neutrality. The outcomes of this assessment provide a scientifically sound basis to understand how land management can contribute to drought mitigation and risk management, leading to a proposal for a new concept of Drought-smart land management (D-SLM) and practical guidance for scaling up D-SLM.

1 FAO 2018. FAO Migration Framework-Migration as a choice and opportunity for rural development: <http://www.fao.org/3/ca3984en/ca3984en.pdf>.

Key Messages

Strong linkages between land use, water use, and drought

There are strong links between the drought-land nexus and human decisions on land use and land use change which impact water availability and determine ecosystem and human resilience to drought. Water reaches land via precipitation and, in some climates and systems, irrigation. It leaves land via runoff (water not absorbed by soil that then runs downslope), transpiration (water emitted by plants as they cool), soil evaporation (water loss directly from the land surface, especially bare and sealed surfaces) and, in some cases, via artificial drainage (removal of excess water through underground pipes or tiles). Between inflows and outflows, some water remains in the soil for periods of time; the amount and duration of soil water storage depends on soil properties such as organic matter content, pore space, and size and on processes such as infiltration rate, that is, the speed at which water filters into the soil.

Whereas healthy soils can store water that functions as a buffer in times of drought, human-induced land degradation reduces soil water holding capacity and amplifies water scarcity and increases the vulnerability to droughts. Hence, restoration or rehabilitation of degraded land and enhancing soil health can create better resiliency to drought. Soil loss, especially of the upper layers that contain most organic matter, leads to a reduction in the capacity to retain soil moisture. Land degradation can also contribute to reduced infiltration of water. **Global modelling studies have found that more effective management of water in soil has significant potential to both improve crop production and reduce the overall amount of water runoff resulting from agricultural systems.** Impervious surfaces such as pavements seal the soil surface, eliminating rainwater infiltration and natural groundwater recharge.

Gaps and needs for integrating land use and land management practices into drought risk management as a proactive approach

Policy approaches and actions seeking to provide ex-post relief to drought-affected populations and economic activities are less effective than proactive actions utilizing drought risk management measures to mitigate the effects of drought. Strategies based around drought relief and ex-post interventions are costly and incentivize the continuation of drought-sensitive economic activities, thus increasing the future costs of drought relief rather than building resilience against droughts. Proactive drought risk management is a more efficient way to reduce drought impacts on communities, economies and the environment.

Many examples have illustrated that human-induced land degradation has made droughts last longer, while well-managed land provides a buffer for drought. Reductions in soil moisture, including those brought on through unsustainable land management and/or rainfall deficits, can aggravate the severity and/or duration of droughts, meaning that these activities must be pro-actively taken into account in drought policy responses. This determines the success of the policy responses as

indicated on page 27 in Figure 1 represents this concept and process, and the potential for policies to move the black marker indicating the current situation towards either water security (blue) or water scarcity (yellow).

Investing in land-based interventions that seek to simultaneously address land degradation, drought and water scarcity has high economic, social and environmental returns, but a lack of impact data and vulnerability assessments are often barriers to proactive drought management, particularly drought risk mitigation.

Effectiveness and benefits of Drought-smart land management practices

The effectiveness and multiple benefits of Drought-smart land management practices for drought risk mitigation through improving ecosystem and social resilience at local and national levels varies depending on a variety of factors. The table (see page 62) provides a synthesis of D-SLM measures organized into 14 groups made up of different types of strategies and interventions. These are considered with respect to four land use types (crop, grazing, forests and woodlands, and mixed) and an assessment of the impact of the D-SLM practices on soil, water, biophysical/ecosystem attributes and socioeconomic factors that determine ecosystem and human resilience to drought. A detailed description of 17 D-SLM practices related to these measures is provided in the Annex (on page 108). Also taken into consideration were the strength of scientific evidence of the effectiveness of these practices and their capacity to deliver multiple benefits. The main findings of the assessment were as follows:[2]

1. There is robust evidence and high agreement that adoption of D-SLM practices alleviates the negative impacts of droughts on the productivity of croplands, grazing lands, forests and woodlands, and mixed land uses, including under climate change;[3]

2. There is high confidence that most D-SLM practices contribute to higher crop yields, especially after a long-term application, under water shortages and marginal soils;

3. There is medium confidence that D-SLM practices for improving pasture management have positive impacts on forage production and livestock productivity under droughts;

4. Many, but not all, D-SLM practices contribute to soil carbon sequestration (robust evidence, high agreement);

2 The presented assessment makes use of the Intergovernmental Panel on Climate Change uncertainty language style, as presented at: <http://www.ipcc-wg2.awi.de/guidancepaper/ar5_uncertainty-guidance-note.pdf>.

3 The presented assessment makes use of the Intergovernmental Panel on Climate Change uncertainty language style, as presented at: <http://www.ipcc-wg2.awi.de/guidancepaper/ar5_uncertainty-guidance-note.pdf>.

5. Application of D-SLM practices in degraded lands can positively affect biodiversity (medium confidence);

6. D-SLM practices have higher socioeconomic returns than conventional practices under droughts and in marginal soils. Many, but not all, D-SLM practices allow for improved drought resilience without curtailing farmers' opportunities to maximize their benefits during normal or wet years (robust evidence, medium agreement);

7. D-SLM practices enhance all dimensions of food security (medium evidence, high agreement); and

8. Further drought vulnerability and risk assessments in different contexts covering both natural (climatic, soil and water) and socioeconomic aspects are needed for more ecologically effective implementation of the D-SLM practices in integrated and collaborative drought risk mitigation across ecosystems, administrative boundaries and rural-urban landscapes.

Enabling policies and tools of guidance for Drought-smart land management

This report proposes a set of five enablers for D-SLM adoption and implementation. They include: a landscape approach, capacity-building and development, good land and water governance, geo-spatial analysis, and finance:

1. A "landscape" is a socio-ecological system. It includes: topography, natural resources, biodiversity and culture, as expressed in various land uses. Droughts extend beyond administrative boundaries, therefore, an integrated landscape approach aids in problem-solving across sectors and boundaries. Moreover, a landscape approach is fundamental to LDN. Hence, for successful drought risk management, it is important to adopt landscape-scale management of land and water resources and to understand how landscape management impacts people's livelihoods;

2. Developing capacity on the land-drought nexus and communicating the multiple benefits of D-SLM across sectors, communities of practice and disciplines is crucial. Enhancing the uptake and sustainability of D-SLM initiatives across sectors hinges on capacity in and communication on the multiple benefits of D-SLM across sectors, communities of practice and disciplines;

3. Good, effective and participatory land and water governance is as important to drought mitigation as the application of the best technologies because it creates the enabling environment for the adoption and scaling up of D-SLM and its associated technologies. Such an environment requires, inter alia, effective institutions combined with the empowerment of women (one of the majority groups among rural land and water users) and legal security (land tenure, water rights);

4. Remote sensing and geospatial information are powerful tools that can be employed to monitor and assess the status of land surface health or stress, detect environmental changes and assess the impacts of those changes. Integration of multi-temporal and multi-sensor data at various scales allows for the detection of crop-specific drought stress and can thereby support D-SLM by helping determine the effectiveness of strategies; and

5. Fostering and increasing awareness around D-SLM is linked to sufficient financing. Successful implementation of D-SLM and such initiatives depends on the effective mobilization of resources from all sources, including national budgets, partnerships with external donors and innovative sources of finance (e.g. interlinking with carbon financing through voluntary credits, public-private partnerships), ideally concurrent with local and national programming. D-SLM does not necessarily require additional financial resources but usually involves redirecting and making more effective use of existing financing.

Urgent actions needed

Land use coupled with water use is projected to continue increasing at the global level as a function of population growth, economic development and changing consumption patterns, among other factors. Industrial and domestic demand for water will likely grow much faster than agricultural demand, although agriculture will remain the largest overall user. Land and water use for food will face a double challenge as human demand for food and competition for it from the other sectors are both set to increase.[4] Climate change exacerbates the situation by accelerating the occurrence and intensity of climate-related disasters such as droughts and floods.

The technical report recommends scientific communities, policy-makers, and practitioners to take urgent actions as follows:

1. **Proposal 1:** Strengthening the interlinkages between national land and national drought policies, consider changing the policies to fully reflect the influence of land use and management and land degradation on water availability and water scarcity, and consider the positive role D-SLM practices could have in building the resilience of communities and ecosystems to drought, when pursued in the context of LDN;

2. **Proposal 2:** Taking measures to ensure the governmental departments dedicated to drought management integrate land use, land use change and land degradation as factors in drought and drought risk management practices and policies, while also ensuring that their land and water use departments integrate D-SLM practices into their relevant policies and initiatives;

4 <http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2018-nature-based-solutions/>

3. **Proposal 3:** Enhancing cross-sectoral collaboration and coordination in national, regional and international policies and programmes to promote the interventions necessary to optimized adoption, implementation and scaling-up of D-SLM to landscape level, focusing on a set of five enablers, including:

   a). Implementing integrated land use planning and landscape management;

   b). Strengthening national and local capacity on the multiple benefits of D-SLM across sectors, communities of practice and disciplines, taking into consideration gender integration;

   c). Ensuring effective local institutions in combination with place-based policies and legal security on land tenure and water rights to ensure relevant and inclusive design, implementation, monitoring and evaluation of land-based interventions to mitigate the effects of drought;

   d). Developing user-friendly tools which improve the access of policy-makers, planners and practitioners at all levels to geospatial analysis that integrates Earth observations, including satellite and in-situ data of land, water and meteorology, through the use of geographic information systems, which would allow the integrated monitoring and mapping of land cover, including water bodies, land degradation and drought risk; and

   e). Mobilizing both conventional and innovative finance, including from public and private investors, in the form of ecosystem service payments, carbon emission offsetting, insurance coverage and investments in sustainable land-based value chains to support and promote D-SLM, ideally concurrent with local and national programming; and

4. **Proposal 4:** Enhancing collaboration among relevant international treaties and multilateral organizations lead by UNCCD secretariat and the SPI, with the World Meteorological Organization, the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme and other relevant land, water and meteorological organizations, in the context of the Integrated Drought Management Programme, to facilitate coordination and interaction between LDN and drought risk management communities, notably by creating a common understanding of definitions and the cross-sectoral nature of drought risk management and land management.

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List of Abbreviations

CA	conservation agriculture
DRAMP	Drought resilience, adaptation and management policy
DRM	drought risk management
D-SLM	Drought-smart land management
EbA	Ecosystem-based Adaptation
Eco-DRR	Ecosystem-based Disaster Risk Reduction
EO	Earth Observation
FFS	farmer field school
FMNR	farmer managed natural regeneration
ICZM	integrated coastal zone management
IDMP	Integrated Drought Management Programme
IWM	integrated watershed management
IWRM	integrated water resources management
LBI	Land-based intervention
LDN	land degradation neutrality
NbS	nature-based solutions
NDC	nationally determined contribution
PSF	pond sand filter
RUSLE	Revised Universal Soil Loss Equation
SLM	sustainable land management
SPI	Science-Policy Interface

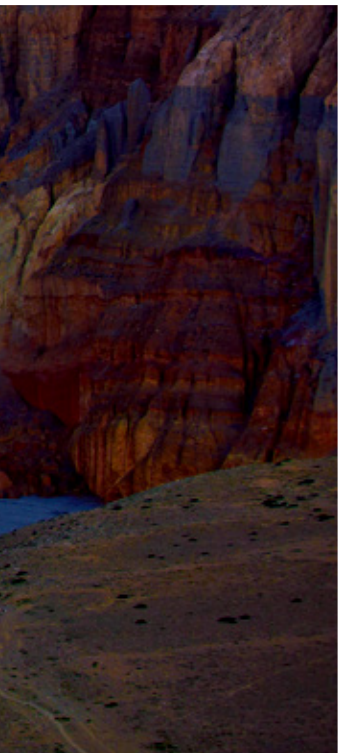
Glossary of Key Terms

Term/Concept	Definition	Source
Drought	Drought is a prolonged absence or marked deficiency of precipitation. Drought means the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems.	World Meteorological Organization (WMO), 1992. <http://www.droughtmanagement.info/find/glossary/ Article1 of the United Nations Convention to Combat Desertification (UNCCD), 1994. http://catalogue.unccd.int/936_UNCCD_Convention_ENG.pdf>
Drought risk	The risk for drought is a combined effect of drought hazard (likelihood) and drought consequence (vulnerability).	Global Water Partnership (GWP) idmp-act-5.4-technical-note. <https://www.gwp.org/globalassets/global/gwpcee_files/idmp-cee/idmp-act-5.4-technical-note.pdf>
Drought risk mitigation	Any structural/physical measures (e.g., appropriate crops, dams, engineering projects) or non-structural measures (e.g., policies, awareness, knowledge development, public commitment, and operating practices) undertaken to limit the adverse impacts of drought.	Integrated Drought Management Programme (IDMP). <http://www.droughtmanagement.info/wp-content/uploads/2016/10/WS6-Drought-Preparedness-and-Mitigation.pdf>

Term/Concept	Definition	Source
Drought risk management	Drought risk management (DRM) is the process of data and information gathering for risk analysis and evaluation; appraisal of options; and making, implementing, and reviewing decisions to reduce, control, accept, or redistribute drought risks. It is a continuous process of analysis, adjustment and adaptation of policies and actions to reduce drought risk, including reducing the vulnerability and enhancing the resilience of the receptors threatened. DRM focuses on delivering a drought-resilient society by reducing drought risks and promoting environmental, societal and economic opportunities now and in the longer term. It recognizes that risks can never be removed entirely, and that reducing risk may be at the expense of other societal goals.	UNCCD, 2018. Reporting manual for the 2017–2018 UNCCD reporting process. <http://www.unccd.int/convention/2017-2018-unccd-reporting-process>
Drylands	Arid, semi-arid or dry sub-humid areas, in which the ratio of mean annual precipitation to mean annual potential evapotranspiration lies between 0.05 and 0.65. Areas with a ratio of less than 0.05 are considered hyper-arid deserts.	UNCCD. ICCD/CRIC(9)/CRP.1
Land	Means the terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system.	UNCCD, 1994. United Nations Convention to Combat Desertification, Article 1.
Land-based interventions	Measures that are tied to the use and management of land.	Defined in this report.

Term/Concept	Definition	Source
Land degradation neutrality (LDN)	A state whereby the amount and quality of land resources necessary to support ecosystem function and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems.	Decision 3/COP.12, UNCCD, 2015.
Land cover	The Physical material at the surface of the Earth which may be vegetated or non-vegetated, natural or managed.	UNCCD, 2018. Reporting manual for the 2017–2018 UNCCD reporting process.
Land cover class	A category of land cover differentiated by a combination of diagnostic attributes based on a nationally-refined application of an international standard such as the FAO Land Cover Classification System	UNCCD, 2018. Reporting manual for the 2017–2018 UNCCD reporting process.
Land use	Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). In this report, five major land-use types will be considered: cropland, grazing land, forestland, mixed land and others.	IPCC, 2014: Annex II: Glossary. In: Climate Change 2014: Synthesis Report, WOCAT glossary. <https://www.wocat.net/glossary>
Marginal Land	Marginal land is land that is of little agricultural value because crops produced from the area would be worth less than any rent paid for access to the area.	William Baumol, Alan Blinder, Economics: Principles and Policy (2011), p. 409.

Term/Concept	Definition	Source
Resilience	The ability of a system to absorb disturbance and reorganize itself so as to retain essentially the same function, structure, and feedbacks. Resilience is a neutral property, neither good nor bad (Whether or not resilience is beneficial in any situation depends on the specific circumstances – whether the system is in a desirable or undesirable state).	UNCCD, 2018. Reporting manual for the 2017-2018 UNCCD reporting process.
Sustainable land management (SLM)	The use of land resources – including soils, water, vegetation, and animals – to produce goods and provide services to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions.	WOCAT glossary. <https://www.wocat.net/glossary>
Water scarcity	An imbalance between supply and demand of freshwater in a specified domain (country, region, catchment, river basin, etc.) as a result of a high rate of demand compared with available supply, under prevailing institutional arrangements (including price) and infrastructural conditions.	Food and Agriculture Organization of the United Nations (FAO), 2012: Coping with water scarcity: An action framework for agriculture and food security.



Introduction to land-drought nexus

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The connection of the land-drought nexus to human activities which impact water scarcity and further reinforce drought effects.

Drought is one of the major drivers of global food and water insecurity, affecting agricultural production and access to food and water. Drought and hunger can, in the extreme, force people to abandon their land, resorting to migration as the last livelihood strategy (FAO, 2018). As noted by the 2018 UN Report on Progress towards the Sustainable Development Goals (SDGs) world hunger appears to be rising again, after a prolonged period of decline.[5] Conflicts and drought are seen as among the key factors causing the reversal in the long-term progress in fighting global hunger, making the prospect of ending hunger and malnutrition by 2030 more difficult. The consequences of drought can shape the destinies of those who experience it in infancy by affecting their physical and cognitive development (Damania et al., 2017).

Land management offers opportunities for mitigating the effects of drought and, more generally, refocusing actions on "proactive drought management". It also increases the resilience of people and ecosystems to drought.

5 See the following report of 2018, accessed on 30.11.2018: <https://sustainabledevelopment.un.org/content/documents/18541SG_SDG_Progress_Report_2018_ECOSOC.pdf>.

At the 13th Conference of the Parties (2017) of UNCCD, the Science-Policy Interface (SPI) was invited to review the existing synthesis reports and primary literature to provide guidance to support the adoption and implementation of land-based interventions for drought management and mitigation. This report is the outcome of a systematic review and assessment of key documents provided by the UNCCD secretariat and by the Working Group 2 of the SPI and of additional scientific literature collected by the authors.

1.1. Objective and structure of the report

The objective of the technical report is to provide a comprehensive review of existing synthesis reports and primary literature in order to: (a) highlight the potential of land-based interventions to mitigate the effects of drought by increasing the resilience of ecosystems and the socioeconomic well-being of populations; and (b) provide guidance to support the adoption and implementation of land-based interventions for drought management and mitigation in the context of LDN to facilitate transition from the current "reactive" drought crisis management to "proactive" drought risk management.

This technical report consists of 5 chapters. Chapter 1 justifies the connection of the land-drought nexus to human activities which impact

water scarcity and further reinforce drought effects. With this as the baseline, Chapter 2 introduces the main terminology characterizing actions for drought mitigation (i.e. against drought impacts and vulnerability) and proposes a new concept of "Drought-smart land management", followed with the description of the framework of the synthesis and assessment in scope, scale and methodologies on D-SLM measures within sustainable land management (SLM) technologies. Building on that, Chapter 3 first defines D-SLM strategies and interventions per land-use type, as they are presented in the literature. Second, it assesses the D-SLM strategies based on scientific evidence, along three dimensions of impacts on: (i) biophysical and ecosystem health, (ii) economic viability, and (iii) social resilience. The potential synergies, trade-offs, and constraints arising across the interventions are also presented. Chapter 4 provides technical guidance on how to foster land-based interventions for drought mitigation. It proposes a set of 5 enablers necessary for a sustainable scale-up of Drought-smart land management. Finally, Chapter 5 offers some policy proposals.

Land management offers opportunities for mitigating the effects of drought and, more generally, refocusing actions on "proactive drought management". It also increases the resilience of people and ecosystems to drought.

1.2. Justification on land-drought nexus

There are strong links between land use, water use, and drought.

Droughts exacerbate land degradation, for example, by intensifying sand and dust storm activity (Middleton and Kang, 2017; UNEP, WMO and UNCCD, 2016). On the other hand, land degradation may also amplify water scarcity and increase vulnerability to droughts. For this reason, investing into interventions that seek to simultaneously address both has high economic, social and environmental returns.

Land and drought management are fundamentally connected through water use. Water reaches land via precipitation and, in some climates and systems, irrigation. It leaves land via runoff (water not absorbed by soil that then runs downslope); transpiration (water emitted by plants as they cool); soil evaporation (water loss directly from the land surface, especially

bare and sealed surfaces); and, in some cases, via artificial drainage (removal of excess water through underground pipes or tiles). Between inflows and outflows, some water remains in the soil for periods of time; the amount and duration of soil water storage depends on soil properties such as organic matter content, pore space, and size and on processes such as infiltration rate, the speed at which water filters into the soil.

Whereas healthy soils can store water that functions as a buffer in times of drought (UCS, 2017), land degradation reduces soil water holding capacity and amplifies water scarcity and increases the vulnerability to droughts. Hence, enhancing soil health can create better resiliency to drought (O'Geen, 2012). Soil loss, especially of the upper layers that contain most organic matter, leads to a reduction in the capacity to retain soil moisture (Emerson, 1995; Amundson et al., 2015; Lang, 2006). Land degradation can also contribute to reduced infiltration of water. **Global modelling studies have found that more effective management of water in soil has significant potential both to improve crop production and to reduce the overall amount of water runoff resulting from agricultural systems** (UCS, 2017). Impervious surfaces such as pavements seal the soil surface, eliminating rainwater infiltration and natural groundwater recharge.

Global water use has increased by a factor of six over the past 100 years (Wada et al., 2016). Agriculture accounts for about 70% of global water withdrawals, the vast majority of which is used for irrigation. Water use by industry and domestic water use roughly account for the remaining 20% and 10% of global water withdrawals, respectively. Water use is projected to continue increasing at the global level, as a function of population growth, economic development and changing consumption patterns, among other factors. Industrial and domestic demand for water will likely grow much faster than agricultural demand, although agriculture will remain the largest overall user. Agriculture will face a double water challenge where agricultural demand for water, and competition for it by the other sectors, are both set to increase (World Water Assessment Programme/UN-Water, 2018). Climate change exacerbates the situation by accelerating the occurrence and intensity of climate-related disasters such as droughts and floods.

Agriculture ministers from many countries have acknowledged these challenges by making significant commitments to improve the sector's water use and increase its resilience to water risks. In January 2017, under the G20 German Presidency, G20 agriculture ministers adopted a declaration and an action plan entitled "Towards food and water security: Fostering sustainability, advancing innovation". Shortly after, at the 9th Global Forum on Food and Agriculture, 83 agriculture ministers adopted the Communiqué "Agriculture and Water – Key to Feeding the World" outlining their intention to enhance farmers' water access, improve water quality, reduce water scarcity, and manage surplus water. In the past, policy solutions have been identified to fulfil these political commitments but have not always been adopted effectively (Gruère, 2018).

Policies need to take into account the human decisions that contribute to water scarcity and droughts

Many examples have illustrated human-induced impacts on water scarcity and drought. Human-induced land degradation made droughts last longer and more severe during the 1930s Dust Bowl in the USA (Cook et al., 2009). There are examples of how land use management practices, e.g. afforestation in arid areas, exacerbated local water scarcity (Delang & Yuan, 2015). Reductions in soil moisture, including through unsustainable land management, can aggravate the severity of droughts. As a result, the understanding that human activities can impact the level of water scarcity, and sometimes the severity and duration of droughts, means that these activities need to be pro-actively taken into account in drought policy responses. This determines the success of the policy responses: in Figure 1 we represent this concept by showing the potential for policies to move the black marker indicating the current situation either toward water security (blue) or water scarcity (yellow). Another key point that can be taken from Figure 1 is that much more than just water inputs affect water security/scarcity. Other factors such as human actions/planning, drought, and climate change also play a critical role in this process.

As a result, the understanding that human activities can impact the level of water scarcity, and sometimes the severity and duration of droughts, means that these activities need to be pro-actively taken into account in drought policy responses.

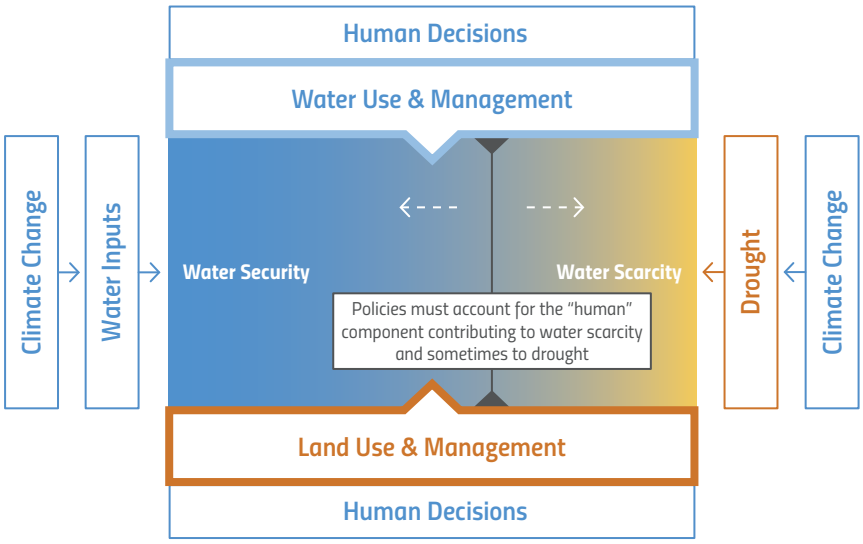

FIGURE 1

Human decisions impacting land, water and drought

Note: The black marker (triangle) denotes a hypothetical current situation, and its movement left or right would be influenced by policies that would contribute to water security (towards the left) or water scarcity (towards the right).

Policy approaches and actions that seek to provide ex-post relief to drought-affected populations and economic activities are less effective than proactive actions for mitigating the effects of drought.

A shift from "reactive" to "proactive" approaches to address drought and its effects, i.e. from drought relief to drought risk management, has been championed or embraced by key international or regional initiatives. These include: the High-level Meeting on National Drought Policy (March 2013) – where the World Meteorological Organization and the Global Water Partnership established the Integrated Drought Management Programme (IDMP); the UN-Water collaborative initiative (March 2013–May 2015), the 2015–2030 Sendai Framework for Disaster Risk Reduction, the SDGs (September 2015), and the African Drought Conference (August 2016). Part of the motivation is financial: strategies based around drought relief and ex-post interventions are very costly (Gerber and Mirzabaev, 2017). Often, they are also counter-productive: they incentivize the continuation of drought-sensitive economic activities, thus increasing the future costs of drought relief, rather than building resilience against droughts (Gerber and Mirzabaev, 2017). Examples of countries who, seeing their drought relief bills mounting over the past decades, have increasingly shifted their attention to proactive drought risk management include Australia, India, the USA, the European Union (Birthal et al., 2015) and Mexico, amid the general and increasing perception that risk management strategies generally offer greater efficiency (Wilhite and Pulwarty, 2017) in reducing drought impacts on communities, economies and the environment.

The cost-effectiveness of drought risk mitigation, realized by addressing the "underlying drought risk factors" and vulnerability, is recognised in the "Drought resilience, adaptation, and management policy" (DRAMP) framework adopted at the 13th Conference of the Parties of the UNCCD from 6 to 16 September 2017.[6] The DRAMP framework defines drought risk mitigation measures as comprising [...] "any structural or physical measures (such as appropriate crops, dams, engineering projects) and non-structural measures (such as policies, awareness, knowledge development, public commitment, legal frameworks and operating practices) that are undertaken to limit the adverse impacts of drought."

In that context, this report highlights the potential of land-based interventions to mitigate the effects of drought by increasing the resilience of ecosystems and the socio-economic well-being of populations.

6 See ICCD/COP(13)/19, accessed 30.11.2018 at : <https://www.unccd.int/sites/default/files/sessions/documents/2017-08/ICCD_COP%2813%29_191711042E.pdf>.

It is needed to understand more on what the potential of land-based interventions is to mitigate the effects of drought by increasing the resilience of ecosystems and the socio-economic well-being of populations.

Drought-smart land management: definitions, concepts and framework of the synthesis and assessment

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2.2. Definitions and concepts relevant to Drought-smart land management 34

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Drought-smart land management: framework of the synthesis and assessment to enhancing understanding the role of land-based interventions determining ecosystem and human resilience to drought.

This Chapter introduces the main terminology characterizing actions for drought mitigation (i.e. against drought impacts and vulnerability) and proposes a new concept of "Drought-smart land management", or D-SLM and explains how it relates to the established terminology. Building on that this Chapter defines the framework of the synthesis of D-SLM measures and an assessment of the impact of the D-SLM practices on soil, water, biophysical/ecosystem attributes and socioeconomic factors that determine ecosystem and human resilience to drought.

2.1 Definitions and concepts relevant to drought

It is well recognized that there is no universally accepted drought definition, and drought definitions have been developed by different stakeholders beyond the meteorological aspects alone, extended by its degree of impacts mostly on the agriculture, hydrological, socioeconomic, and ecological sectors. Decision-makers must be aware that definitions of drought, water scarcity, and aridity may have implications on the effectiveness of associated policies, particularly when considering the land-drought nexus, as different definitions account (or do not account) for land in different ways.

An understanding of those definitions and how they are being used in national policies will influence whether or not those policies adequately address both land management and drought and whether drought management strategies and action plans include land use, land management and restoration/rehabilitation actions able to mitigate drought. An improved understanding of the relationship between land-based interventions and drought mitigation is urgently needed in order to improve the targeting and monitoring of interventions and policies. In all cases, the human response is a critical component that must be a part of any effective proactive drought and land management planning approach.

It is recognized that, in the context of drought, the terms mitigation, management, and response have nuanced and often conflicting definitions. The use of mitigation in this report refers to actions and programmes intended to moderate or even prevent impacts from

drought. Typically, management and response often describe actions taken to alleviate impacts during or after an occurred event. In this report, proactive drought management is used as an all-inclusive term representing all three when considered in the context of planning and preparation for extreme conditions before difficulties associated with drought occur.

Drought risk management

Drought risk management is the process of data and information gathering for risk analysis and evaluation; appraisal of options; and elaboration, implementation, and reviewing decisions to reduce, control, accept, or redistribute drought risks. It is a continuous process of analysis, adjustment, and adaptation of policies and actions to reduce drought risk, including reducing the vulnerability and enhancing the resilience of the affected populations. Drought risk management focuses on delivering a drought-resilient society by reducing drought risks and promoting environmental, societal and economic opportunities now and in the longer term. It recognizes that risks can never be removed entirely, and that reducing risk may be at the expense of other societal goals (UNCCD, 2018).

Drought risk management focuses on delivering a drought-resilient society by reducing drought risks and promoting environmental, societal and economic opportunities now and in the longer term. It recognizes that risks can never be removed entirely, and that reducing risk may be at the expense of other societal goals (UNCCD, 2018).

Indeed, the IDMP and its partners have adopted three pillars of drought risk management that form the building blocks of a successful drought policy.[7] These three pillars are: (1) Monitoring and Early Warning; (2) Vulnerability and Impact Assessment; (3) Mitigation, Preparedness and Response.

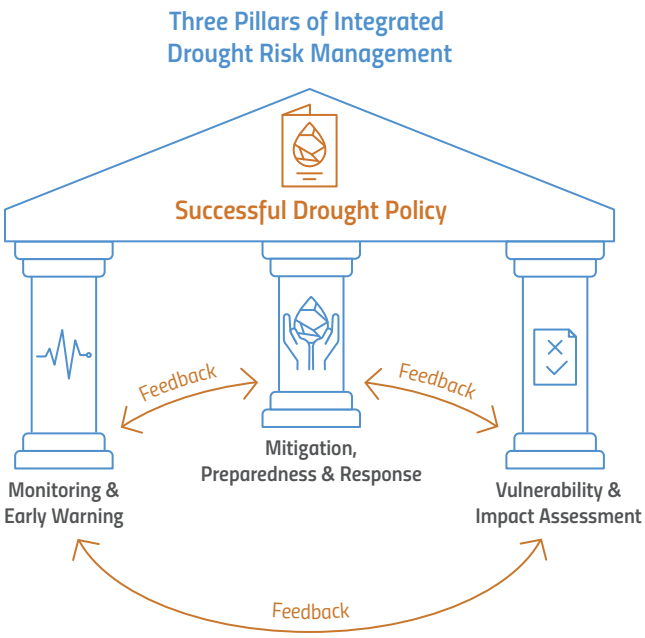


FIGURE 2

Three pillars of integrated drought risk management

Source: Integrated Drought Management Programme (IDMP)

7 See <http://www.droughtmanagement.info/pillars/>, consulted last on 27.02.2019.

These three pillars feed into drought management plans, "a planning tool that can be applied to the basin or other scale and that defines mechanisms and a methodology for detecting and predicting droughts, establishes thresholds for different stages of drought as it intensifies and recedes, defines measures to achieve specific objectives in each drought stage, ensures transparency and public participation in the development of drought strategies."[8]

D-SLM interventions can be devised and implemented at different scales, with actions at the local and national scales providing the incentive structures and enabling the environment to conduct, support or increase actions at the land users' level.

2.2 Definitions and concepts relevant to Drought-smart land management

Sustainable land management (SLM), nature-based solutions (NbS), Ecosystem-based Adaptation (EbA), and Ecosystem-based Disaster Risk Reduction (Eco-DRR) have been well recognized by scientists and policy-makers working on addressing land degradation, climate change mitigation and adaptation, biodiversity conservation and water-related disaster reduction, as proactive, effective approaches for improving long-term ecosystem and human resilience. While all of these approaches have unique features, all provide examples of land-based interventions which are relevant in the context of drought.

Land-based interventions

Land-based interventions in this report are defined as actions that are tied to the use and management of land. There is a wide range of potential interventions which confer resilience to drought, including certain types of infrastructure for water harvesting or erosion control, climate-smart agriculture practices such as conservation farming, technologies to improve water use efficiency, afforestation, and reforestation. These interventions share core characteristics from the concepts of SLM, NBS, EbA, and Eco-DRR and offer opportunities for mitigating the effects of drought and, more generally, refocusing actions on "proactive drought management", thereby increasing the resilience of ecosystems and people to drought.

8 See <http://www.droughtmanagement.info/glossary/>, consulted last on 21.11.2018

Land-based interventions of specific interest in this report are those that support the delivery of terrestrial ecosystem services as they are affected by a temporary divergence from normal trends (long term averages) in precipitation and soil moisture. These must be differentiated from those interventions targeting (permanent) water scarcity in typically dry climatic zones.

Drought-smart land management

Within the SLM-based definition of land-based interventions, this report introduces a new concept of Drought-smart land management.

D-SLM improves the resilience to drought for the land-users and society at large. Such D-SLM interventions improve the soils' capacity to accept, retain, release and transmit water, and increase plant water use efficiency. They can do so broadly by increasing the water supply where it is needed by living organisms (e.g. crop root systems) or by reducing water demand (e.g. drought-resistant crop varieties). D-SLM interventions can be devised and implemented at different scales, with actions at the local and national scales providing the incentive structures and enabling the environment to conduct, support or increase actions at

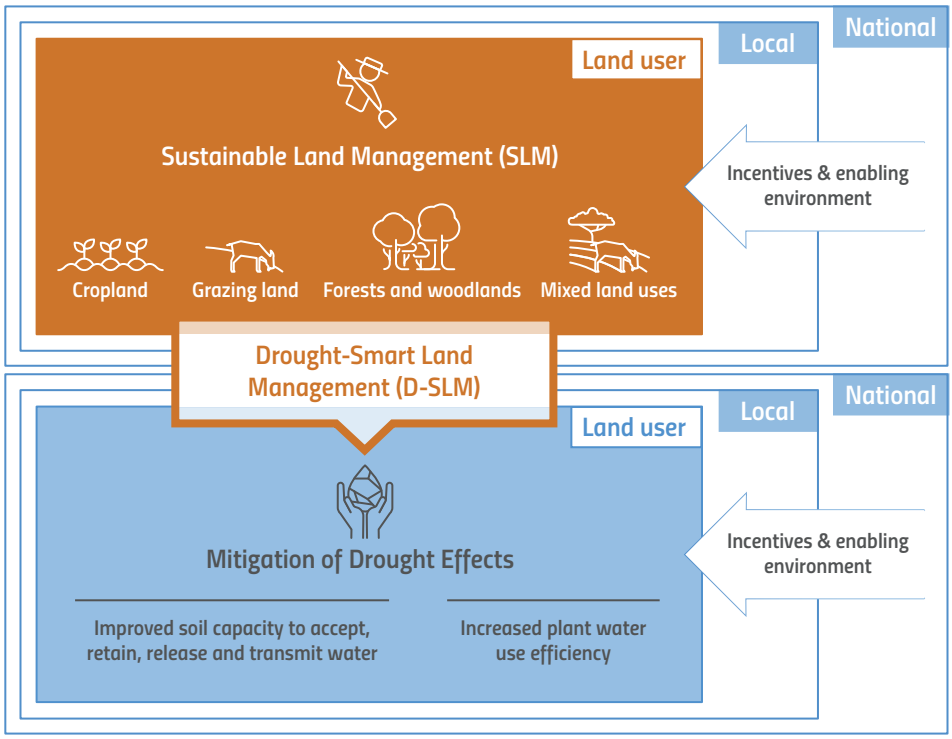


FIGURE 3
Drought-smart land management (D-SLM)

the land users' level. D-SLM interventions contribute to avoiding, reducing and reversing land degradation under the LDN framework. D-SLM also contributes to pillar 3 of Drought Risk Management, in particular as it assists in the mitigation of drought risks and of drought effects and improves preparedness. On the other hand, pillar 2 of Drought Risk Management, i.e. impact assessments, help to identify which aspects of D-SLM are most important and efficient.

Land degradation neutrality

Land degradation neutrality (LDN) is defined by the UNCCD as a state in which "the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase at special temporal and spatial scale or ecosystem" (Orr et al., 2017). The mechanism for LDN, i.e. the accounting of future gains and losses in natural land capital, makes explicit reference to sustainable land management and its practices as tools for avoiding, reducing or reversing land degradation. D-SLM practices Implementation in context of LDN through integrated land use planning enables optimize land use land and keep in the balance of land to serve for the provision and other ecosystem services and building the resilience of communities and ecosystems.

2.3 Framework of the synthesis and assessment on Drought-smart land management

To enhance scientific understanding on the potential of land-based interventions to drought mitigation and risk management by increasing the resilience of ecosystems and the socioeconomic well-being of populations, the scoop, scale and methodology of a synthesis and assessment based on existing synthesis reports and primary literature review are framed.

2.3.1 Scope

The scope of the synthesis and assessment is defined as follows: it covers sustainable land management practices or technologies as they associate to four major land use types as defined in WOCAT (2002) and adapted in Sanz et al. (2017, p. 45). These four land use types are:

- Croplands: annual cropping, perennial cropping, tree and shrub cropping.
- Grazing lands: extensive and intensive grazing lands.
- Forests/woodlands: natural forest, forest plantations, other.
- Mixed lands: agroforestry (cropland and forest), agro-pastoralism (cropland and grazing land), agro-silvo-pastoralism (cropland, grazing land and forest), silvo-pastoralism (forest and grazing land). In this report, urban areas are also discussed within this mixed land use category.

BOX 1

Established definitions relevant to land management

Sustainable land management

Sustainable land management (SLM) seeks to integrate the management of land, water, biodiversity, and other environmental resources to meet current and future human needs while sustaining ecosystem services (World Bank, 2006). A specific SLM technology, in this regard, is a practice, consisting of one or several agronomic, vegetative, structural, and management measures, applied in the field to control land degradation and/or to enhance land productivity (adapted from WOCAT glossary). This definition outlines a broad set of SLM practices, a significant number of which can serve as land-based interventions for drought risk mitigation.

Nature-based solutions

D-SLM belongs to the group of nature-based solutions (NbS). Many different definitions exist but, in a nutshell, NBS are inspired and supported by nature and use, or mimic, natural processes (European Commission, 2015). An NBS can involve conserving or rehabilitating natural ecosystems and/or the enhancement or creation of natural processes in modified or artificial ecosystems. NBS offer unique and effective solutions to climate change. The underlying approach is a pro-active application of the sustainable management and conservation of natural resources to address major global challenges (food security, Disaster Risk Reduction, economy) (IUCN, 2012).

Ecosystem-based approaches to climate change adaptation and Disaster Risk Reduction

D-SLM belongs to the group of Ecosystem-based approaches to climate change adaptation and Disaster Risk Reduction. These are holistic approaches that use biodiversity, and ecosystem functions and services to manage the risks of climate-related impacts and disasters. Ecosystem-based Adaptation (EbA) is the use of biodiversity and ecosystem functions and services, as part of an overall adaptation strategy, contributing to the well-being of societies, including indigenous peoples and local communities, and helping people adapt to the adverse effects of climate change. EbA aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change (CBD, 2009). Ecosystem-based Disaster Risk Reduction (Eco-DRR) is the holistic, sustainable management, conservation and restoration of ecosystems to reduce disaster risk, with the aim of achieving sustainable and resilient development (Estrella and Saalismaa, 2013). Voluntary guidelines for the design and effective implementation of EbA and Eco-DRR were adopted by the Conference of the Parties to the Convention on Biological Diversity during its fourteenth meeting in November 2018.

Although the world's drylands are vulnerable and threatened by land degradation and drought, the scope of this report goes beyond drylands, since both drought and land degradation are a global phenomenon, not limited to drylands.

Although the world's drylands are vulnerable and threatened by land degradation and drought, the scope of this report goes beyond drylands, since both drought and land degradation are a global phenomenon, not limited to drylands. Agriculture has traditionally been the main drought-sensitive sector, although other sectors such as water transport, energy, and tourism are increasingly affected and recognized as such.9 Unlike these other sectors though, the role of water in agriculture is very difficult to substitute. There are also very limited options to substitute for agriculture to provide food, and land-based interventions are key tools to increase the ecosystem and social resilience of the sector to droughts. The scope of this synthesis and assessment also includes silviculture: together with agriculture, the two sectors cover a very large share of the managed terrestrial ecosystem services.

The synthesis and assessment result are structured around land-use types, as many decisions on land-based interventions are taken and implemented by the land-users themselves. Across all land use types, Sanz et al. (2017) define fourteen groups of SLM "technologies" (or practices) under which specific technologies can be classified. In this report, we apply these terms globally. They are:

1. Integrated soil fertility management,
2. Minimum soil disturbance,
3. Pest and diseases control,
4. Soil erosion control,
5. Vegetation management,
6. Water management,
7. Reducing deforestation,
8. Afforestation and reforestation,
9. Sustainable forest management,
10. Forest restoration,
11. Grazing pressure management,
12. Animal waste management,
13. Agroforestry (trees combined with crops, grasses and/or animals),
14. Agro-pastoralism (animals grazing or feeding of crop residues and grazing of fallow land).

To the extent possible, the review of the impacts of SLM technologies on drought risk mitigation will conform to the above typologies. The value of doing so is that it will highlight if impacts on drought resilience are realized more easily or systematically for specific (combinations of) land use types and categories of SLM innovations. This may help to draw policy conclusions based on common denominators across very specific examples and case studies found in the literature and to move away from purely case-specific recommendations.

The final element in determining the scope of the assessment is in the categorization of the impacts of these technologies or practices on the mitigation of drought effects, which can be either a) direct, meaning they impact the variability of water availability/moisture (i.e. not water scarcity) or b) indirect, meaning they impact on the land users' capacity to respond to drought by adapting to (temporally) drier conditions. As the definition of an indicator

9 See Wilhite, Svoboda and Hayes, 2007, on the impacts of drought in the USA, and WMO & GWP, 2014, for a global perspective.

benchmarks for drought, drought risks, and impacts are by nature highly case specific, working with these different levels of classifications is necessary to reach more systematic conclusions.

2.3.2 Scale

The geographical scale framing the report focuses on the land users' level, where most land use decisions are taken and SLM technologies applied. This "micro-scale" focus stems from the observation that the importance of micro-scale drought mitigation activities is often underappreciated (Gerber and Mirzabaev, 2017). Yet, it is reasonable to assume that those suffering directly from the effects of drought, the land users, should have the strongest incentives to act in a way that increases their resilience to drought effects. If they do not, it is likely that their capability to do so is constrained. **Hence, this report also seeks to relate to the local and national level, where policies are decided and applied, thus determining critical elements of the land users' "enabling environment". The report differentiates here between interventions at the local and national scales that directly have an impact on drought risk mitigation (e.g. the construction of an irrigation infrastructure) and those that shape the enabling environment of the land users and incentivize either SLM practices, or build resilience to drought, or both (e.g. secure land tenure regimes, subsidies for small-scale irrigation technologies, etc.).**

The time scale of both the land-based interventions and their potential co-benefits for drought risk management is the final element to be considered in this report. The timing of the implementation of SLM technologies, the time scale to be considered to capture their primary, intended impacts and the time scale that would allow to capture increased drought resilience are potentially not aligned. Indeed, OECD (2016) considers ex-ante risk mitigation strategies such as drought risk mitigation as long-term strategies (as opposed to short term, ex-post crisis management). On the other hand, many SLM have a much shorter-term impact (e.g. bunds or terraces have a rather immediate effect in stopping erosion), with bigger impacts if sustained over a long period of time. Some SLM technologies have high upfront costs, but lower maintenance costs (e.g. erosion control through terracing), while others require relatively small but repeated investments (e.g. rotational grazing, microfertilization, etc.). **It is thus conceivable that the attribution of the impact of SLM technologies on drought resilience is technically extremely challenging. This issue is not explicitly covered in the literature reviewed and this report reflects this situation: D-SLM strategies are assessed separately for their economic viability (shorter-term, direct impacts) and for their impacts on (longer-term) social resilience.**

2.3.3 Methodology

The methodology is based on a literature review and assessment. This starts with the systematic review and assessment of the key documents provided by the UNCCD secretariat under the call to which this report is responding, which provide an excellent connection to experience with and actions against drought and land degradation. Additional literature has been provided by the Working Group 2 of the SPI.

The list of primary sources was extended, firstly by applying a "snowballing" approach: the technical and scientific publications referenced in the key documents mentioned above were consulted, always with the aim to get to the original source providing the evidence of the impacts of D-SLM.

This snowballing approach was complemented by a literature search. Using a stepwise search of keywords using the Google Scholar scientific search engine, the search helps to identify the latest publications that may fill the gaps in the earlier assessments of the literature. The filters and keywords applied during the search are linked to specific D-SLM interventions selected from the groups of SLM practices and their list of specific interventions presented in Sanz et al. (2017).

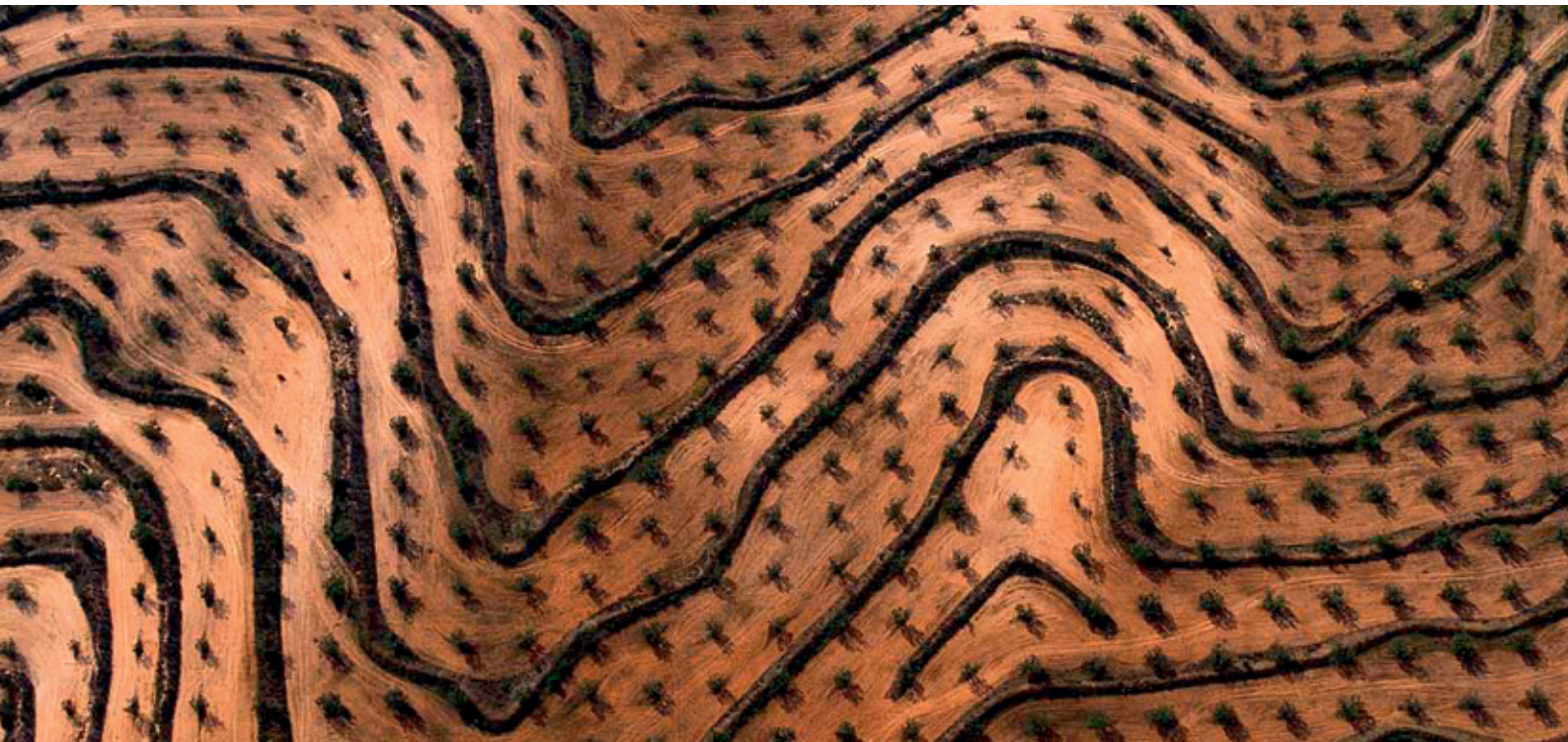
For instance: Sanz et al. (2017) report that integrated soil fertility management can provide a range of services addressing land degradation and climate change adaptation. Following this information, a Google Scholar search was conducted using the combination of keywords such as "composting and yields", "biochar, carbon sequestration", "integrated soil fertility management and food security", etc. The review and assessment prioritized the more recently published literature (since 2008), but takes into consideration older, still relevant and important publications as well. The emphasis of the review is on peer-reviewed literature, supplemented by relevant sources of grey literature.

The methodology, i.e. the reliance of key material provided by the UNCCD secretariat and the additional scientific literature search, is the result of two main elements:

1. The precise objective of this scientific report determined by the UNCCD secretariat and during the consultation with the SPI Working Group 2 (meeting of October 11th, 2018, and subsequent exchanges between the consulting team and the SPI members).

2. The concordance between the objective and scope of the report and the effective success of the literature search in uncovering objective, evidence-based accounts of the impacts of land-based interventions on drought risk mitigation (DRM).

Assessment on D-SLM to avoid, reduce and reverse land degradation contributes to drought mitigation and risk management are framed with land users and practical focus, gender perspective and separated short term (for economic resilience) and long term (for ecosystem and social resilience) benefits consideration.



Effectiveness and co-benefits of Drought-smart land management

3.1. Synthesis of Drought-smart land management practices 44

3.2. Assessment of Drought-smart land management practices 50

Sound science evidence shows potential of 14 groups of D-SLM measures in four land use types to positively contribute to drought risk mitigation, land degradation neutrality, biodiversity conservation, soil carbon sequestration, and allow for improved drought resilience without curtailing farmers' economic benefits.

This chapter presents a synthesis and assessment of D-SLM practices which *improve soils' capacity to accept, retain, release and transmit water, and increase plant water use efficiency* (Sanz et al., 2017), thus enhancing drought resilience. It is recognized that all SLM measures can indirectly contribute to drought resilience by improving soil fertility and enhancing economic and social resilience against a variety of shocks, including extreme weather events (Sanz et al., 2017).

This cross-mapping of D-SLM practices to LDN hierarchy is intended for facilitating their mainstreaming under national LDN commitments (Global Mechanism, 2017).

3.1. Synthesis of Drought-smart land management practices

This section, firstly, takes stock of land-based interventions for drought risk mitigation, referring to them as D-SLM practices, under major land use types, namely: croplands, grazing lands, forests and woodlands, and mixed land uses. This classification adopts WOCAT's classification of land use types, which has been endorsed by the UNCCD as the primary recommended database for the reporting on best SLM practices. The synthesis also links them to the LDN hierarchy of avoiding, reducing and reversing land degradation (Cowie et al., 2018; Orr et al., 2017). This cross-mapping of D-SLM practices to LDN hierarchy is intended for facilitating their mainstreaming under national LDN commitments (Global Mechanism, 2017). Due to space limitations, the definitions of the specific D-SLM practices are given in Annex 1.

3.1.1 Croplands

D-SLM practices contribute to drought risk mitigation in croplands by improving components of the production system enhancing soil moisture holding capacity, water infiltration and availability, and by reducing water losses, through a variety of measures controlling soil erosion, minimizing or controlling soil disturbance and improving soil water retention, enhancing soil fertility, improving water and vegetation management.

Controlling soil erosion. D-SLM practices for controlling soil erosion, either by water or wind, help maintain soil organic matter and fertility, and increase water infiltration, thus increasing water and nutrient availability for plant growth and increasing the resilience of crops against droughts (Maetens et al., 2012). Such soil erosion control measures include interventions that reduce wind and runoff velocity, namely: 1) vegetative barriers, shelterbelts and strips (grass strips, shrub and tree buffers), organic trash lines (e.g. Emikikizo in Uganda) (Liniger & Critchley, 2007), and increasing soil cover through cover crops and mulching, 2) structural barriers including soil bunds, semi-circular bunds, stone lines and walls (e.g. Mitsheto in South Africa), bench and sloping terraces (e.g. Fanya juu in Kenya and Tanzania, Zhuanglang loess terraces in China), and check dams (Wei et al., 2016). Terracing practices help reduce soil erosion and allow for soil water recharge (Wei et al., 2016). These D-SLM practices primarily contribute to avoiding and reducing land degradation. They have a relatively limited impact for reversing land degradation.

Minimizing or controlling soil disturbance and improving soil water retention. Long-term use of conventional tillage practices can compromise soil water retention capacity, whereas practices for minimizing soil disturbance, such as various methods of reduced tillage: zero tillage, minimum tillage with mulching, and ridge or contour tillage, improve soil physical quality, maintain higher soil moisture, enhance soil biological activity and add to soil organic carbon (Acharya et al., 1998; Klik & Eitzinger, 2010; Lanckriet et al., 2012). Soil disturbance is also reduced by planting cover crops, including for green manure and mulching (Almagro et al., 2013; Celano et al., 2011). Cover crops and mulching increase soil water content and soil carbon, by reducing water runoff and evaporation from the soil surface and increasing water infiltration to soils (Basche, 2017). Reduced tillage and mulching could be combined with crop rotations, in what is called as conservation agriculture practices (Derpsch, 2005; Hobbs et al., 2008; Kienzler et al., 2012; Scopel et al., 2013). In the cases of compacted soils, with root-restricting layers, on the other hand, mechanical disruption through deep ripping can be used to loosen compacted soils and improved their water permeability (Harari, Gavilano, & Liniger, 2017). Laser land levelling helps improve water application efficiency (Abdullaev et al., 2007; Aryal et al., 2015; Kaur et al., 2012). Precision levelling of fields reduced irrigation demands by 20-30% in grain production in Arizona, USA (Vickers, 2018). D-SLM measures for minimizing soil disturbance contribute to avoiding and reducing land degradation. In some cases, for example, planting cover crops and applying mulch can help reverse land degradation.

These D-SLM practices primarily contribute to avoiding and reducing land degradation.

Integrated soil fertility management seeks to optimize soil nutrients and water for crop growth (Obia et al., 2016; Sanz et al., 2017; Woolf et al., 2010), which is achieved by combining the application of chemical and organic soil additives, such as livestock manure, compost (Bekchanov & Mirzabaev, 2018; Doan et al., 2015), green manure (Cherr et al., 2006; Garcia-Franco et al., 2015; Zhang et al., 2017), bio-humus and biochar (Singh & Cowie, 2015; Van Zwieten et al., 2010), including using such indigenous practices as Terra Preta raised garden beds (Haiti), and key hole gardens (Lesotho) (Harari et al., 2017), chinampas (using interweaving reeds in water bodies to create plots for crop production) and milpas (shifting cultivation) in Mexico (Saavedra et al., 2017). Integrated soil fertility management practices contribute to all three categories of the LDN hierarchy of avoiding, reducing and reversing land degradation.

Improved water management, including such practices as more precise irrigation scheduling and rates, drip irrigation, spate irrigation, sub-soil drip irrigation, irrigation at night to avoid evaporative losses, and deficit irrigation allow for water-savings in crop production (Chai et al., 2016; Harari et al., 2017; Sanz et al., 2017). Resilience against droughts in rainfed crop production could also be enhanced by supplemental irrigation using various rainwater harvesting techniques (Akhtar et al., 2016). There are numerous examples of rainwater harvesting techniques adapted to local conditions across the world, such as Zai pits (Burkina Faso) (Nyamekye et al., 2018), Tassa (Niger) (Bouzou Moussa & Dan Lamso, 2004), Ndiva (Tanzania) (Enfors & Gordon, 2008), sub-surface water harvesting, kyariz systems (Turkmenistan) (Bekturova & Romanova, 2007), rock catchment, pond sand filter (PSF) and others (Harari et al., 2017; Oweis et al., 2012). Increasing the water retention capacity at a large scale could be achieved by the construction of water reservoirs, retention pits, farm ponds, etc. and by reducing the water losses through seepage in irrigation channels. Water reservoirs and rainwater harvesting also allow for off-season irrigation. Supplemental irrigation using groundwater was found to have led to groundwater depletion and secondary salinization in many contexts (de Graaf et al., 2017; MacDonald et al., 2016; Parisi et al., 2018; Russo & Lall, 2017), requiring careful planning and regulation of accompanying drainage systems and groundwater use rates. Soil moisture sensors and smart irrigation meters (Aqeel-ur-Rehman et al., 2014; Haley & Dukes, 2012; Vellidis et al., 2008), sap flow meters (Han et al., 2018), marginal water reuse (Qadir & Oster, 2004; Qadir et al., 2010), drones and remote sensing technologies for targeted monitoring of plant water needs (Lawley et al., 2016), and advanced irrigation scheduling customized to real weather conditions contribute to improving water use efficiency in drought-prone areas (Vickers, 2018). Such soil moisture meters and precision irrigation reduced water requirements by 30% in almond (Prunus dulcis) plantations in central California, USA (Vickers, 2018). Deficit irrigation, e.g. through partial root zone irrigation, was found to lead to the same level of crop yields but using 20 to 30% less irrigation water (Chai et al., 2016). Improved water management practices, depending on the context, can contribute to all of the LDN categories of avoiding, reducing or reversing land degradation.

Improved vegetation management measures include weed control reducing water losses by weed growth and allowing crops to receive more water (Singh et al., 2008). Weed control measures, especially when coupled with integrated pest management practices, also allow for reducing the application of herbicides

and pesticides, thus, helping avoid deterioration of the quality of surface and groundwaters (Bossio et al., 2010). Introducing drought-resistant crops and crop varieties, including often neglected and under-utilized crops, adopting deep-rooting crops, improving plant nutrition for early root development are yet another set of D-SLM activities to enhance crop drought resilience. Other improved vegetation management approaches include diversified crop rotations, e.g. with legumes (Biederbeck et al., 2005; Lenssen et al., 2007), transitions to agro-forestry practices, land use changes from croplands to grazing lands (Harari et al., 2017). For instance, legume-based crop rotations improved water infiltration between 70% to 238% in agronomic experiments in Malawi, Mozambique, Zambia and Zimbabwe (Thierfelder et al., 2013). These D-SLM practices of improved vegetation management contribute to all of the LDN categories of avoiding, reducing or reversing land degradation.

3.1.2 Grazing lands

Grazing pressure management practices were a major form of D-SLM practices widely used in grazing lands throughout the history in order to cope against droughts. A prime example of these practices is a long-distance rotational grazing, usually associated with nomadic pastoralism (Dong, 2016). Presently, due to increasing conversion of rangelands to crop production and subsequent fragmentation of the expanse of grazing lands (Behnke, 2008; Goldman & Riosmena, 2013; Hobbs et al., 2008; Stokes et al., 2006) such practices of long-distance rotational grazing are increasingly marginalized. Rotational grazing approaches help reduce rangeland degradation by modifying and spreading out grazing pressure (Harari et al., 2017; Mirzabaev et al., 2016). However, when confronted with droughts, which are a frequent and regular feature of most rangelands, local rotational grazing is often insufficient, and other measures need to be used, such as long-distance movement of livestock to areas not affected or less affected by drought (Mirzabaev et al., 2016), in situ drought survival stall feeding of livestock, and establishment of fodder banks can allow for minimizing livestock losses (Ben Salem & Smith, 2008; Bennison et al., 1997; Jordaan et al., 2018; Kurade et al., 2017). Herd management practices involve the choice of species composition that maximizes the pastoralist's capacity to overcome drought impacts without depleting their livestock asset base. At the same time, reducing livestock mortality during droughts may have unintended consequences of constraining post-drought recovery of rangelands, requiring measures for continued feed supplementation even after droughts in order to allow for pasture recovery (Schulze et al., 2016). Grazing pressure management practices contribute to avoiding and reducing land degradation, they are also useful for reversing land degradation, but to a lesser extent.

Water management is another key area for improving livestock resilience to droughts. Rotational grazing is facilitated by placement of watering points, i.e. wells, where livestock could be watered using groundwater, along the grazing routes (Harari et al., 2017). Where the availability of groundwater allows, it can be also used for supplemental irrigation of pasturelands when meteorological drought does not allow for sufficient precipitation for forage growth (Oweis et al., 2012). Rotational grazing approaches are also combined by area enclosures and rangeland resting. The forage in enclosed areas could be kept for feeding to livestock during drought years, thus, serving as drought-time reserves of fodder (Liniger & Critchley, 2007). Water management practices contribute primarily to avoiding and reducing

land degradation, but also could be used for reversing land degradation when pastures are re-seeded using supplemental irrigation.

Vegetation management by the establishment of deep-rooting forage plants, which are more resilience to droughts than shallow rooting forage plants, in grazing lands both increase carbon sequestration (Fisher et al., 1994) and also make more forage available for grazing during drought periods (Sanz et al., 2017). However, when introducing new grass species precautions need to be taken to avoid local biodiversity losses (Gibbons et al., 2017). Sustainable vegetation management in rangelands also involves appropriate fire management (du Toit et al., 2015; Limb et al., 2016; Scholes & Merwe, 1996). Application of phosphorus and treatment with herbicides allowed to maintain grasslands for a longer time after fires in Mediterranean batha communities delaying shrub encroachment (Henkin & Seligman, 2011). Shifting to agro-pastoral systems, where free-ranging livestock production is combined with stall-feeding using fodder produced on-farm could be another way for boosting drought resilience in rangeland areas (Sanz et al., 2017). These D-SLM practices of improved vegetation management contribute to all of the LDN categories of avoiding, reducing or reversing grazing land degradation.

3.1.3 Forests and woodlands

Forests play an important role in shaping local micro-climate, they contribute to water protection and reducing the risks of droughts (Sanz et al., 2017). For example, the Amazon forest transpiration was found to contribute to about one-third of precipitation falling across the Amazon region (Staal et al., 2018). The contribution of **afforestation, reforestation, and of reducing deforestation** to drought resilience consists in improved provision of forest ecosystem services, particularly, water conservation and regulation. WOCAT and Global Mechanism document successful applications of farmer-managed natural regeneration (FMNR) initiatives (Harari et al., 2017) and of reforestation measures (Global Mechanism, 2016).

Droughts increase the chances of forest fires (Brando et al., 2014; Nepstad et al., 2004). **Sustainable forest management measures** that appropriately manage forest fires and their spread serve as measures for increasing drought resilience in forested areas themselves. Such sustainable forest management measures include reducing surface fuels, decreasing the potential for human-caused forest fires, prescribed burning, and others (Nelson & Chomitz, 2011; Stephens & Ruth, 2005). Novel technological tools such as multi-sensor technologies and wireless monitoring systems can be applied to gather field ecological data for early warning of forest fires, as was done in Beijing Jiufeng National Forest Park and Inner Mongolia in China (Zheng et al., 2018). These D-SLM measures contribute to all of the LDN categories of avoiding, reducing or reversing forest degradation.

3.1.4 Mixed land uses and urban areas

Mixed land uses are those where crop production and/or animal husbandry is combined with tree plantations (Sanz et al., 2017). These refer primarily to agro-forestry and agro-pastoral systems. In addition, this section also discusses on the D-SLM practices in urban areas. Urban areas have been expanding rapidly both in terms of the territory and populations, with increasing demands for water and growing vulnerability to droughts (Güneralp, Güneralp, & Liu, 2015). For example, vulnerability of urban areas to droughts was recently vividly demonstrated by the drought impacts on Cape Town, South Africa (Wolski, 2018).

Agro-forestry and agro-pastoral systems including agri-silviculture, silvo-pastoral, and agro-silvo-pastoral contribute to soil fertility and enhance soil water retention capacity (Mbow et al., 2014; Mbow, Van Noordwijk, & Minang, 2014), and thus, when properly managed, are more resilient to droughts than single land uses (Marques et al., 2016; P. Nair, 1993; Sanz et al., 2017).

Integrated watershed management (IWM) and catchment rehabilitation are approaches that combine the management of land, water and vegetation at the watershed level to limit drought impacts. The application of watershed approaches in India increased cropping intensity by 33%, while reducing soil erosion and runoff, and improving groundwater availability (Joshi et al., 2005). Application of IWM approaches reduced water runoff and soil erosion by 27% and 89%, respectively, in Tigray, Ethiopia (Haregeweyn et al., 2012). Catchment rehabilitation, e.g. through reforestation, enhances the ecosystem functions of watersheds and allows for less soil erosion and often increases water supply (Chaturvedi et al., 2014). Integrated watershed approaches also include measures for water budgeting, i.e. allocation on water use to different types of landscapes. This is particularly important in view of increasing water use by rapidly growing urban areas (Ozturk et al., 2013).

Water management is another highly effective approach for strengthening drought resilience in mixed land uses, as well as in urban landscaping and gardening settings. Mandatory measures for restricting lawn and landscape irrigation (Vickers, 2018), adoption of high efficiency rotating spray nozzles, drip and micro-spray irrigation for gardens were shown to have high effectiveness in encouraging water conservation in urban settings (Vickers, 2018). For example, restricting the number of times lawns could be watered to twice/weekly in Dallas, USA, reduced water demand by 13% (Vickers, 2018).

Green infrastructure, including well-planned combinations of blue-green measures (water-vegetation), can help in mitigating drought impacts in urban areas (Gill et al., 2007; Young et al., 2014). The combination of blue-green measures helps drought risk mitigation in urban areas through making use of nature-based solutions for cooling via evapotranspiration, water harvesting, and groundwater during the rainy period, and use of these stored waters during drought periods (Voskamp & Van de Ven, 2015). Green infrastructure also yields additional benefits in the form of pollution reduction, carbon sequestration and biodiversity habitat in urban areas (Demuzere et al., 2014; Norton et al., 2015). Urban parks and street trees play an important role in mitigating the effects of drought in urban areas (Gillner et al., 2015). Proper selection of tree species can enhance relative humidity in urban areas and reduce air and surface temperatures (Gillner et al., 2015; Sjöman et al., 2015). Tree species selection for urban areas also needs to take into account that even during non-drought periods water supply to trees in many urban areas can be more limited than in rural settings due to impervious surfaces such as asphalt and concrete (Drunasky & Struve, 2005; Percival et al., 2006).

D-SLM measures of adopting agro-forestry and agro-pastoralist practices, water management, integrated watershed management, and urban green infrastructure contribute to all of the LDN categories of avoiding, reducing and reversing land degradation.

This is particularly crucial for assessing the resilience of poor people, who are overwhelmingly exposed to the impacts of natural hazards such as droughts, and who would benefit from interventions tying drought risk management with a global resilience package aimed at their well-being (Hallegatte et al., 2017).

3.2 Assessment of Drought-smart land management practices

In this section, the drought risk mitigation potential of the D-SLM interventions is assessed from biophysical and ecosystem health, economic viability, and social resilience dimensions. This assessment approach recognizes the coupled nature of social and ecological systems (Cherlet et al., 2018; Reynolds et al., 2007) and the fact that resilience against droughts is dependent on the integration of all the three of these dimensions (Wilhite & Pulwarty, 2017).

D-SLM practices present with both synergies and trade-offs along biophysical, economic and social dimensions, with synergies dominating in most cases (high confidence).

Drought is a business risk which farmers and other land users try to manage.

Drought is a business risk which farmers and other land users try to manage. This should provide the necessary incentives for investments in pro-active risk mitigation actions to decrease the effects of drought. Yet, lack of prior knowledge on drought occurrences (requires functioning forecasting and early warning systems) and their impacts (requires systematic data collection at the level of the land users, e.g. through advisory and extension services) are hurdles to the up-take of proactive drought risk management actions (OECD, 2016). In this context, drawing on positive collateral impacts of land-based interventions and demonstrating these impacts in the form of improved drought resilience might prove an effective strategy. These positive externalities potentially provide no-regret options for drought risk mitigation: as land-based interventions are assessed on their cost-benefit ratio in terms of (sustainable) land productivity improvements, their adoption is largely independent of their impacts on drought risk mitigation. As these impacts become more readily quantifiable, these interventions will provide the scope for important win-win situations in the land-drought nexus: their benefits in terms of increased drought resilience can reinforce their adoption and/or the extent of their application, thus creating positive spill-over effects in the form of land productivity gains, and vice-versa. Further, from an economic perspective, it is important that land-based interventions and their positive externalities in terms of drought resilience are defined in such a way that they capture indirect effects through increased resilience for intermediary outcomes (e.g. crop yields) as well as end-of-the-line outcome indicators (e.g. income, well-being, health, etc.). This is particularly crucial for assessing the

resilience of poor people, who are overwhelmingly exposed to the impacts of natural hazards such as droughts, and who would benefit from interventions tying drought risk management with a global resilience package aimed at their well-being (Hallegatte et al., 2017).

3.2.1 Previous related assessments of the impacts of SLM practices

In the Report of the SPI of the UNCCD on the role of SLM practices for climate change mitigation and adaptation, Sanz et al. (2017) indicated that integrated soil fertility management approaches such as application of biochar, bio-humus, and compost, changing fertilizer application rates, timing and precision, and microfertilization have the biggest impact on soil water availability and retention. Whereas, soil erosion control measures such as terracing, bunds, tree and grass strips, and measures to reduce soil disturbance such as conservation tillage and mulching, are suggested to have medium impact on soil water availability and retention (Sanz et al., 2017). Finally, water management technologies such as spate irrigation, micro-irrigation schemes, spiral water pumps, and subsurface drainage, and water harvesting are indicated to have the least impact on water availability and retention (Sanz et al., 2017).

Another comprehensive analysis of the sustainable land management practices compiled under the UNCCD-endorsed WOCAT database by Liniger & Critchley (2007) reached slightly different conclusions and indicated that SLM measures such as terraces, grazing land management, agroforestry, conservation agriculture, manuring/composting, water harvesting, had medium and high positive impacts on soil moisture (Liniger & Critchley, 2007). Among the SLM technologies considered only vegetative strips were found to have a low impact on soil moisture (Liniger & Critchley, 2007).

3.2.2 Biophysical and ecosystem health

Adoption of D-SLM practices alleviates the negative impacts of droughts on the productivity of croplands, grazing lands, forests and woodlands, and mixed land uses, including under climate change (Delgado et al., 2013; Eekhout & de Vente, 2019; Gerber & Mirzabaev, 2017; Sanz et al., 2017) (robust evidence, high agreement).[10]

Adoption of D-SLM practices alleviates the negative impacts of droughts on the productivity of croplands, grazing lands, forests and woodlands, and mixed land uses, including under climate change.

There is *high confidence* that most D-SLM practices contribute to higher crop yields, especially after a long-term application, under water shortages and marginal soils.

Integrated soil fertility management and green manuring considerably increase crop yields, particularly when customized to local conditions (Wu & Ma, 2015). Application of compost and livestock manure doubled maize (*Zea mays L.*) yields in Kenya (Hine & Pretty, 2008), doubled or tripled millet (*Panicum miliaceum*) and groundnut (*Arachis hypogaea*) yields

10 The presented assessment makes use of IPCC uncertainty language style, as presented at <http://www.ipcc-wg2.awi.de/guidancepaper/ar5_uncertainty-guidance-note.pdf>. Depending on the feedback from UNCCD/SPI, these assessment terms could be modified based on UNCCD/SPI style.

in Senegal (Parrott & Marsden, 2002), tripled or quadrupled potato (Solanum tuberosum) yields in Bolivia (Scialabba & Hattam, 2002). On the other hand, low compost application doses did not have any impacts on crop yields during a three-year experiment in Virginia, USA, despite improving soil bulk density and porosity, implying that a longer period is needed for the materialization of compost application benefits in terms of crop yields (Evanylo et al., 2008). An experiment in Melle, Belgium, showed compost application started having positive effects on yields only in the fourth year (D'Hose, et al., 2012).

The yield impacts of biochar application are heterogeneous and depend on biochar type and soil conditions (Alburquerque et al., 2013). A review by Ali et al. (2017) showed that biochar application can help alleviate salt and drought stress in plants. A half of the studies on the impact of biochar application on crop yields reviewed by Spokas et al. (2012) showed yield increases, while the other half showed yield declines or no impacts. A meta-analysis by Crane-Droesch et al. (2013) showed that crop yields in soils with low cation exchange and low carbon responded positively to biochar application, while more fertile soils were less likely to benefit from additional biochar application (Crane-Droesch et al., 2013). Biochar application to ferrisols was found to significantly increase wheat (*Triticum aestivum*), radish (*Raphanus raphanistrum subsp. sativus*) and soybean (*Glycine max*) biomass productivity under a glasshouse study in Australia (Van Zwieten et al., 2010). In Tai Lake plain, China, biochar amendments of 10 t ha^{-1} and 40 t ha^{-1} raised rice (*Oryza sativa* (L.)) yields by 12% and 14% in unfertilized soils, and by 8.8% and 12.1% in soils with nitrogen fertilization (Zhang et al., 2010). In sandy acidic soils of western Zambia, application of maize cob biochar and wood biochar together with conservation tillage increased maize yields by three to four times (Cornelissen et al., 2013). However, in soils with acidic and neutral clay loams and silty clay with variable cation exchange capacity, such biochar application had no impact on maize yields (Cornelissen et al., 2013).

Erosion control measures, such as the use of contour hedgerows in the sloping areas of the Philippines resulted in 15% higher yields than under traditional practices (Shively, 1999). Establishment of vegetative strips around agricultural fields increased crop yields in central Sulawesi, Indonesia, by providing habitats for crop pollinators (Hoehn et al., 2008). The use of stone bunds increased grain yields by 41% in the arid and semi-arid areas of Burkina Faso (Dutilly-Diane et al., 2003). Stone bunds were found to be particularly conducive to higher crop productivity in semi-arid areas, rather than in areas with higher rainfall levels (Kassie et al., 2008). Adoption of ridging in rice cultivation in Ghana increased yields by 24% (Abdulai & Huffman, 2014). The long-term yields of teff (*Eragrostis Tef* (ZUCC)), barley (*Hordeum vulgare*) and maize on terraced fields in Ethiopia were twice or three times higher than in fields without terracing (Adgo et al., 2013). Application of laser land levelling increased rice and wheat yields by about 7-9% in India (Aryal et al., 2015), and cotton (*Gossypium hirsutum*) yields from 8% to 59% in Tajikistan (Abdullaev et al., 2007).

Minimizing soil disturbance through conservation agriculture (CA) practices have positive impacts in terms of improving soil moisture and topsoil organic matter (Palm et al., 2014), in many cases, resulting in higher crop yields, especially in well-drained soils prone to soil erosion (Govaerts et al., 2007; Zhang et al., 2009). A global meta-analysis by Pittelkow et al. (2015) showed that single no-till practices,

on average, led to lower crop yields; however, when they were combined with other elements of conservation agriculture, i.e. mulching and crop rotations, they resulted in higher yields, particularly in drier environments (Pittelkow et al., 2015). In Eastern and Southern Africa, the adoption of conservation agriculture practices led to increases in maize and teff yields between 20% to 120% (Rockström et al., 2009). The impact of conservation agricultural practices on maize, millet, and sorghum (*Sorghum Bicolor* (L.)) yields showed greater heterogeneity in Western Africa, but the average effects were found to be positive (Bayala et al., 2012). Fasinmirin & Reichert (2011) found that cassava (*Manihot esculenta* (CRANTZ)) yields were higher under no-tillage practices than conventional tillage practices in the tropics. In the Eastern Gangetic Plains in South Asia, although rice and wheat yields were higher under conventional tillage during the initial period, yields under conservation tillage practices surpassed those under conventional tillage starting the second year for wheat, and the sixth year for rice (Jat et al., 2014). On the other hand, the dependence of CA practices on higher pesticide use is one of their disadvantages. As a result, without application of herbicides, and in soils with nitrogen deficiency, the yields declined, especially in the short-run after the establishment of CA practices (Farina et al., 2011; Soler et al., 2011; Verhulst et al., 2011). In Segura river catchment in Spain, the application of reduced tillage and green manure, was found capable to significantly mitigate crop water stress due to increased water scarcity under climate change (Eekhout & de Vente, 2019). Similarly, inclusion of cover crops was also found to lead to higher crop yields (Altieri, 1999; Branca et al., 2011; Chabi-Olaye et al., 2007; Pretty, 1999), including through increasing soil organic carbon (Poeplau & Don, 2015), weed control and nitrogen supply (Campiglia et al., 2010).

Water harvesting, and supplemental irrigation technologies help increase yields and stabilize farmer incomes in the face of climatic variability (Fox & Rockström, 2003; Makurira et al., 2007; Ngigi, 2003) (*robust evidence, high agreement*). A combination of supplemental irrigation using rainwater harvesting, nutrient management, and improved tillage increased maize and sorghum yields in Kenya and Burkina Faso by 70% to 300%, respectively (Rockström et al., 2002). On the other hand, in settings when small-scale irrigation systems based on water harvesting are over-used, water harvesting technologies were no longer sufficient to cope with droughts (Enfors & Gordon, 2008). Rainwater harvesting approaches combining planting and infiltration pits did not result in higher crop yields in Zimbabwe: maize yields were 45% higher under conventional tillage than with planting pits. However, the yield differential declined to 30% in the third year (Nyakudya et al., 2014). Application of drip irrigation technologies resulted in lower yields of cotton compared to full irrigation in Turkey (Dağdelen et al., 2009), despite having higher water use efficiency per kg of produced cotton, implying that drip irrigation technologies could outperform conventional irrigation practices under water shortages, but may underperform in terms of crop yields when water availability is not a constraint (Dağdelen et al., 2009). Mitigation of drought impacts on crop yields could also be achieved by deficit irrigation (also known as supplemental irrigation), when irrigation is applied only during critical crop growth stages (Geerts & Raes, 2009). Using floodwaters for spate irrigation in arid areas of Gareh-Bygone Plain in Iran allowed to harvest 1.6 and 2.1 t ha^{-1} of barley seed and straw, whereas in the control rainfed plot, the total mass of barley seed and straw was 0.8 t ha^{-1} (Ghahari et al., 2014). Integrated watershed management approaches resulted in 250% increases in crop yields in India

(Wani et al., 2003). Long-term on-farm experiments in India showed that integrated watershed management led to increases in grain yields from 0.9 t ha^{-1} to 4.7 t ha^{-1} (Wani et al., 2003).

Improved vegetation management practices through the adoption of drought-tolerant maize varieties were shown to have 30–40% higher yields during drought years than usual varieties planted in Sub-Saharan Africa, but the same level of yield during normal years (Shiferaw et al., 2014). In many cases, agroforestry practices lead to higher crop yields in adjacent fields (Nair, 1993). However, care needs to be taken in the choice of tree species to avoid allelopathic effects on crops (Ahmed et al., 2018; Hoshi et al., 2016). The maize yields under agroforestry practices were reported to be 7–12 times higher than outside the canopy in Zambia (Yengwe et al., 2018) due to the import of nutrients through litterfall. The positive difference was especially pronounced during drought years (Yengwe et al., 2018). In Bolivia, although cocoa yields were lower under agroforestry systems compared to mono-cropping, the total amounts of all harvested products and incomes from them were higher under agroforestry systems (Schneider et al., 2017).

There is *medium confidence* that D-SLM practices for improving pasture management have positive impacts on forage production and livestock productivity under droughts. Improved pasture management involving seeding with deeper-rooting fodder crops was found to increase livestock productivity (Sleugh et al., 2000). Agropastoral practices allow for improving livestock productivity by supplemental feeding using the forage crops grown on farm (Liniger & Critchley, 2007; Sanz et al., 2017). The highest impact land-based intervention for improving water retention and forage availability in grazing lands were found to be herd management practices through lowering stocking density, whereas other interventions such as enclosures, rotational grazing, off-season irrigation were suggested to have low or moderate impact on forage availability and water retention (Sanz et al., 2017).

Corroborating this, a broader literature shows mixed evidence on the impacts of rotational grazing on forage production and livestock productivity (Briske et al., 2017; Hawkins et al., 2017). Briske et al. (2008) found that in 20 out of 23 experiments they reviewed plant production was equal or higher under continuous grazing than rotational grazing. Similarly, in 27 out of 32 experiments animal production per area was equal or higher under continuous grazing. On the other hand, rotational grazing was found to have resulted in significantly higher forage production and quality compared to continuous grazing in the upper Midwest areas in the USA (Oates et al., 2011). Rotational grazing was found to be more conducive to plant recovery after rangeland fires than continuous grazing (Teague et al., 2010). In arid and semi-arid areas, adjustments in stocking rates were more effective in improving and maintaining rangeland health than fencing or rotational grazing (Bailey & Brown, 2011). In Central Asia, continuous grazing of livestock near settlements led to land degradation (Kerven et al., 2008), whereas pooling of livestock herds to allow migratory grazing to remote pastures increased economic profitability of livestock production (Mirzabaev et al., 2016).

Many D-SLM practices, but not all, contribute to soil carbon sequestration (*robust evidence, high agreement*). Establishment of shrub and tree plantations for erosion control in croplands contributes to carbon sequestration in the soils. Afforestation and reforestation

are major D-SLM practices contributing to carbon sequestration (Berthrong et al., 2009; Djanibekov & Khamzina, 2016; Laganiere et al., 2010; Niu & Duiker, 2006). Globally, about 749 million hectares were identified as suitable for afforestation and reforestation activities, primarily in Latin America and Sub-Saharan Africa (Zomer et al., 2008). To illustrate, reforestation in Latin America was estimated to allow sequestering 31.09 Pg CO_2 over 40 years, offsetting all carbon emissions from fossil fuel use and industry in the region during the 1993–2014 period (Chazdon et al., 2016). Afforestation of marginal lands in the Midwest region in the USA was found to offset about 8% of the total carbon emissions from that region (Niu & Duiker, 2006). Afforestation of marginal lands in arid areas of Uzbekistan was shown to sequester 0.09–0.15 t C ha^{-1} $year^{-1}$ (Hbirkou et al., 2011). Similarly, promising opportunities for carbon sequestration are available with agroforestry practices. The carbon sequestration potential of semi-arid and arid tropics under extensive tree-intercropping systems was estimated at 5–10 kg C ha^{-1} over 25 years, while the same for humid tropics was 100–250 kg C ha^{-1} over ten years in perennial systems and home gardens (Nair et al., 2009).

Integrated soil fertility management and green manuring, in addition to its positive impacts on soil carbon, reduces nitrogen leakage to the environment and related pollution, and mitigates greenhouse gas emissions (Fageria, 2007; Stavi, 2013). Biochar preparation allows to sequester about 50% of initial carbon, whereas direct burning and biological decomposition result in less than 20% sequestration of carbon (Lehmann et al., 2006). Applying biochar instead of burning in slash-and-burn systems can offset about 12% of carbon emitted through land use change annually (0.21 Pg C) (Lehmann et al., 2006). Total biochar potential for carbon sequestration was estimated at 0.7 GtCeq. yr^{-1} (Smith, 2016), corresponding to about 1.8% of total annual carbon emissions.

The evidence about the contributions of reduced tillage to carbon sequestration is mixed (Palm et al., 2014). Especially in drylands, there were cases without a consistent and measurable increase in soil organic carbon under reduced tillage practices. A meta-analysis by Luo et al., (2010) found that no-tillage practices increased soil carbon by 3.15 ± 2.42 t ha^{-1} in the top 10 cm of soil, but reduced soil carbon by 3.30 ± 1.61 t ha^{-1} in the 20–40 cm soil layer. On the other hand, there is robust evidence that cover crops help sequester carbon (Kaye & Quemada, 2017; Poeplau & Don, 2015). It was estimated that wide-spread adoption of cover crops can mitigate 10% of greenhouse gases (Kaye & Quemada, 2017). The estimates by Poeplau & Don (2015) show an annual carbon sequestration of 0.12 ± 0.03 Pg C yr^{-1} if cover crops are introduced to 25% of the global cropland area, corresponding to the removal of 8% of direct greenhouse gas emissions from agriculture.

Improving the management of degraded grazing lands will increase their sink capacity (Smith, 2014). In fact, sustainable management of grazing lands could help mitigate to a certain extent the greenhouse gas emissions from the ruminant production systems (Soussana et al., 2010), with improved grazing land management being able to sequester 148 Tg CO2 yr^{-1} (Henderson et al., 2015), corresponding to about 2.7% of greenhouse gas emissions from agriculture.

Application of D-SLM practices in degraded lands can positively affect biodiversity (medium confidence). Establishment of tree and shrub buffers, afforestation and reforestation activities in degraded lands contribute to higher

biodiversity (Bremer & Farley, 2010). In areas with natural forests, afforestation of agricultural lands contributes to biodiversity conservation through providing additional habitats, facilitating connectivity and serving as buffering edges (Brockerhoff et al., 2008). However, afforestation activities in natural non-forest areas need to take proper care of preserving the native vegetation (Brockerhoff et al., 2008). For example, afforestation in natural grasslands can threaten native plant communities and biodiversity (Buscardo et al., 2008; Veldman et al., 2015).

Vegetative strips in the margins of agricultural fields represent an important habitat for birds, arthropods, crop pollinators and pest predators (Hiron et al., 2013; Marshall & Moonen, 2002; Vickery et al., 2009; Wratten et al., 2012), especially when no other areas for harbouring biodiversity, such as forests, exist in the vicinity (Wretenberg et al., 2010). Rotational grazing practices could allow for improved reproduction and survival of such rangeland nesting birds as bobolinks (*Dolichonyx oryzivorus*) and savanna sparrows (*Passerculus sandwichensis*) in north-eastern USA (Perlut & Strong, 2011).

Reduced and no-tillage practices were found to increase the diversity of some elements in soil biota (e.g. lumbricids – i.e. earthworms) but reduce the diversity of some others (e.g. collembolans- i.e. springtails) (van Capelle et al., 2012). Similarly, Ernst & Emmerling (2009) found that direct seeding increased the diversity of anecic earthworm species (also corroborated by Peigné et al. (2009)) but reduced the density of endogeic earthworm species.

Indeed, a global assessment of returns from restoration of degraded lands showed that, on average, each dollar invested into land restoration had social returns of five dollars after a 6-year period (Nkonya et al., 2016).

Cover crops were found to increase biodiversity (Kaye & Quemada, 2017; Lal, 2004) and soil microbial abundance (Maul et al., 2014). Use of native cover crops, such as grasses *Austrodanthonia richardsonii* and *Chloris truncata* and a mix of saltbushes *Atriplex semibaccata* and *Atriplex suberecta*, led to a higher number of beneficial invertebrates contributing to pest control in Australian vineyards. However, a proper care needs to be taken for them not to increase also local pest numbers (Danne et al., 2010).

Integrated watershed management approaches that prioritized the conservation of biodiversity were found to yield successful results in the Chittagong Hill Tracts, Bangladesh (Biswas et al., 2012). Similar conclusions on the positive role of integrated watershed management on biodiversity, especially in a fragile ecosystem, were reached for Rajasthan, India (Pathak et al., 2013) and Los Negros, Bolivia (Asquith & Vargas, 2008).

3.2.3 Economic viability

D-SLM practices have higher economic returns than conventional practices under droughts and in marginal soils. Many D-SLM practices, but not all, allow for improved drought resilience without curtailing farmers' opportunities for maximizing their benefits during normal or wet years (robust evidence, medium agreement). Using the WOCAT database, Liniger & Critchley (2007) concluded that most of the D-SLM technologies, such as conservation agriculture, manuring/composting, vegetative strips and agroforestry, terraces and grazing land management practices, have neutral or even negative cost-benefit ratios in the

short-term. However, almost all of these technologies had positive cost-benefit ratios in the long-term (Liniger & Critchley, 2007). Indeed, a global assessment of returns from restoration of degraded lands showed that, on average, each dollar invested into land restoration had social returns of five dollars after a 6-year period (Nkonya et al., 2016). However, many land users, especially smallholder farming families in the developing countries, cannot afford even such relatively short return periods. This implies that land users' access to long-term financing options is a vital mechanism for wider D-SLM adoption.

To illustrate, Pannell et al. (2014) indicate that the profitability of conservation agriculture practices is heterogeneous and context-dependent. In India, conservation tillage practices became more profitable than conventional tillage in rice-wheat systems after 2–3 years of establishment (Jat et al., 2014). About half of the profits under conservation tillage practices came from higher yields, while another half came from tillage and fuel cost savings (Erenstein & Laxmi, 2008). Experimental data from Germany showed that average net returns from reduced tillage and direct seeding practices for growing cereals were at 111 Euros ha^{-1} and 55 Euros ha^{-1} after four years of trials, whereas the conventional tillage recorded net losses of seven euros ha^{-1} for the same period (Verch et al., 2009). In arid environments in Malawi, the profitability of conservation tillage practices was three times higher than that of conventional tillage in maize and legumes cultivation, whereas in high rainfall areas in Malawi conservation tillage practices still had about 23%–33% higher gross margins than conventional tillage practices (Ngwira et al., 2013). In central Kenya, application of conventional tillage in growing maize was more profitable in highly fertile soils. In contrast, conservation tillage practices showed higher profitability in less fertile fields (Guto et al., 2012). In central Pennsylvania, USA, cover crops were found to increase eight of 11 ecosystem services at different points in their growth period without negative impacts on main crop yields (Schipanski et al., 2014). However, the major drawback from using cover crops was their establishment costs, which were feasible only with higher fertilizer prices or government subsidies (Schipanski et al., 2014). Despite numerous soil and water-related benefits, adoption of legume-based rotations was not as profitable as alternative maize monocropping in several eastern and southern African countries (Thierfelder et al., 2013).

Soil erosion control measures such as ridging was found to increase net benefits from rice cultivation in Ghana by 16% (Abdulai & Huffman, 2014). In Ethiopia, soil and stone bunds and grass strips led to higher crop yields and, in the case of soil bunds, also decreased production risks in the face of climatic variability (Kato et al., 2011). Corroborating this, the application of stone bunds and stone terraces was found to increase crop revenues by 27% and 17%, respectively, in the highlands of Ethiopia (Pender & Gebremedhin, 2007). The profitability of growing teff, barley and maize with terracing was between 3 to 5 times higher than without terracing in Anjenie, Ethiopia (Adgo et al., 2013). In contrast to these, Kassie et al. (2011) found that crop incomes with *fanya juu* terraces in the same location were lower than without such terraces. Laser land levelling of fields under irrigated crop production resulted in 22% higher net profits in Tajikistan (Abdullaev et al., 2007). In India, application of laser land levelling in rice-wheat systems increased net profits by 144 USD ha^{-1} (Aryal et al., 2015).

Biochar application was found to be economically viable only to a marginal extent,

depending on the length of the period of application (Spokas et al., 2012). Application of biochar for cereal cultivation was found economically profitable when the positive effects of biochar were assumed to extend to 30 years in Sub-Saharan Africa, whereas in north-western Europe all considered scenarios of biochar application in cereal production were loss-making (Dickinson et al., 2015). In the US setting, the biochar application was not economically viable without subsidies for adoption and possibility to sell sequestered carbon (Galinato et al., 2011). Application of biochar without additional inorganic fertilizers was also not economically viable in most studied cases in four different agricultural systems in China (Clare et al., 2014).

The risk of crop failures during droughts limits smallholder farmer investments into crop productivity-enhancing investments (Cooper et al., 2008; Rockström & Barron, 2007). Many conventional farmer practices for minimizing drought impacts, such as choice of drought-tolerant but low profitable crops, low-density planting, limit the extent by which smallholders can benefit from good or normal years (Cooper et al., 2008).

Application of water saving technologies of drip irrigation allowed to save 25% of irrigation water but resulted in 34% reduction on the profitability of cotton cultivation in Turkey (Dağdelen et al., 2009). During drought periods and arid locations, application of water-saving technologies for maximizing crop water productivity is more profitable than conventional irrigation methods used for maximizing crop yields (Geerts & Raes, 2009). Application of integrated watershed management approaches showed that each dollar invested into integrated watershed management results in two dollars of return (Joshi et al., 2005). In Andhra Pradesh, India, the application of integrated watershed management approaches increased the profitability of crop production by more than three times (Wani et al., 2003).

High upfront costs represent a significant barrier for adoption of some, but not all, D-SLM practices (robust evidence, high agreement). Giger et al. (2018) analysing the WOCAT database of SLM technologies identified that the median costs of their application is about 500 USD per ha, ranging from 20 USD per ha to 5000 USD. A set of WOCAT technologies analysed by Harari et al. (2017) have costs ranging between 0 to 20,000 USD per hectare or unit. Introduction of permanent cover crops, structural measures such as terracing and bunds, require significant upfront investment costs, and often need to be subsidized (Liniger & Critchley, 2007; Sanz et al., 2017). High upfront cost and requirements of technical knowledge can prevent the adoption of such measures as perennial seed grass areas, laser land levelling, etc. The most expensive type of land-based interventions are structural measures which require, e.g. construction of terraces, semi-bunds, stone hedges. In many cases, those D-SLM interventions with low upfront costs are most promising for adoption at wider scales, such as integrated soil fertility management measures, changes in crop types (Liniger & Critchley, 2007; Sanz et al., 2017).

Subsidizing D-SLM measures is socially beneficial since they generate numerous additional non-provisioning ecosystem services. Numerous studies show that many of these land-based interventions have positive cost-benefit ratios even at the private level (Kirui, 2016; Mirzabaev et al., 2016; Mulinge et al., 2016; Nkonya et al., 2016; Pender et al., 2009), however, the social cost-benefit ratios of D-SLM practices are usually even higher (Nkonya et al., 2016). In fact, Nkonya et al. (2016) found

that only 46% of the benefits of sustainable land management are in the form of improved crop and livestock production that land users can commercialize, whereas 54% are in the form of non-provisioning ecosystem services enjoyed by the whole society. The role of subsidies for D-SLM practices is even more critical considering the time lags it takes for them to start being profitable. For example, the use of native plants instead of exotic plants for establishing gardens in California, USA, reduced water use by 77%. However, it was more expensive than planting exotic plants, but the additional costs were fully recovered in 2–3 years due to reduced maintenance costs (Vickers, 2018). The amount of subsidies needed for facilitating the uptake of D-SLM practices varies depending on the type of D-SLM technology and specific country context. For example, the adoption of direct seeding with mulching in Bac Kan, Vietnam, was estimated to require from 50 to 200 USD ha^{-1} of subsidies, which represents about 30% of the gross margins under the conventional practices (Affholder et al., 2010).

3.2.4 Social resilience

D-SLM practices enhance all dimensions of food security (medium evidence, high agreement). As seen in previous sections, D-SLM practices contribute to higher crop yields and livestock productivity, thus, improving food availability. Higher incomes that land users generate from applying D-SLM practices improve their food access. Since D-SLM practices are particularly more effective than conventional practices under drought conditions, they help smoothen drought shocks on food consumption. Diversified crop rotations, producing a larger number of crop categories, contributes to nutritional aspects of food security, especially among semi-subsistence smallholder family farms. To illustrate, rotational grazing practices were found to have positive impacts on food security in West Africa (Amole & Ayantunde, 2016). Adoption of no-till practices for growing wheat and barley improved food security in several locations across Morocco, through higher crop yields and farming incomes (Liniger & Critchley, 2007). Similar impacts were reported in Kenya with conservation tillage practices (Liniger & Critchley, 2007). Zai pits with additional manuring allowed doubling cereal yields in normal years and ensured that farmers were able to get some yields during drought years, contributing to their food security (Liniger & Critchley, 2007). Increases in cropping intensity through the application of integrated watershed management approaches in India allowed producing enough food for 18 persons per hectare of cultivated land as compared to four persons per hectare under the conventional practices (Wani et al., 2003).

Since D-SLM practices are particularly more effective than conventional practices under drought conditions, they help smoothen drought shocks on food consumption.

Higher agricultural incomes and/or lower food prices resulting from the application of D-SLM practices help reduce poverty (medium evidence, high agreement). Establishment of tree shelter beds in Inner Mongolia, China, as windbreaks in sandy areas led to higher incomes from agricultural production both through higher crop yields and rotational logging of trees without disrupting their windbreak functions (Liniger & Critchley, 2007). Reforestation of degraded sloping areas in China under the Grain for Green Program, on average, resulted

in poverty reduction for the involved communities and households, especially when additional sources of off-farm income were taken into account (Delang & Yuan, 2015). Shelterbelts planted with silky oaks (*Grevillea robusta*) along farm boundaries in Embu, Kenya, boosted crop yields by improved nutrient cycling and the addition of organic matter to soils through falling leaves (Liniger & Critchley, 2007). Moreover, the wood products from selective logging of these trees provided with an additional stream of income (Liniger & Critchley, 2007). Similar multiple income-generating functions of vegetative strips were recorded in Veneto region, Italy (Borin et al., 2010).

It was projected that the adoption of terraces and agroforestry practices in the Peruvian Andes increases per capita incomes by 15% and lowers poverty by 9%, but only with the carbon price higher than 100 US dollar per ton (Antle et al., 2007). At the carbon prices below 50 US dollars per ton, Antle et al. (2007) found limited economic potential of terraces and agroforestry practices in the same region. Similarly, erosion control measures such as stone bunds, filter walls, zaï, half-moons were found to have helped secure rural livelihoods and reduce poverty in Burkina Faso (Sawadogo, 2011). Application of integrated watershed management approaches increased water availability and allowed for diversification into higher value crops in Tad Fa and Wang Chai (Thailand), Kothapally (India) and Xiaoxincun (China) (Wani et al., 2012).

Although there is high agreement in the literature that environmental degradation and droughts have larger impacts on women than men due to women's more limited access to resources to cope with such environmental shocks (Dessy et al., 2019; Stehlik et al., 2000; Su et al., 2017; Tichagwa, 1994), there is limited evidence distinguishing gender-specific effects of these D-SLM practices. **Studies evaluating these D-SLM options from gender lens highlight higher barriers for adoption of D-SLM practices among women than among men due to more restricted access to resources and agricultural advisory services** (Centrone et al., 2017; Farnworth et al., 2016; Parks et al., 2015; Najjar et al., 2019). The impacts of D-SLM practices on women will strongly vary from place to place depending on differences in socially constructed roles for women and men prevalent in those settings. **A recent publication focusing on the connection between gender and drought (Mapedza, Giriraj, Matheswaran, Nhamo (2019)), states that "Gendered understanding of droughts will help bring out the innovative solutions that women are developing to help cope and ameliorate the impact of droughts within the developing countries. Women need to be viewed as sources of solutions as they have to deal with the consequences of drought.** Gender equality is defined by OSAGA (2001) as 'the equal rights, opportunities, and outcomes for girls and boys and women and men. It does not mean that women and men are the same, but their rights, responsibilities, and opportunities do not depend on whether they are born female or male'. This is central for better disaster management cycle from mitigation, preparedness, response and recovery (WEDO 2007)."

To support gender mainstreaming, in 2017 the UNCCD adopted its first Gender Action Plan (GAP) which called upon UNCCD stakeholders to support and build upon technical capacities in the design and implementation of gender-responsive programmes (Collantes et al.2018). Additionally. the conceptual framework presented by the SPI brings gender equality issues to the center of LDN. Unpacking the complexities of gender, will enable a better understanding of how men and women are best able to cope with droughts in the developing world (Mapedza et al. 2019).

3.2.5 Trade-offs of D-SLM practices

The previous sections have elaborated on the synergies of the D-SLM practices along various dimensions. This section, therefore, discusses on the potential trade-offs of D-SLM practices.

Most benefits of D-SLM practices occur in the longer term, while the costs are incurred upfront, limiting their adoption by risk-averse land users with low access to long-term credit (robust evidence, medium agreement). Many of the cost-benefit analyses of D-SLM technologies compare their use against the profitability of traditional practices, while ignoring auxiliary trade-offs. For example, the use of mulching and manure application are found to increase drought resilience by improving soil fertility, improving yields, reducing evaporative losses of water from soils. Compared with no mulching and no manure application where the crop yields can be lower, they have positive cost-benefit ratios. However, such analyses ignore the alternative uses of crop residues as livestock fodder rather than mulch, or of manure as household energy source instead of organic fertilizer to soils. Proper cost-benefit assessments need to take into account such opportunity costs. The use of mulch under conservation agriculture practices competes with its use as fodder for livestock (Lal, 2015), and this has been considered a major barrier for adoption of conservation agriculture practices in Sub-Saharan Africa (Palm et al., 2014). Moreover, yield losses under single no-tillage practices, and constraints to the adoption of residue retention and crop rotation were found to considerably limit the potential contribution of conservation agriculture practices to sustainable intensification and poverty reduction (Pittelkow et al., 2015). Besides a trade-off in terms of plant residue uses, a major limiting factor for the economic viability of direct-seeding with mulching in Bac Kan, Vietnam, was high labor requirements for the spreading of mulch (Affholder et al., 2010).

Many of the cost-benefit analyses of D-SLM technologies compare their use against the profitability of traditional practices, while ignoring auxiliary trade-offs.

Approaches of integrated watershed management applied in Andhra Pradesh, India, in the early 1980s showed higher profitability than conventional methods but were dis-adopted by farmers after the end of the project: main reasons than being a bias towards larger farmers, lack of farmer participation in technology development, and lack of capacity building (Wani et al., 2003). Similarly, despite positive impacts of integrated watershed management documented in Wang et al. (2016) in various locations, the major challenges included lack of coordination and of unified organization for management and clear boundaries, lack of relevant data and data sharing mechanisms for monitoring the progress and outcomes, and limited participation of the public (Wang et al., 2016).

Despite their numerous beneficial aspects, a potential trade-off of afforestation and reforestation programs in arid areas could be lower water yield and decreased water availability for other purposes (Buytaert et al., 2007; Delang & Yuan, 2015; McVicar et al., 2007). Moreover, afforestation projects conducted in grasslands were suggested to have the risk of damaging local ecosystems (Jindal et al., 2008).

One of the traditional ways for coping with drought shocks practiced by pastoralists is to maximize the herd numbers even beyond the optimal profitability levels, as the larger herds allow for smoother recovery after droughts. This practice is one of the reasons for overstocking and overgrazing in some rangeland areas (Zimmerman & Carter, 2003).

The table below summarizes the information on impacts, costs, and benefits, trade-offs and constraints along the major categories of D-SLM practices by land use, including the impacts on food security and poverty reduction. Discussed impacts on food security and poverty are relevant for both women and men.

TABLE 1

Drought-smart land management measures: impacts, costs and benefits, synergies, trade-offs and constraints

Land Use	D-SLM Category	LDN Category	Upfront Costs	Net Economic Returns	Food Security and Poverty Reduction	Trade-Offs and Constraints
Croplands	Controlling soil erosion	Avoid, Reduce, Reverse		Neutral and negative in the short term*, positive in the long-term	O	Labor availability could be a constraint
	Minimizing soil disturbance	Avoid, Reduce, Reverse		Often, but not always, positive already in the short-term	+	Competition between uses of plant residues for mulching or for livestock feeding
	Integrated soil fertility management	Avoid, Reduce, Reverse		Usually already positive in the short-term	++	Competition between uses of livestock manure as soil amendment and energy source.
	Improved water management	Avoid, Reduce, Reverse	to	Usually already positive in the short-term, especially in arid environments or where water is priced.	+	Lack of water markets and pricing can limit incentives for their adoption
	Improved vegetation management	Avoid, Reduce, Reverse	to	Usually already positive in the short-term	+	May require technical capacities for their adoption by farmers
Grazing lands	Grazing pressure management	Avoid, Reduce, Reverse		Usually already positive in the short-term	+	In some areas competes with expanding crop production
	Water management	Avoid, Reduce, Reverse	to	Limited evidence	O	Limited evidence
	Vegetation management	Avoid, Reduce, Reverse	to	Usually already positive in the short-term	+	Limited evidence
Forests/ Woodlands	Sustainable forest management, afforestation, reforestation, and of reducing deforestation	Avoid, Reduce, Reverse		Neutral and negative in the short term, positive in the long-term	+	Limited evidence
Mixed land uses	Adopting agro-forestry and agro-pastoralism	Avoid, Reduce, Reverse	to	Neutral and negative in the short term, positive in the long-term	+	Takes relatively long time for implementation
	Water management	Avoid, Reduce, Reverse	to	Usually already positive in the short-term	O	Lack of water markets and pricing can limit incentives for their adoption
	Integrated watershed management	Avoid, Reduce, Reverse		Positive in the long-term	O	Takes relatively long time for implementation
	Urban green infrastructure	Avoid, Reduce, Reverse	to	Positive	O	Requires considerable technical capacities for planning and implementation

Avoid
Reduce
Reverse

O Limited evidence

Source: the authors' compilation based on literature.
*Note: Drought-smart land management (D-SLM). *Short-term – one or two growing seasons.*

To improve drought resilience of the people and ecosystem, we need to remove the barriers for adoption of D-SLM practices among women, to support access to resources and agricultural advisory services.

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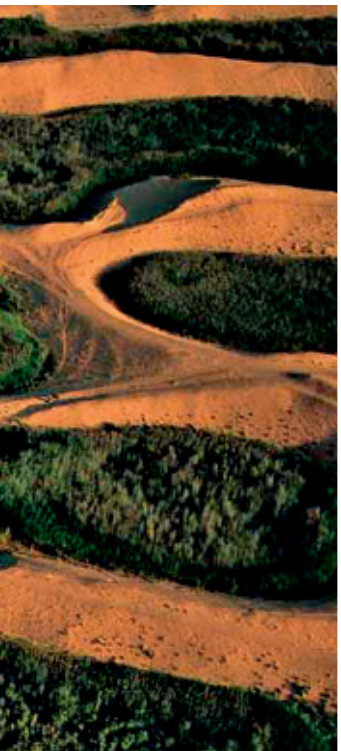


Enabling policies and tools for upscaling Drought-smart land management

A set of 5 enablers: landscape approach, capacity development, good land and water governance, geospatial analysis, and finance, to foster adoption and implementation of land-based interventions for drought mitigation and risk management.

This chapter provides technical guidance on how to foster land-based interventions for drought mitigation. It proposes a set of five enablers for a sustainable upscaling of D-SLM. They include: a landscape approach, capacity development, good land and water governance, geospatial analysis, and finance. Each one of these enablers are discussed in more detail below. These enablers can be used for fostering D-SLM and to integrate LDN and DRM. In addition, there are instances where LDN and DRM overlap to create the environment for D-SLM.

Landscape approach

A 'landscape' is a socio-ecological system. It includes: topography, natural resources, biodiversity, and various land uses. It is influenced by climate and culture as well as ecological processes and human activity. They have an impact on surface and subsurface water flows. A landscape has various functionalities and boundaries. Understanding how these interrelated but spatially separated interactions occur is very important for drought risk management. Fostering Drought-smart land management requires stakeholders to adopt a landscape approach for development planning. People live in spaces but operate in sectors. Working across sectoral boundaries in a participatory nature is critical for successful landscape approaches (see also Box 1). Sectors of particular importance for implementing D-SLM are agriculture, environment, and water. Biggs et al. (2015) propose to explicitly focus on livelihoods and livelihood dynamics within nexus framings to capture bottom-up approaches and local opportunities for sustainable development. The importance of understanding the socio-ecological system defining the landscape as well as cross-sectoral cooperation is also highlighted under the voluntary guidelines for the design and effective implementation of EbA and Eco-DRR (Source: CBD/COP/14/L.23).

Earth Observation and Geospatial analysis

Geospatial analysis and integration of Earth Observation (EO) including satellite and in-situ data by using Geographic Information Systems (GIS) allows the monitoring and mapping of land surfaces including water bodies. Observation

over large areas can be conducted to analyze land dynamics. The availability of different sensors and sensor systems for remote sensing analysis further enable mapping on multiple scales and in different levels of detail. Spatial resolutions of different sensors range from Centimeters to Kilometers and have to be considered depending on the need of rather global applications or analysis on and within small areas. Further, different spectral resolutions allow detection of land cover and land cover types within different wavelengths (e.g. optical and microwave data) and support observations in different level of detail with regard to e.g. specific crop types. With regard to D-SLM practices the higher the resolution the better as analysis on the field level is of relevance (See Box 2 on EO-based mapping of different land cover dynamics). The use of high-resolution imagery with regard to small scale agriculture, dominant in rural areas e.g. in sub-Saharan Africa, would, therefore, be an advantage (Burke & Lobell, 2017; Neigh et al., 2018). In-situ data can augment these analyses and provide crucial validation and calibration of the remotely sensed data.

In the context of fostering D-SLM EO can be employed for different purposes, the most important ones are (i) targeting of interventions areas and (ii) monitoring of effective adoption of practices and implementation of interventions areas and (ii) monitoring of effective adaptation of practices and implementation of interventions.

Hazard assessment often integrates a GIS which allow the integration of additional in-situ information linked to remote sensing imagery which can support management strategies by geospatial analysis and modeling. The Revised Universal Soil Loss Equation (RUSLE) has been used in this regard in several case study assessments worldwide (Lu, Li, Valladares, & Batistella, 2004; Pandey, Chowdary, & Mal, 2007; G. Singh & Panda, 2017). Salinization as one major consequence of drought conditions leading to, but also representing a type of land degradation can be monitored on local scales including optical and radar imagery (Gorji, Sertel, & Tanik, 2017; Gorji, Tanik, & Sertel, 2015; Metternicht & Zinck, 2003). This is also valid for irrigation management practices. Bastiaanssen, Molden, & Makin (2000) e.g. listed a number of satellites and sensors that can provide image input which is suitable for agricultural water management. Especially with regard to drought management remote sensing allows to detect those areas where e.g. farm management practices most likely reduce drought impact on agricultural land (Graw et al., 2017). The project EvIDENz[16] represents an example how drought risk can be measured by the integration

In the context of fostering D-SLM EO can be employed for different purposes, the most important ones are (i) targeting of interventions areas and (ii) monitoring of effective adoption of practices and implementation of interventions areas and (ii) monitoring of effective adaptation of practices and implementation of interventions.

16 The EvIDENz project is financed by the Federal Ministry for Economic Affairs and Energy (BMWi). The overall objective of the EvIDENz project is to develop and demonstrate methods and products on drought risk assessment that respond to national needs for the example of South Africa and Ukraine, and defined indicators of the Sendai Framework for Disaster Risk Reduction (SFDRR). <https://www.zfl.uni-bonn.de/research/projects/evidenz>

BOX 2

Participation and cross-sectoral cooperation

An assessment of the socio-ecological system defining the landscape helps to analyse the problem, define the boundaries for interventions, and screen for entry points for D-SLM. This information should feed into an in-depth stakeholder analysis before engaging stakeholders throughout the implementation process, and also iteratively benefits from information from stakeholders. Engagement of stakeholders and rights holders will increase ownership and likely also the success of any intervention.

Droughts extend beyond administrative boundaries; therefore, an integrated landscape or systems approach aids in problem-solving across sectors and boundaries. Transboundary cooperation can enable the sharing of costs and benefits and prevent potentially negative impacts of measures taken unilaterally. Transboundary cooperation can also provide opportunities for socioeconomic development and managing issues at appropriate ecosystem scales.

Key actions

- Identify indigenous peoples and local communities, stakeholders and rights holders likely to be affected by D-SLM interventions, and identify people, organizations and sectors that have influence over planning and implementation, using transparent participatory processes.

- Ensure full and effective participation of all relevant stakeholders and rights holders, including indigenous peoples and local communities, the poor, women, youth and the elderly, ensuring they have the capacity and sufficient human, technical, financial and legal resources to do so (in line with the safeguards).

- Learn from well-established cross-sectoral planning mechanisms, such as integrated water resources management (IWRM), integrated coastal zone management (ICZM) and land-use planning, to strengthen cross-sectoral cooperation and enhance uptake of D-SLM into relevant sectoral frameworks;

- Develop a common understanding of vulnerabilities at the transboundary scale and for different sectors through the use of common models and scenarios and agreed-upon methodologies and sources of information.

Source: Adapted from CBD/COP/14/L.23

of remote sensing technologies and socio-economic information (Walz et al., 2018). These input data would also represent the potential for further system dynamic modeling on the national scale.

Crop stress detection due to droughts with data fusion integrating vegetation, soil moisture and temperature information conducted in Ukraine show that the combination of different variables can explain crop stress dynamics due to droughts (Ghazaryan et al., 2016). With regard to soil fertility management high-resolution imagery can monitor and control how crops react under different fertilizer and soil conditions (Moran, Inoue, & Barnes, 1997; Seelan, Laguette, Casady, & Seielstad, 2003). Information from drones ensure the use of high-resolution data and further allows own data collection time intervals (Khanal, Fulton, & Shearer, 2017). The establishment of measures to prevent soil erosion on croplands can be monitored to evaluate the effectiveness of these methods. Studies on this have been conducted on local (Panagos, Karydas, Gitas, & Montanarella, 2012) to global scales (Sepuru & Dube, 2018).

Capacity development

Communicating the multiple benefits of D-SLM across sectors, communities of practice, and disciplines is crucial to enhancing uptake and sustainability of initiatives, in addition to opening avenues for funding. National and international policy agreements provide an opportunity to bridge the gap between different communities of practice. Interlinkages between land management and drought risk management are well described in the previous chapter. Actions to develop capacity should start with some prior assessments of the existing skills and capacity of policymakers and local decision makers to address gaps and needs. It is also useful to consider the different information and communication needs of different stakeholder groups in order to develop effective outreach, build a common knowledge base and seek to identify a common language among stakeholders to support their cooperation. Strengthening public and private agriculture advisory services and land user capacities has shown to be an effective means of supporting D-SLM at scale. The Farmer Field School (FFS) approach was successful in numerous projects, transferring skills to farmers and also to FFS facilitators and trainers in piloting and validating D-SLM technologies through participatory experimentation (FAO, World Bank, and NEPAD, 2016). Traditional or local-community knowledge of ecosystem functioning, and landscape specifics can be a significant asset. Improvements need to be made in the incorporation of this knowledge into assessments and decision making. An important source of knowledge and information is WOCAT which has been endorsed by the UNCCD as the primary recommended database for the reporting on best SLM practices.

Good land and water governance

Good rural governance is as important to drought mitigation as is the application of the best technologies. Political will and strong institutions can create the environment to enable widespread adoption of D-SLM. An important success factor to make landscape approaches work is a functional decentralization. Decentralization in combination with place-based policies and legal security (lend tenure, water rights) are essential to ensure relevant and inclusive design, implementation, monitoring and evaluation of land-based interventions to mitigate drought effects. To facilitate the effectiveness and efficiency of landscape approaches and to enable coordination and strategic planning, local and national bodies have to be strengthened,

in terms of both human and financial resources. Good governance also underpins LDN. Important principles in this context and adapted from Orr et al. (2017) are:

1. removing and reversing policy drivers that lead to poor land management

2. applying the principles and standards of the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security to ensure tenure rights and security (FAO, 2012)

3. taking account of availability of resources (human and economic) for implementing D-SLM;

4. making provision for monitoring and reporting on implementation;

5. developing a mechanism for the coordination of integrated land use and management planning across scales and sectors to ensure stakeholder input to national and international decision-making and reporting;

6. developing a mechanism for the timely review of implementation outcomes and recommendations for improvement; and

7. ensuring upward and downward accountability and transparency.

BOX 3

Earth Observation for land and drought monitoring

Mapping of different land cover classes as well as drought is conducted widely on global to national scales with free available datasets and is further facilitated by a large number of open tools within Geographic Information Systems (GIS) (Giri, 2012). Distinctions between cropland, forest and grasslands can be made based on the spectral signature within a pixel of a satellite image (Jong, Meer, & Clevers, 2004). Results might differ depending on the data product and classification approach used (Foody, 2002). Nevertheless, detection of broader land cover classes such as croplands and forest but also of urban areas can be easily made with simple classification methods nowadays (Giri, 2012).

Croplands can be classified and further monitored depending on their phenology. Integrating time series data of e.g. vegetation allows to detect the start, peak and end of the growing season (Muro et al., 2018; Yan et al., 2017). The use of hyperspectral data, meaning satellite information derived from a sensor receiving information in a high level of detail within the electromagnetic spectrum, further allows the distinction of crop types (Foerster, Kaden, Foerster, & Itzerott, 2012; Inglada et al., 2015).

BOX 3 (con'd)

Grasslands are highly dynamic and with regard to EO data often difficult to monitor as they react fast to rainfall. Pressure on grasslands due to e.g. livestock has been monitored with remote sensing in various regions (Estel et al., 2018; Kawamura et al., 2005). In large areas of Eastern and Southern Africa further the detection and monitoring of bush encroachment represents an ongoing challenge (Graw, Oldenburg, Dubovyk, & Piroska, 2017; Skowno et al., 2017).

Forests and woodlands monitoring are largely conducted with satellite information. A number of studies have been focusing on this topic in various countries of the Amazonian (Tucker & Townshend, 2000) such as in Ecuador (Viña, Echavarria, & Rundquist, 2004) or in Brazil (Stone, Brown, & Woodwell, 1991). Cloud coverage is the main obstacle when conducting near real time analysis or trends over time. Therefore, methods are developed that help to deal with data gaps and non-usable images to detect deforestation and afforestation (DeVries et al., 2015; Rufin, Müller, Pflugmacher, & Hostert, 2015).

Mixed land uses are often difficult to determine with remote sensing as the analysis unit refers to a single pixel which contains one single classification. The higher the spatial and spectral resolution the more detailed land cover and land use classes can be identified. Nevertheless, adding ground information by e.g. household surveys or collected GPS information during field research activities allows to relate changes and development in a pixel to the land use activity here. Studies linking remote sensing information to in-situ observations show, that the validation with ground-based information is still of high relevance to avoid misinterpretation of trends shown in land development derived from remote sensing (Fox, 2003; Graw, Smale, & Menz, 2016; Mertens, Sunderlin, Ndoye, & Lambin, 2000).

Drought and land stress can be monitored using EO by e.g. relating the actual status of land to its previous conditions to detect changes and especially loss or gain of productivity over time (Graw et al., 2017). Compared to Vegetation condition monitoring observation of precipitation only does not sufficiently detect areas affected and impacted by a meteorological drought, it only might refer to a potential hazard. Modeling approaches to get more accurate information on overall drought dynamics with regard to especially climatic and environmental variables include the integration of cloud cover and temperature analysis (Estel et al., 2018; Urban et al., 2018) soil moisture information (SM) using free available microwave data (Bolten, Crow, Zhan, Jackson, & Reynolds, 2010) but also analysis on evapotranspiration (ETP) by integrating land surface temperature (LST) information (Karnieli et al., 2013; Wang, Rich, & Price, 2003). Another variable used for drought monitoring, which especially became known through the Cape Town drought conditions in 2017/2018 is the monitoring of water dam levels or the lake surface areas (Stevens & Voiland, 2018). Water dam levels or water areas can be observed via change detection taking into account different images over time.

Payment for environmental services schemes provide monetary and non-monetary incentives to upstream communities, farmers and private land owners to protect, restore and conserve natural ecosystems and to adopt sustainable agricultural and other land use practices.

Finance

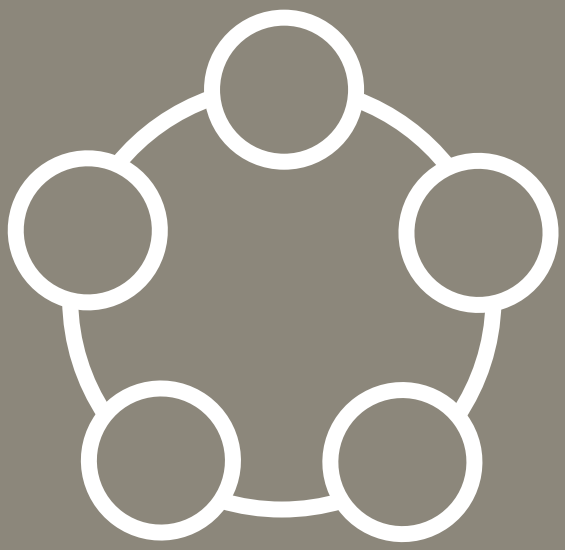
Fostering D-SLM is linked to sufficient financing. Successful implementation of initiatives depends on the effective mobilization of resources from all sources, including national budgets, external donors and innovative sources of finance, ideally concurrent with local and national programming. D-SLM do not necessarily require additional financial resources but usually involve redirecting and making more effective use of existing financing.

Effective use of financial and human resources can be enhanced by seeking synergies among policies, commitments and investments at both the global and national levels (Orr et al. 2017). Fostering policy coherence and integrating commitments (e.g., leveraging climate finance) would involve highlighting the links between, for example, climate change adaptation and D-SLM, taking into consideration that adaptation initiatives in many cases are land-based, and that D-SLM interventions deliver drought adaptation benefits.

The assessment of D-SLM contained in this report points to returns on investments which include positive environmental and social externalities. Payment for environmental services schemes provide monetary and non-monetary incentives to upstream communities, farmers and private land owners to protect, restore and conserve natural ecosystems and to adopt sustainable agricultural and other land use practices. These actions generate benefits to downstream water users in the form of water regulation, flood control, and erosion and sediment control, among others, thus ensuring a constant, high-quality water supply, and helping reduce water treatment and equipment maintenance costs (UN-Water 2018).

Transforming agricultural policy represents a significant pathway for financing the further uptake of D-SLM. The vast majority of agricultural subsidies, and probably the majority of public funding and almost all private sector investment in agricultural research and development, support the intensification of conventional agriculture, which increases water insecurity (UN-Water 2018). Mainstreaming the concept of sustainable land management in agriculture would also be a major advance in financing for D-SLM.

D-SLM do not necessarily require additional financial resources but usually involve redirecting and making more effective use of existing financing.



Integrating land management into drought mitigation and risk management demands policies to encourage and incentivize cross-sector, cross-administrative boundary cooperation, as well as land users' engagement under integrated land-scape approach in context of land degradation neutrality.

Conclusions and policy options for immediate actions

Policy proposals for immediate actions to integrate D-SLM practices into drought mitigation.

The previous chapters outlined why land and drought management need to be more fundamentally linked. It reveals the strong linkages between land use and drought and that the management of both land and drought is fundamentally connected through water use and the significant capacity of human decisions in land and water management to alter, either positively or negatively, the resilience of communities and ecosystems. It also documents the biophysical mechanisms and processes which, when managed appropriately, provide opportunities to adapt to drought through an improvement in the ability of soils to accept, retain, release and transmit water, and increase plant water use efficiency.

The nexus of land and drought was described concluding that policies need to ensure that the "human" factor embodied in land and water use decisions is fully integrated in drought risk management policies.

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It identifies that a lack of data on the impacts of the implementation of D-SLM practices on drought mitigation and the potential economic returns that may result from enacting D-SLM is a barrier to integrating drought risk management practices into land use and land management practices and policies.

Within the group of SLM-based interventions, this report introduced the new concept of Drought-smart land management (D-SLM). D-SLM improves the resilience to drought for the land-users and society at large, as well as improve the soils' capacity to accept, retain, release and transmit water, and increase plant water use efficiency. They can do so broadly by increasing the water supply where it is needed by living organisms (e.g. crops' root systems) or by reducing water demand (e.g. drought-resistant crop varieties).

The results emerging from the synthesis and assessment show the scientific evidence to date on the potential of 14 groups of D-SLM

measures in four land use types to simultaneously positively affect drought risk mitigation, land degradation prevention, restoration/rehabilitation, biodiversity conservation, soil carbon sequestration (robust evidence, high agreement), and allow for improved drought resilience without curtailing farmers' opportunities to maximize their benefits during normal or wet years (robust evidence, medium agreement). The results also show the potential for these D-SLM practices to improve productivity, leading to higher socioeconomic returns than conventional practices under drought conditions, including in marginal soils, thereby enhancing all dimensions of food security (medium evidence, high agreement).

The report re-emphasizes how, when compared to ex-post interventions, greater ecological and economic cost-benefit efficiency can be realized through proactive D-SLM interventions by building resilience and de-incentivizing the continuation of drought-sensitive economic activities and decreasing the future costs of drought relief.

The report proposes guidance through enhancing five enablers to support adoption, implementation and scaling up of D-SLM. It brings to the forefront the need for vulnerability and risk assessments in different contexts covering both natural (climatic, soil and water) and socio-economic aspects. Both aspects are necessary for more ecologically effective implementation of D-SLM practices in order to more effectively pursue integrated and collaborative drought risk mitigation across ecosystems, administrative boundaries and rural-urban landscapes.

It reveals that well-optimized, local and context-based D-SLMs defined as biological or geographical in scope, through the implementation of integrated land use planning and integrated landscape management in the context of LDN, can improve the resilience and reduce the vulnerability of ecosystems, land-users and society at large to drought, offer opportunities for mitigating the risk of drought and, more generally, contribute to "proactive drought risk management".

Drawing on scientific evidence effectiveness and synergistic impacts of D-SLM were illustrated. Bringing this report to a closure this final chapter offers some proposals to the policy-makers and practitioners and scientific communities for taking actions.

The report proposes guidance through enhancing five enablers to support adoption, implementation and scaling up of D-SLM. It brings to the forefront the need for vulnerability and risk assessments in different contexts covering both natural (climatic, soil and water) and socio-economic aspects.

1. **Proposal 1:** Strengthening the interlinkages between national land and national drought policies, consider changing the policies to fully reflect the influence of land use and management and land degradation on water availability and water scarcity, and consider the positive role D-SLM practices could have in building the resilience of communities and ecosystems to drought, when pursued in the context of LDN;

2. **Proposal 2:** Taking measures to ensure the governmental departments dedicated to drought management integrate land use, land use change and land degradation as

factors in drought and drought risk management practices and policies, while also ensuring that their land and water use departments integrate D-SLM practices into their relevant policies and initiatives;

3. **Proposal 3:** Enhancing cross-sectoral collaboration and coordination in national, regional and international policies and programmes to promote the interventions necessary to optimized adoption, implementation and scaling-up of D-SLM to landscape level, focusing on a set of five enablers, including:

   a). Implementing integrated land use planning and landscape management;

   b). Strengthening national and local capacity on the multiple benefits of D-SLM across sectors, communities of practice and disciplines, taking into consideration gender integration;

   c). Ensuring effective local institutions in combination with place-based policies and legal security on land tenure and water rights to ensure relevant and inclusive design, implementation, monitoring and evaluation of land-based interventions to mitigate the effects of drought;

   d). Developing user-friendly tools which improve the access of policy-makers, planners and practitioners at all levels to geospatial analysis that integrates Earth observations, including satellite and in-situ data of land, water and meteorology, through the use of geographic information systems, which would allow the integrated monitoring and mapping of land cover, including water bodies, land degradation and drought risk; and

   e). Mobilizing both conventional and innovative finance, including from public and private investors, in the form of ecosystem service payments, carbon emission offsetting, insurance coverage and investments in sustainable land-based value chains to support and promote D-SLM, ideally concurrent with local and national programming; and

4. **Proposal 4:** Enhancing collaboration among relevant international treaties and multilateral organizations lead by UNCCD secretariat and the SPI, with the World Meteorological Organization, the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme and other relevant land, water and meteorological organizations, in the context of the Integrated Drought Management Programme, to facilitate coordination and interaction between LDN and drought risk management communities, notably by creating a common understanding of definitions and the cross-sectoral nature of drought risk management and land management.

Drawing on scientific evidence effectiveness and synergistic impacts of D-SLM contributing to "proactive drought risk management".

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Annex: Description of Drought-smart land management practices

	Name	Impact on Water
1	**Bund:** "A structural measure with an embankment of soil or stones, constructed along the contour and stabilized with vegetative measures (grass and fodder trees)" (Sanz et al., 2017).	Increases water retention and infiltration
2	**Terrace:** "A structural measure constructed by carefully removing a superficial soil layer from one part of a field, concentrating it on the lower end of that field in order to reduce slope gradient and length. Another terrace is created directly downslope to form a cascade of terraces" (Harari et al., 2017). In contrast to bunds, terraces are long-term measures requiring higher investments (Gebremedhin & Swinton, 2003)	Improves soil moisture holding capacity and water infiltration and reduces runoff
3	**Mulching:** "Covering the ground with a layer of plant materials" (Bayala et al., 2012)	Improves soil water retention and transmission, reduces drought stress
4	**Cover crops:** "Crops that replace bare fallow during winter period and are ploughed under as green manure before sowing of the next main crop" (Poeplau & Don, 2015)	Improves soil water retention and transmission, reduces drought stress for subsequent crops
5	**Vegetative strips:** "Any vegetated area set-aside from the main cropping regime within or around a field" (Marshall & Moonen, 2002)	Reduces soil erosion and enhances soil water retention, improves water quality, often also serves as bio-drainage

Other Biophysical Impacts	Socio-economic impacts	References
Reduces soil erosion, prevents soil fertility loss, facilitates biomass accumulation and nutrient enhancement, improves yields	Increases agricultural incomes through improved yields but entails high upfront costs, reduces production risk under a variable climate	(Dutilly-Diane et al., 2003; Kato et al., 2011; Sanz et al., 2017; Wei et al., 2016)
Controls erosion, accumulates biomass, recharges soil water, enhances nutrients and usually increases crop yields	Improves incomes and increases food production, contributing to food security and poverty reduction	(Adgo et al., 2013; Harari et al., 2017; Liniger & Critchley, 2007; Pender & Gebremedhin, 2007; Sanz et al., 2017)
Protects soil against wind and water erosion, provides nutrients which have a positive effect on yields	Increases agricultural incomes, trade-offs as a source of fodder and labour requirements for mulch spreading	(Affholder et al., 2010; Bayala et al., 2012; Harari et al., 2017; Sanz et al., 2017)
Sequesters carbon, reduces soil erosion and compaction, and nitrogen leaching, increases biodiversity and weed control, improves yields	Increases agricultural incomes	(Altieri, 1999; Blombäck et al., 2003; Campiglia et al., 2010; Chabi-Olaye et al., 2007; Kaye & Quemada, 2017; Lal, 2004; Poeplau & Don, 2015)
Benefits biodiversity and air quality, sequesters carbon, reduces the transportation of contaminants and suspended sediments by water flow	Usually has positive effects on yields, leading to higher agricultural incomes	(Borin et al., 2010; Dorioz et al., 2006; Harari et al., 2017; Liniger & Critchley, 2007; Marshall & Moonen, 2002; Sanz et al., 2017)

	Name	Impact on Water
6	**No-till, reduced tillage:** "Growing crops (or pastures) without disturbing/minimum disturbance of the soil through tillage" (Sanz et al., 2017)	Efficient use of soil water: increases infiltration, reduces water loss, increases water availability for plants
7	**Laser land levelling:** Use of high-precision laser equipment for the levelling of fields	Reduces water runoff, improves water use efficiency
8	**Biochar soil amendment:** "Biochar is a carbonaceous material obtained from thermal decomposition of residual biomass at relatively low temperature and under oxygen limited conditions (pyrolysis)" (Alburquerque et al., 2013)	Improves soil water transmission
9	**Compost soil amendment:** "Application of organic matter from weeds and bio-waste decomposed by Microorganism" (Sanz et al., 2017)	Improves soil water holding capacity
10	**Water harvesting technologies:** "Are a range of technologies for collecting and storing water for productive uses" (Nyakudya et al., 2014) such as Zai pits (Burkina Faso), Tassa (Niger), half-moons, Ndiva (Tanzania), sub-surface water harvesting, kyariz systems (Turkmenistan), rock catchment, pond sand filter (PSF) (see section 2.1)	Improves soil water availability and retention, increases groundwater recharge

Other Biophysical Impacts	Socio-economic impacts	References
Increases crop production and yield stability, has heterogeneous impacts on soil biota	Reduces energy costs, sometimes increases labour inputs, increases herbicide applications.	(Erenstein & Laxmi, 2008; Ernst & Emmerling, 2009; Guto et al., 2012; Pittelkow et al., 2015; Sanz et al., 2017)
Produces higher yields than under conventional levelling, improves field traffic ability	Increases agricultural profitability	(Abdullaev et al., 2007; Aryal et al., 2015; Kaur et al., 2012)
Sequesters carbon sequestration, manages contaminants, increases soil fertility	Economic viability of biochar application may be low	(Alburquerque et al., 2013; Clare et al., 2014; Cornelissen et al., 2013; Lehmann et al., 2006; Smith, 2016)
Improves soil tilth. Its decomposition slowly releases available nutrients for plant uptake. Composting could help reduce environmental degradation from the open dumping of organic waste.	Increases yields, especially with longer-term application	(Bekchanov & Mirzabaev, 2018; Doan et al., 2015; Evanylo et al., 2008; Sanz et al., 2017)
Reduces soil erosion, increases biomass production, enhances soil nutrient cycling	Increases incomes and food security	(Akhtar et al., 2016; Fox & Rockström, 2003; Oweis et al., 2012; Vohland & Barry, 2009)

	Name	Impact on Water
11	**Improved irrigation technologies:** Irrigation technologies such as drip irrigation, spate irrigation, sub-soil drip irrigation, irrigation at night, etc. which reduce water application in crop production	Increases water use efficiency in crop production
12	**Integrated watershed management:** An approach that combines the management of land, water and vegetation at the watershed level to limit drought impacts	Conserves water, improves groundwater levels
13	**Rotational Grazing:** Involves sequential use of multiple pastures to optimize re-growth of pasture plants	Helps to cope with rainfall variability, improves infiltration rates and runoff in rangelands
14	**Afforestation:** Establishment of trees on an area where there were no trees previously	Improves water conservation and regulation, decreases water availability for other vegetation in some arid areas
15	**Reforestation:** Replanting of trees on an area which was previously deforested	Improves water conservation and regulation, decreases water availability for other vegetation in some arid areas
16	**Agroforestry:** Agriculture incorporating cultivation of trees	Improves water availability and water regulation
17	**Agropastoralism:** Integration of crop production and livestock production activities	Improves resilience against rainfall variability and droughts

Other Biophysical Impacts	Socio-economic impacts	References
Reduces secondary salinization and waterlogging, fungal diseases due to excessive root zone moisture and nutrient losses through leaching	Increases the profitability of agricultural production, especially during drought periods and in settings with water pricing. In areas without water shortages, yields may be lower than under conventional irrigation technologies (e.g. furrow and flooding irrigation).	(Dağdelen et al., 2009; Geerts & Raes, 2009; Harari et al., 2017; Sanz et al., 2017; Vickers, 2018)
Reduces soil erosion	Increases yields and cropping intensity, improves food security	(Joshi et al., 2005; Wang et al., 2016; Wani et al., 2012; Wani et al., 2003)
Limits rangeland degradation and soil compacting by livestock trampling, increases soil C and C to N ratios	Helps sustain livestock herds during drought years and under high rainfall variability	(Bailey & Brown, 2011; Briske et al., 2008; Teague et al., 2010)
Reduces soil erosion, sequesters carbon, improves biodiversity	Increases incomes from marginal areas	(Djanibekov & Khamzina, 2016; Harari et al., 2017; Niu & Duiker, 2006; Sanz et al., 2017)
Reduces soil erosion, sequesters carbon, improves biodiversity	Increases incomes from marginal areas	(Chazdon et al., 2016; Harari et al., 2017; Sanz et al., 2017)
Sequesters carbon, reduces soil erosion, increases soil fertility and bio-drainage	Improves incomes and food security	(Nair, 1993; Nair et al., 2009)
Reduces soil degradation in rangelands	Improves incomes and food security	(Harari et al., 2017; Liniger & Critchley, 2007; Sanz et al., 2017)

Drought and land are fundamentally linked, but not necessarily in policies and practices.

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While the it is commonly understood that land use and management decisions can exacerbate the potential impact of drought, the positive impact that well-designed land-based interventions can have over the long term remains largely outside the policies and practices employed to mitigate drought. This report provides an opportunity to build a bridge between land and drought founded on the assessment, synthesis and synopsis of scientific knowledge linking these two domains.

This UNCCD-SPI technical report provides well-established scientific evidence for understanding the strong linkages between land use and drought and how management of both is connected through water use. It introduces a new concept of Drought-smart land management (D-SLM) and organizes relevant approaches and practices in fourteen groups across four major classes of land use. The objective is to guide decision makers and land managers working on "proactive drought risk management" towards interventions designed to improve community and ecosystem resilience to drought, ideally leading to higher socioeconomic returns than conventional practices under drought conditions. It also proposes guidance for enhancing five enablers to support adoption, implementation and scaling up of D-SLM. And it brings to the forefront the need for vulnerability and risk assessments in different contexts, covering both natural (climatic, soil and water) and socio-economic aspects of land and drought management.

Download the corresponding Science-Policy Brief here:

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ISBN 978-92-95117-21-1 (hard copy)
ISBN 978-92-95117-27-3 (electronic copy)

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