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Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation

A Report of the Science-Policy Interface

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Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation

A Report of the Science-Policy Interface

The report provides scientifically sound practical guidance for selecting SLM practices that help address DLDD, climate change adaptation and mitigation, and for creating an enabling environment for their large-scale implementation considering local realities. It targets a broad audience from scientists, policy makers, landowners, community stakeholders and enterprises.

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In its decision 21/COP.12 the Conference of the Parties (COP) to the United Nations Convention to Combat Desertification (UNCCD) decided to adopt the Science-Policy Interface (SPI) work programme for the biennium 2016–2017, which requested the SPI to undertake work to highlight the science-based synergistic potential of sustainable land management (SLM) practices to address desertification/land degradation and drought (DLDD), climate change mitigation and adaptation (objective 2). Sustainable land management (SLM) represents a holistic approach to achieving long-term productive ecosystems by integrating biophysical, sociocultural and economic needs and values. SLM is one of the main mechanisms to achieve land degradation neutrality. To foster and facilitate the adoption of SLM practices that address desertification/land degradation and drought while mitigating climate change and enhancing climate change adaptation, the Science-Policy Interface assessed the synergistic potential of SLM practices while also critically evaluating the possible trade-offs between the different objectives. The assessment provides a scientifically sound basis to understand the potential of SLM to contribute to multiple objectives and provides practical guidance for creating an enabling environment for the selection and large-scale implementation of effective, locally adapted SLM practices.

In accordance with the rules and procedures established by the UNCCD Conference of the Parties (COP), the report was prepared by an author team of 5 lead authors and 7 contributing authors. In December 2016, following a competitive public tender, the Basque Centre for Climate Change (BC3) was commissioned to prepare this report in association with the Mediterranean Center for Environmental Studies and the SPI. A scoping meeting was held on 19-20 December 2016 in Bonn, Germany; SPI members as well as representatives of BC3, external experts in SLM, climate change and sustainable development participated in the meeting.

Following an intensive assessment of technical documents and peer-reviewed scientific literature, a draft produced by the authors underwent a three step review process, including an internal review (7 reviewers), and external scientific peer-review (6 reviewers) as well as a review by the Bureau of the COP. The lead authors have ensured that all government and expert review comments received appropriate consideration.

Foreword

The advancing threat of land degradation, combined with the effects of climate change, continues to put the security and stability of the world's population at risk. To build a more secure, sustainable and resilient future, we need to design and implement innovative approaches and practices that address the global challenges from a multi-dimensional perspective.

Sustainable Land Management (SLM) is the obvious solution that equips us with the tools to respond to the most pressing environmental issues. SLM helps to build resilient and productive ecosystems by integrating biophysical, socio-cultural and economic needs and values, and forms one of the main mechanisms to achieve Land Degradation Neutrality (LDN). SLM provides opportunities to recover tens of Gt of the lost carbon in the world's agricultural and degraded soils, while enhancing land-based climate change adaptation.

In its new report, the SPI categorises and assesses a diverse array of SLM practices and identifies their potential to create synergies between combating Desertification, Land Degradation and Drought (DLDD), and achieving climate change mitigation and adaptation goals. While outlining potential solutions for combating desertification and land degradation, the report stresses the need to recognise that an one-size-fits-all SLM solution does not exist. The design and benefits of SLM practices primarily depend on the highly variable local environmental, socioeconomic and cultural conditions. As confirmed by well-established knowledge base, built upon dedicated research and practical experiences, "good SLM practices" blend a variety of approaches that help increase and stabilize crop productivity, ensure ecological sustainability and holistically address DLDD, climate change adaptation and mitigation.

The adoption of SLM practices is still implemented by only a limited number of innovative land users and practitioners. To scale up the implementation of SLM, we need to ensure the involvement of scientists, policy makers, land users and owners, community activists and entrepreneurs from the initial assessment stage and up to the long-term maintenance. The sustained support of all stakeholders throughout the process, from the design of SLM projects all the way to implementation and monitoring, is instrumental to the wider acceptance of SLM practices.

Thanks to the SPI's scientific assessment presented in this report, we can develop a new basis for action to pilot, test and validate new solutions built on innovation. Practice confirms that implementing SLM is the key to providing sustainable livelihoods for millions of people, maintaining or increasing environmental sustainability, and ultimately achieving the global LDN vision, while contributing to climate change adaptation and mitigation.

M Barbut

Monique Barbut
Executive Secretary
United Nations Convention to Combat Desertification

Executive Summary

Sustainable Land Management (SLM) represents a holistic approach to achieving long-term productive ecosystems by integrating biophysical, socio-cultural and economic needs and values. SLM is one of the main mechanisms to achieve Land Degradation Neutrality (LDN).

To foster and facilitate the adoption of SLM practices that address DLDD while mitigating climate change and enhancing climate change adaptation, this report assesses the synergistic potential of SLM practices while also critically evaluating the possible trade-offs between the different objectives. The assessment provides a scientifically-sound basis to understand SLM's potential to contribute to multiple objectives, and provides practical guidance for creating an enabling environment for selection and large-scale implementation of effective, locally-adapted SLM practices.

Overall objective

The objective of the present report is to "highlight the science-based synergistic potential of SLM practices to address DLDD, climate change mitigation and adaptation" as a contribution to the UNCCD's Science Policy Interface (SPI) work programme 2016-2017. By doing so, the linkages between SLM practices to address DLDD, climate change adaptation and mitigation, and resulting synergies and trade-offs, are considered.

Key messages

SLM as land-based solutions for desertification, land degradation, drought, climate change adaptation and mitigation

Land provides vital environmental functions and ecosystem services, including provisioning, regulating, supporting and cultural services. These ecosystem services support production of food, feed, fuel, and fibre to society, regulates risks of natural hazards, and provides cultural and spiritual services for human well-being. Desertification, Land Degradation, Drought (DLDD) and climate change can negatively affect ecosystem service provision, with severe implications for sustaining livelihoods and humans' well-being.

There is increasing scientific evidence of the potential advantages of adopting SLM technologies and practices as land-based solutions to simultaneously address DLDD, climate change adaptation and mitigation, while often achieving other co-benefits, such as protection of biodiversity and securing the quantity and quality of soil and water resources. So far, assessments of SLM adoption have been generally focused on specific technologies and single benefits (i.e., yield improvement strategies; soil quality; climate change adaption and/or mitigation, etc.), leaving out other potential environmental impacts, synergies and trade-offs. Therefore, comprehensive multi-objective assessments, including assessments of co-benefits, trade-offs, barriers for implementation and enabling conditions are needed to further underpin scientific conclusions.

Few generalisations can be made of findings from local SLM impact studies, because their effectiveness is inherently dependent on the local socio-economic, environmental and cultural context. Therefore, reliable quantitative assessments of the global impacts of SLM are difficult to make, and were not the objective of this report. Nevertheless, there is widespread scientific evidence of the advantages of single SLM practices to simultaneously address DLDD, climate change adaptation and mitigation, based on empirical, site-specific research. This assessment report provides many local examples, based on which it concludes that the most efficient in terms of their simultaneous contribution to address DLDD, climate change mitigation and adaptation, are combinations of SLM practices that aim to:

- **Increase and stabilise crop productivity** through combinations of vegetation management, crop diversification, soil fertility and sustainable water management practices. Although the adoption of these practices might have a modest impact on climate change mitigation in drylands, they positively contribute to climate change adaptation, water management and addressing *DLDD*, which are a priority in these regions.

- **Increase productivity in grazing lands** through combinations of vegetation and animal waste management, prioritising the use of indigenous species, diversifying and selecting the most appropriate species for particular areas considering their resilience to forecasted climate change (adaptive management), and by managing the timing and severity of grazing to ensure that the carrying capacity is not exceeded in order to avoid overgrazing.

- **Maintain or increase forest cover** through afforestation, reforestation, and sustainable and adaptive management, **while reducing deforestation**, in particular in the tropical forests. These practices have a significant potential for climate change mitigation and biodiversity preservation while preventing land degradation and to increase the resilience of forest-dependent communities. Enhancing forest carbon stocks and forest cover with the most appropriated mix of species, and prioritising the use of indigenous species, in combination with watershed management and assisted regeneration practices, will enable managed and unmanaged forest ecosystems to adapt to extreme events, such as heatwaves, droughts, floods, landslides, and sand and dust storms, as well as pest and disease control.

- **Promote agroforestry practices** such as plantations of crop combinations under multipurpose tree systems, intercropping with green covers in perennial woody crops, and inclusion of livestock, which contributes to achieving multiple benefits. The adoption of mixed systems contributes to increased soil quality and carbon sequestration, maintains soil fertility and nutrient cycling and controls soil erosion, while providing food and income to local communities and enhancing resilience to climate change.

Increasing Soil Organic Carbon (SOC) stocks is key to most SLM practices, and provides synergies for addressing DLDD, climate change adaptation and mitigation. Besides contributing to climate change mitigation by removing CO_2 from the atmosphere, enhancing organic carbon in soils improves soil health and fertility, water and nutrient retention capacity, food production potential and resilience to drought. The potential and magnitude of each of these benefits will depend on the baseline conditions, and local environmental, socio-economic and cultural conditions.

SLM practices have a strong potential to enhance SOC sequestration, although estimates of this potential should consider the full Greenhouse Gas (GHG) balance, including possible interactions between the carbon and nitrogen cycles that could affect the net climate change mitigation potential of applied practices. Even when the mitigation potential of SLM is not fully achieved, its impact on SOC should be considered, since increasing SOC has crucial positive benefits for achieving LDN, climate change adaptation, food security, and protecting biodiversity.

Large-scale adoption of SLM practices in all managed ecosystems (irrigated and rainfed croplands, grazing lands, forests and woodlands) could theoretically sequester about 1–2Gt Carbon per year globally within 30–50 years, although estimates vary in magnitude depending on which land-use categories, management practices, and GHG fluxes are included. At any site, the rate of SOC sequestration through SLM practices declines over time and declines as the saturatioin level is approached. The main carbon sequestration potential is in degraded soils. In soils with high SOC content, preventing SOC losses is priority. Overall, SLM provides an opportunity to recover between 21 to 51 Gt of the lost carbon in the world's agricultural and degraded soils. The achievable local or regional SOC sequestration may be higher or lower than the theoretical SOC sequestration potential based on local environmental, socio-economic, cultural and institutional contexts.

Databases such as the World Overview of Conservation Approaches and Technologies (WOCAT), TERRAFRICA, the World Bank sourcebook, and the Voluntary Guidelines for Sustainable Soil Management (VGSSM) provide comprehensive recommendations and examples of SLM practices. The combined implementation of practices that address both soil and water conservation, the diversification of cropping systems, the integration of crop and livestock systems, and agroforestry are most effective and should be prioritised.

Barriers for SLM adoption and implementation

Despite scientific advances in understanding the causes and outcomes of land degradation, adoption of SLM practices is mostly limited to a minority of innovative land-users and practitioners. Although principles and practices of SLM are well-known and increasingly promoted at the policy and development cooperation level, land degradation is still increasing and becoming a major global threat. This demonstrates the wide gap existing between acknowledgement of the need for SLM and the implementation of successful SLM practices.

Identified barriers for the implementation of SLM are related to technological, ecological, institutional, economic and socio-cultural aspects:

- Lack of access to appropriate technologies, practises or equipment is a major barrier in many countries. This may either due to a lack of access to knowledge and information on SLM options and their proper implementation, or because of insufficient resources in land, labour, inputs, biomass, energy, water or plants.

- SLM practises that are technically effective or suitable for one specific site location are not necessarily the best option for other site locations with different biophysical constraints and socio-economic contexts. **It is therefore important to have area- and case-specific technological packages accompanied by the necessary capacity-building measures and resources for appropriate implementation. Often, knowledge gaps of the ecological implications at different spatial and time scales make it difficult to select the most suitable SLM options.**

- Environmental constraints for implementation of certain SLM practices. As local environmental characteristics (climate, topography, soil quality) often determine the success or failure of SLM practices, initial characterisation of baseline conditions will help to select the most suitable land use and/or management option, depending on local conditions and considering both on-site and off-site benefits.

- Institutional and governance issues are often major barriers that hinder the adoption of SLM practices. For example, governance structures that aggravate or inhibit decision-making at different scales neither encourage cross-sectoral planning, nor address land tenure issues, but cause instability over time. **There is an urgent need for well-trained and effective extension services to facilitate and guide implementation, monitoring and evaluation of the impact of local SLM practices.**

- Limited finance and access to capital for implementation and maintenance of SLM. **Economic considerations and incentives schemes are two of the land-users' primary motivations** for selecting SLM technologies and practises, including a strong dependence on external subsidies for implementation and maintenance.

Opportunities and enabling conditions for upscaling SLM

For successful upscaling and to foster large-scale implementation of SLM, more attention must be paid to the social system from the first involvement stage, up to long-term maintenance. Ensuring stakeholder participation throughout decision-making processes, from the design of SLM projects all the way to implementation and monitoring, will increase the likelihood of acceptance and implementation of SLM. From start to end, the process should be highly solution-oriented, emphasise SLM, and combat a local-participatory approach with global knowledge sharing.

More comprehensive multi-objective assessments, including: co-benefits, trade-offs, barriers for implementation and enabling conditions of single or combined SLM technologies, and practises, are still lacking. Using existing experiences to learn, we must promote future research on how to foster synergies focusing on comparative and more integrated studies. This will be essential for scaling up SLM technologies, while still tailoring them to specific ecological and socio-economic realities.

A framework that assesses co-benefits and trade-offs also promotes the adoption of more coherent SLM choices at different scales (in time and space) of implementation. Such frameworks will facilitate moving towards developing strategies and processes that involve stakeholders at all levels, link bottom-up experience with science-based data and knowledge, and make the best SLM choices to simultaneously address climate change adaptation and mitigation and land degradation. Simultaneously addressing these multiple objectives and goals could be facilitated by a pragmatic and integrated framework to track the best technical choices and to promote the necessary enabling environments and co-benefits, as well as by addressing trade-offs at the appropriated scales and taking specific circumstances into account.

Scientific evidence shows that SLM practices, if widely adopted, as a means to prevent, reduce or revert land degradation and in achieving the LDN (SDG 15.3), also contribute to adapting to, and mitigating, climate change. Furthermore, they help to maintain biodiversity, and they contribute to other SDGs in a number of ways, by alleviating poverty, and foster economic prosperity for land-dependent communities. However, one size does not fit all; specific circumstances need to be carefully taken into account, and there are no silver-bullet SLM solutions. Each environmental and sociocultural context requires assessment of the most appropriated ways to achieve multiple benefits and to reduce trade-offs through SLM.

SLM forms one of the main mechanisms to achieve Land Degradation Neutrality (LDN).

Sustainable Land Management (SLM) represents a holistic approach to preserve ecosystem services in long-term productive ecosystems by integrating biophysical, socio-cultural and economic needs and values.

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LIST OF ABBREVIATIONS

AFOLU	Agriculture, Forestry and Other Land-use
ANR	Assisted Natural Regeneration
BAU	Business as Usual
CA	Conservation Agriculture
CBA	Community Based Adaptation
CBD	United Nations Convention on Biological Diversity
CDM	Clean Development Mechanism
CIFOR	Center for International Forestry Research
COP	Conference of the Parties
CSA	Climate Smart Agriculture
DLDD	Desertification, Land Degradation & Drought
EbA	Ecosystem Based Approach

ELD	Economics of Land Degradation
ES	Ecosystem Services
FESLM	International Framework for the Evaluation of Sustainable Land Management
GLASOD	Global Assessment of Human-induced Soil Degradation
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gas
GDP	Gross Domestic Product
IAM	Integrated Assessment Model
ILM	Integrated Land Management
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LBA	Land Based Approach
LDN	Land Degradation Neutrality
LULUCF	Land-Use, Land-Use Change and Forestry
MA	Millennium Ecosystem Assessment
NAP	National Adaptation Plan
NAPA	National Adaptation Programme of Action
NBS	Nature Based Solutions
NDC	Nationally Determined Contribution
NPP	Net Primary Production
NT	No Tillage
RAPTA	Guidelines for Embedding Resilience, Adaptation and Transformation
SDG	Sustainable Development Goal
SFM	Sustainable Forest Management
SLM	Sustainable Land Management
SOC	Soil Organic Carbon
SPI	Science-Policy Interface of the UNCCD
SWC	Soil and Water Conservation
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	United Nations General Assembly
USD	United States Dollars
WOCAT	World Overview of Conservation Approaches and Technologies
WoS	Web of Science

GLOSSARY OF KEY TERMS

Climate change mitigation and adaptation

Climate change mitigation is an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases. Climate change adaptation is an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001a).

Community based adaptation (CBA)

Process focused on the communities (local scale) that are most vulnerable to climate change, based on the premise of understanding how climate change will affect the local environment and a community's assets and capacities (Reid & Hug, 2007). Development of the discourse and practise of CBA brings the importance of local communities and their knowledge and local capacity for action when faced with particular shocks and stresses to the forefront. It is based on the premise that local communities have the skills, experience, local knowledge and networks to undertake locally appropriate activities that increase resilience and reduce vulnerability to a range of factors, including climate change. Ayers & Forsyth (2009) associate CBA with the following characteristics: operating at the local level (i.e. neighbourhood, settlement, village) in communities that are vulnerable to the impacts of climate change; identifying and implementing community-based development activities that strengthen the capacity of local people to adapt; generating adaptation strategies through participatory processes involving local stakeholders; building on existing cultural norms and addressing local development concerns that underlie vulnerability. CBA is often seen as a response to top-down adaptation that fails to engage with the needs of the most vulnerable members of society (Boyd et al., 2009). CBA is considered by some as a sister concept to the Ecosystem-based approach (Reid, 2015).

Desertification, Land Degradation and Drought (DLDD)	In the context of DLDD, Land degradation means the reduction or loss of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical and biological or economic properties of soil; and (iii) long-term loss of natural vegetation (Article 1(f); UNCCD, 1994). Desertification is defined as the land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (Article 1(a); UNCCD, 1994). Drought is characterised by a deficiency of precipitation that results in a water shortage, and like land degradation, occurs throughout the world, including in humid regions (UNCCD, 2013).
Drylands	Tropical and temperate areas with an aridity index of less than 0.65 (MA, 2005).
Ecosystem-based Adaptation	Sustainably managing, conserving and restoring ecosystems, etc. to provide the services that allow people to adapt to climate change (Collins et al., 2009). It can be considered an application of the EbA focus on bolstering the resiliency of natural ecosystems, so they are prepared for the impacts of climate change (types provided in Box 1), and it is still being developed and tested in the field.
Ecosystem-based approach (EbA)	Strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way, a term being widely used in the framework of Convention on Biodiversity (CBD) (adapted from CBD, 1992). An EbA recognises that humans, with their cultural diversity, are an integral component of ecosystems.
Ecosystem-based Mitigation approaches	Use of ecosystems for their carbon storage and sequestration service to aid in climate change mitigation, where emissions are reduced and sinks are increased through the creation, restoration and management of ecosystems (e.g. forest restoration, peat conservation; adapted from IPCC, 2014) .

Ecosystem Services (ES)	Benefits people obtain from ecosystems (MA, 2005). These include: a) provisioning services, such as supply of nutritious food and water; b) regulating services such as climate change mitigation, flood management and disease control; c) cultural services, such as spiritual, recreational, and cultural benefits; and d) supporting services, such as nutrient cycling, that maintain the conditions for life on Earth (Orr et al., 2017). Furthermore, a defined healthy ecosystem means that it can provide supporting, regulating and cultural services. Ecosystems provide a variety of services, such as drinking water, habitat, shelter, food, raw materials, genetic materials, a barrier against natural disasters and the formation and regeneration of the natural resources in the ecosystem that people depend on for their livelihoods.
Integrated Land Management (ILM)	Way of managing the landscape that involves collaboration among multiple stakeholders from different sectors and social groups, with the purpose of achieving sustainable landscapes. It can take a wide array of forms, depending on the governance structure, size and scope, number and types of stakeholders involved (e.g., producer and community organizations, private companies, civil society, government agencies), and the intensity of cooperation. In some cases, there may simply be information sharing and consultation; in others, more formal arrangements with shared decision-making and joint implementation of activities may be required (adapted from Estrada-Carmona et al., 2014; Reed et al., 2017).
Land-based Approaches (LBA)	Land-based Approaches have the potential to simultaneously increase food security and humans' wellbeing, protect or enhance biodiversity, enable adaptation to climate change, and contribute to climate change mitigation, since restoring the soils of degraded ecosystems has the potential to store between 1.5 and 4 billion tons of CO_2 annually (adapted from IPCC, 2007). In the context of the United Nations Framework Convention for Climate Change (UNFCCC) overall objective (UNFCCC 1992)[1], LBAs to climate change mitigation (mitigation options in the Agriculture, Forestry and Other Land-use sector) issues were initially introduced from the climate-change mitigation perspective,

1 "...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner".

[cont.] Land-based Approaches (LBA)

by representing an opportunity to reduce the rate of the build-up of carbon dioxide in the atmosphere by taking advantage of the fact that carbon can accumulate in vegetation and soils in terrestrial systems. This opportunity was brought into focus at the Third Conference of the Parties (COP) of the UNFCCC in Kyoto in 1997. The Kyoto Protocol included provisions related to Land-use, Land-Use Change and Forestry (LULUCF) activities for Annex I Parties to take afforestation, reforestation, and deforestation and other agreed LULUCF activities (such as forest management, cropland management, grazing land management and revegetation) into account in meeting their commitments under its Article 3. The further development of the modalities to implement these provisions were negotiated later, and resulted in the Marrakesh Accords at its COP.7. Such negotiations were informed by a Special Report from the Intergovernmental Panel on Climate Change (IPCC) on LULUCF (UNFCCC, 1992)[2]. Although land-related adaptation issues are less prominent, they are not of lesser importance. Land-based approaches are therefore considered as a multiple-win adaptation and mitigation option that can simultaneously address the objectives of the three conventions. This should be recognised across the three Rio Conventions (UNCCD, 2015 and Cowie and Schneider, 2007).

Land Degradation

In the present report, and differently from the DLDD concept, land degradation is understood more broadly, with 'land' interpreted to include soils, vegetation, geomorphology, wildlife habitats and water; and 'degradation' implying adverse consequences for humanity and ecological systems (Adeel et al., 2005; Conacher, 2009). Land degradation therefore implies a persistent reduction of land's productivity (Adeel et al., 2005) expressed by a declining provision of the land's ecosystem services, including provisioning and regulating services.

Land Degradation Neutrality (LDN)

A state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remains stable or increases within specified temporal and spatial scales and ecosystems (UNCCD, 2015).

LDN target (global)

The objective to achieve a land degradation-neutral world (United Nations General Assembly, 2015b).

2 United Nations Framework Convention on Climate Change (UNFCCC): 1992.

Landscape-focused terminology

The terms "Landscapes," "Landscape Approaches" and "Integrated Landscape Management," and other similar "landscape-focused" terminology, underpin much of the discourse in contemporary research and donor and development circles related to conservation, agriculture and other land-uses. The plethora of terms is both confusing and yet pervasive. As such, an agreed understanding on what such "landscape approaches" conceptually represent or actually look like on the ground remains elusive. In an attempt to provide a guiding framework to landscape approach, the Center for International Forestry Research (CIFOR) and partner institutions described 10 principles that characterise such an approach (Sayer et al., 2013). These 10 principles emphasise adaptive management, stakeholder engagement and dialogue, and multiple objectives. To successfully achieve the desired multifunctionality in a landscape approach, more attention needs to be paid to both design and implementation. This asks for special attention to: multifunctionality, trans-disciplinarity, participation, complexity, and sustainability (Freeman et al., 2015). Just as there are many varying definitions and interpretations of landscapes, the term "landscape approach" also has been widely applied. For example, an Eco-Agriculture Policy Focus brief provides a list of 80 terms related to integrated land management, many of which can be synonymous or overlap with the concept of a landscape approach (Scherr et al., 2013). In practise, a large range of initiatives can be categorised under the umbrella of landscape approaches.

Land Use

Type of activity being carried out on a unit of land, in urban, rural and conservation settings (IPCC, 2006). In this report five major land-use types will be considered: cropland, grazing land, forestland, mixed land and others (adapted from Smith et al., 2014; WOCAT, 2002).

Nationally Determined Contributions (NDCs)

All Parties from the Paris Agreement are to undertake and communicate ambitious efforts to the global response to climate change. They need to communicate them as defined in Articles 4, 7, 9, 10, 11 and 13, with the aim of achieving the purpose of this Agreement as set forth in Article 2. The efforts of all Parties will represent a progression over time, while recognising the need to support developing country Parties for the effective implementation of this Agreement (UNFCCC, 2015).

Nature-Based Solutions (NBS)

Use of nature in tackling challenges such as climate change, food security, water resources, or disaster risk management has been introduced, which encompasses a wider definition of how to conserve and use biodiversity in a sustainable manner. By going beyond the threshold of traditional biodiversity conservation principles, this concept intends to additionally integrate societal factors, such as poverty alleviation, socio-economic development, and efficient governance principles. The International Union for Conservation of Nature (IUCN) is currently developing guidance on what type of interventions should be considered as a "nature-based solution" (Cohen-Shacham et al., 2016). Other groups are also discussing the definition of the concept of NBS, such as the Horizon 2020 Advisory Group (AG) for Societal Challenge 5 "Climate Action, Environment, Resource Efficiency and Raw Materials" (Balian et al., 2014).

Reclamation

Actions undertaken with the aim of returning degraded land to a useful state. While not all reclamation projects enhance natural capital, those that are more ecologically-based can qualify as rehabilitation, or even restoration (adapted from IPCC, 2007).

Rehabilitation

Actions undertaken with the aim of reinstating ecosystem functionality, where the focus is on provision of goods and services rather than restoration (McDonald et al., 2016).

Resilience

The ability of a system to absorb disturbance and reorganise itself, so as to essentially retain the same function, structure, and feedbacks. Resilience is a neutral property, neither good nor bad (adapted from IPCC, 2007).

Restoration

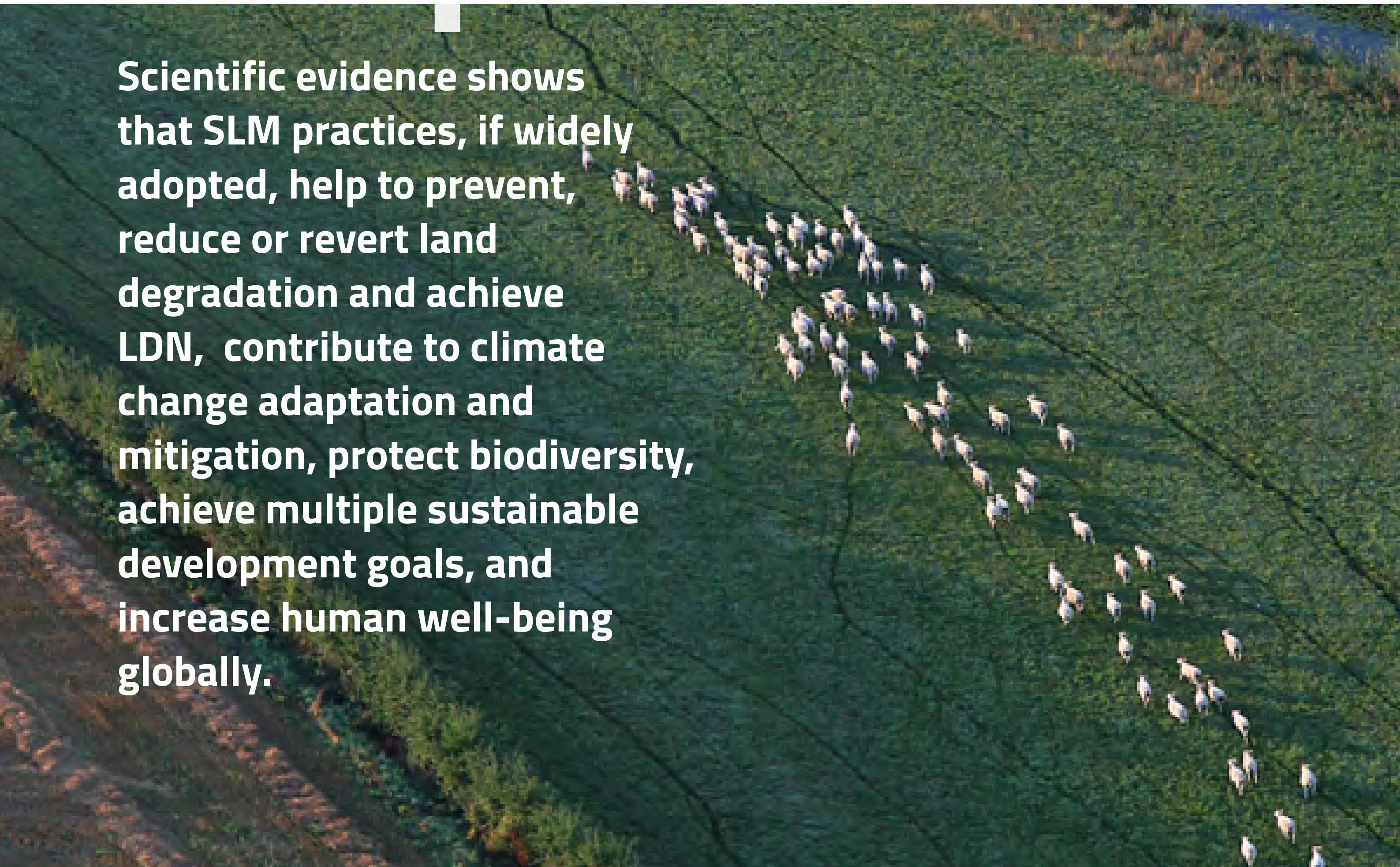
The process of assisting the recovery of an ecosystem that has been degraded. Restoration seeks to re-establish the pre-existing ecological structure and function, including biotic integrity (adapted from IPCC, 2007).

Supply-side mitigation options	Mitigation potentials (e.g. reducing GHG emissions per unit of land/animal, or per unit of product; (Smith et al., 2014). They can be classified by (i) their technical mitigation potential; (ii) ease of implementation (acceptance or adoption by land manager); or (iii) timescale for implementation. These mitigation options can have additive positive effects, but can also work in opposition.
Sustainable Development Goals (SDGs)	The Sustainable Development Goals (SDGs), officially known as Transforming our world: the 2030 Agenda for Sustainable Development, is a set of 17 "Global Goals" with 169 targets between them. Spearheaded by the United Nations through a deliberative process involving its 193 Member States, as well as global civil society, the goals are contained in paragraph 54, United Nations Resolution A/RES/70/1 dated 25 September 2015 (Smith et al., 2014).
Sustainable Development Goal (SDG) 15 and 15.3 target	SDG 15: to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and biodiversity loss. Target 15.3 aims, by 2020, to combat desertification, and restore degraded land and soil, including land affected by desertification, drought and floods, and strives to achieve a land-degradation neutral world, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (Smith et al., 2014).
Sustainable Land Management (SLM) practices	Sustainable land management combines technologies, policies and activities, aimed at integrating socio-economic principles with environmental concerns, so as to simultaneously: maintain or enhance production/services (Productivity); reduce the level of production risk (Security); protect the potential of natural resources, and prevent degradation of soil and water quality (Protection); be economically viable (Viability); and socially acceptable (Acceptability)[3]. In this report, this term is not only restricted to drylands, but applies globally.

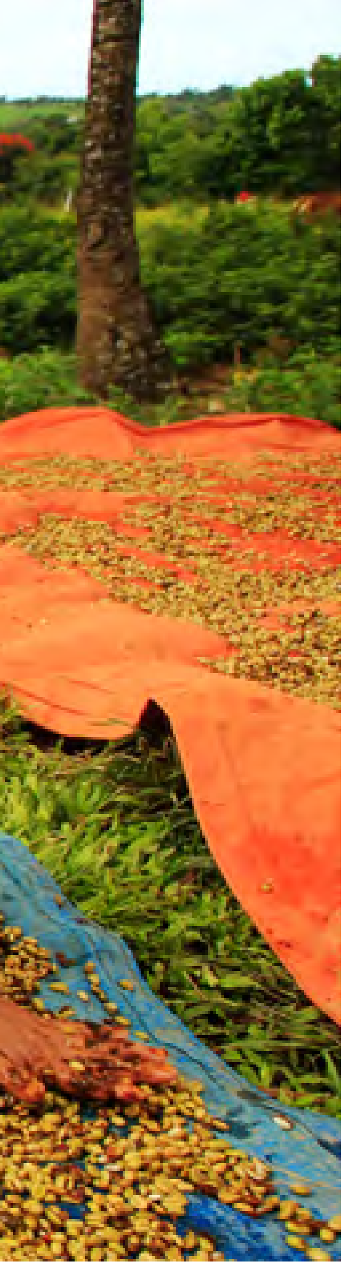
3 The International Framework for the Evaluation of Sustainable Land Management (FESLM) Working Party, Nairobi (1991).

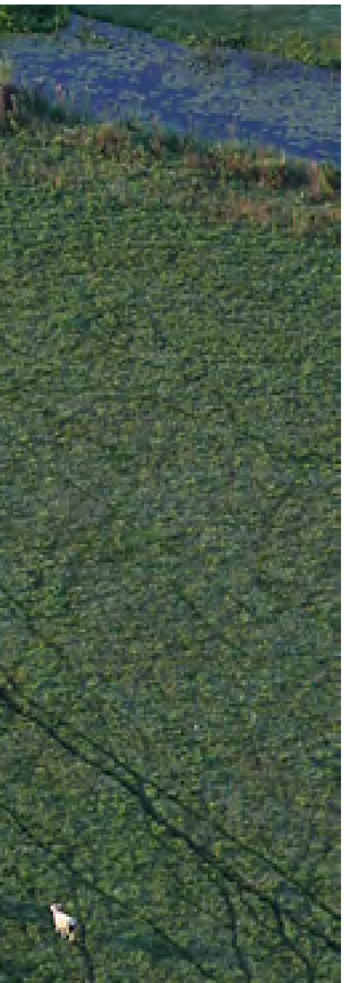
Sustainable Land Management (SLM) represents a holistic approach to preserve ecosystem services in long-term productive ecosystems by integrating biophysical, socio-cultural and economic needs and values.

Chapter 1



Scientific evidence shows that SLM practices, if widely adopted, help to prevent, reduce or revert land degradation and achieve LDN, contribute to climate change adaptation and mitigation, protect biodiversity, achieve multiple sustainable development goals, and increase human well-being globally.





Why Sustainable Land Management?

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1. INTRODUCTION

Human development and environmental sustainability are highly interlinked and threatened by the major anthropogenic-driven environmental challenges of our time. Scientific evidence shows that atmospheric, geological, geomorphological, hydrological, biospheric and other earth system processes, are heavily altered by the human intervention. As a result, there is a consensus that we are in a new human-dominated geological epoch (Lewis & Maslin, 2015). Direct human interactions with the natural environment, especially in the domain of socio-ecological systems, are complex and happen at multiple scales. These scales ranges from the local land owners, and regional and national land-use planning, to the global demand and supply of services and trade patterns. It is thus of primary importance to enhance our understanding of the interlinkages between climate change, land degradation and biodiversity loss, to subsequently improve our capacity to respond to these challenges. Indeed, scientists, policy makers and other social actors are increasingly recognising the need to identify and pursue synergies among Global Change issues, especially related to DLDD, and climate change mitigation and adaptation (see Box 1).

BOX 1:

Science Policy Interface objective 2. Specific mandate for the report

Objective two of the Science-Policy Interface (SPI) work program for the biennium 2016-2017 requests the SPI to "Highlight the science-based synergistic potential of sustainable land management (SLM) practices to address DLDD, climate change mitigation and adaptation" (UNCCD 2015b). The SPI work programme for the biennium 2016-2017 was approved by the twelfth session of the UNCCD (COP12)[4].

4 http://www.unccd.int/en/programmes/Science/International-Scientific-Advice/Documents/SPI_WP2016-2017.pdf

1.1 Report objectives and contents

1.1.1 Report objectives

This report addresses the potential for Sustainable Land Management (SLM) practices to create synergies between management of DLDD and climate change mitigation and adaptation.

Why land-use based actions? Land provides vital resources to society, such as food, fuel, fibres and many other so-called Ecosystem Services (ES) that support production functions, regulate risks of natural hazards, or provide cultural and spiritual services (MA, 2005; Figure 1., see subchapter 1.2.3 *Other approaches*). However, conventional land use practices have interfered with natural processes that maintain these natural systems. This is partially reflected through the decline in the provision of ecosystem goods and services. It is therefore critical that land-use decision-making consider all possible synergies and trade-offs across spatial and temporal scales.

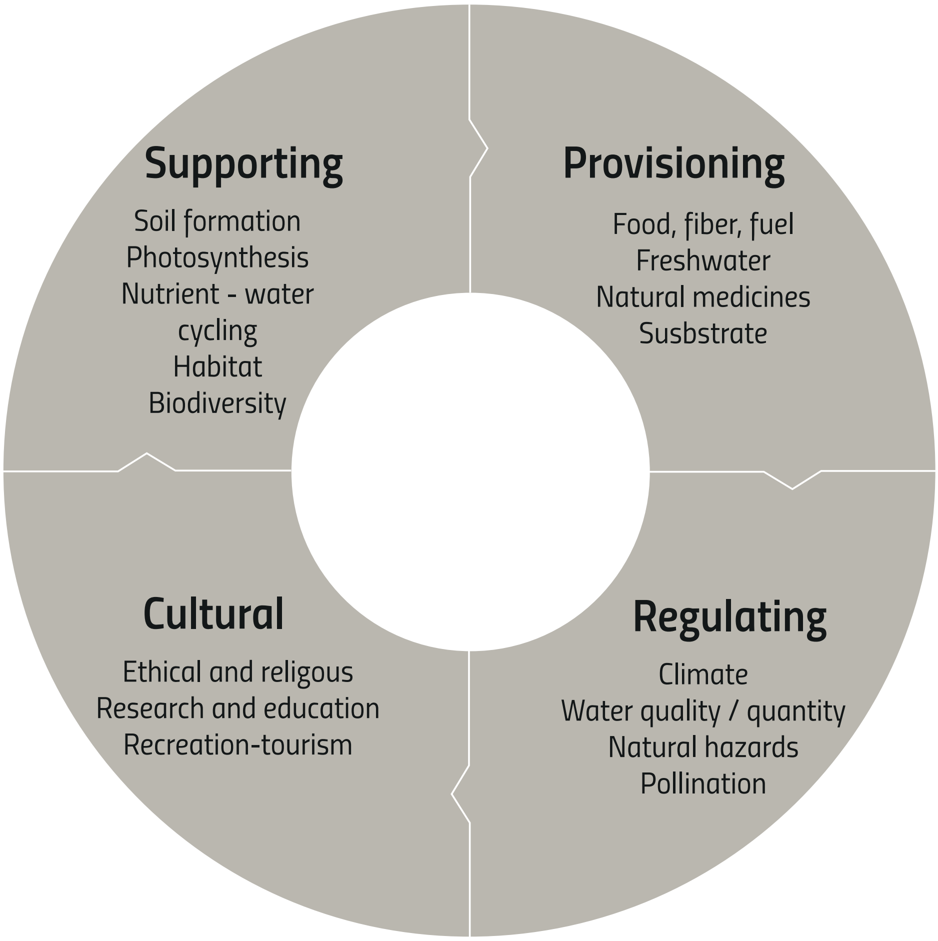

FIGURE 1:

Multiple ecosystem services, goods and benefits provided by land (after MA, 2005; UNEP-WCMC, 2011).

This will help to address issues related to DLDD, which lies at the heart of many development challenges related to reduced land productivity, food insecurity, climate change through greenhouse emissions, migration, and many other social and economic problems.

Why is there a need to respond now? Globally, large areas of land are being affected by land degradation, often caused by unsustainable land-use practices that occur in all climatic regions (Conacher, 2009; UNCCD, 2015). Although the world's drylands continue to be the most vulnerable and threatened by DLDD, the scope of this report goes beyond drylands, since land degradation is a global phenomenon, with 78% of total degraded land located in other terrestrial ecosystems[5].

5 UN General Assembly, 2012. High-level meeting on addressing desertification, land degradation and drought in the context of sustainable development and poverty eradication. A/65/861.

ABOUT 24% OF GLOBAL LAND AREA HAS BEEN DEGRADING OVER THE LAST 25 YEARS, DIRECTLY AFFECTING THE LIVELIHOODS OF 1.5 BILLION PEOPLE (Bai et al., 2008).

According to "A global initiative for sustainable land management," (MA, 2005), around 10–20% of drylands and 24% of the world's productive lands are degraded. Many of the people affected by land degradation live in developing countries where the need to increase agricultural production is greatest. Land degradation, desertification and climate change alone, or interactively, can affect the regulation, support, provisioning and cultural services of terrestrial ecosystems (Noble et al., 2014; Reed & Stringer, 2015). Mismanagement of land already threatens, and will continue to threaten, future global food and energy security (World Bank, 2008), enhance water insecurity (MA, 2005), hamper capacities to adapt to, and mitigate, climate change (Neely et al., 2009), and also alter biodiversity. SLM practices, combined with rehabilitation activities, can be an opportunity to create green jobs and enhance rural economic activity, as recently demonstrated in a sustainable business case in Ghana (The New Economy, 2014).

How to respond? How do we sustainably develop to meet future society demands without further degrading our finite land and water resources? SLM practices can be seen as a vehicle to optimise the contributions of land-use based actions in line with the objectives of the UNFCCC, UNCCD and CBD, and to broadly contribute to sustainable development. Despite improved knowledge of the processes and effects of land degradation, on the one hand, and climate change on the other, there is still poor understanding of the complex interactions between the two and their impacts on human well-being. However, recent experiences regarding land management practices show that important synergies can be obtained while designing approaches, policies and practices on the ground to combat DLDD, to adapt to or mitigate the effects of climate change, and to prevent the loss of biodiversity.

Pursuant to UNCCD Decision 3/COP.12, which aims to make Sustainable Development Goal (SDG) target 15.3 (see Box 1.2) on striving to achieve Land Degradation Neutrality (LDN) one of the central objectives of the 2016–2017 work programme of the UNCCD's SPI, a *Scientific Conceptual Framework for Land Degradation Neutrality* (LDN), has been developed. The SDG target 15.3 is also relevant to the other Rio Conventions[6]. In addition, a new opportunity is emerging from the strong commitment of governments to adapt to, and combat, climate change after the Paris United Nations Framework Convention for Climate Change (UNFCCC) Conference of the Parties in 2015 (COP21), through Nationally Determined Contributions (NDCs) that widely include land-based actions (see Chapter 1.4). In this context, SLM could form an integral component of efforts to achieve LDN, while ensuring ecologically responsible land management practices that can also contribute to actions on climate

6 And pursuant to paragraph 74(f) of the UN General Assembly resolution 2030 Agenda for Sustainable Development, which explicitly states that SDG implementation "will build on existing platforms and processes, where these exist, avoid duplication and respond to national circumstances, capacities, needs and priorities"(UNGA, 2015), looking for common vehicles to implement SDG 15.3 while contributing to the respective objectives of the three Río Conventions should be a major step forward.

change adaptation and mitigation, and generate other co-benefits such as biodiversity conservation. Preliminary studies predict huge costs of future land degradation and emphasise the need to invest in SLM rehabilitation and restoration measures that can reduce the loss of productive land and contribute to achieving the Land Degradation Neutrality (LDN) target (ELD, 2013; UNGA, 2015b).

1.1.2 Report structure and contents

In this report, the potential for SLM practices to address both land degradation and climate change adaptation and mitigation, is demonstrated through a selection of SLM technologies and practices clustered by land types (see Chapter 2), which are qualitatively assessed based on existing literature and expert judgments. This includes a preliminary attempt to address other co-benefits (i.e. biodiversity), as well as qualitative consideration of cost. Finally, aspects related to opportunities, barriers and enabling environments, as well as trade-offs and barriers to SLM implementation are also addressed (see Chapter 4).

The objective of this report is not to give an exhaustive classification of current SLM technologies and practices or to propose new ones. Instead, the report aims to illustrate the potential of different groups of SLM technologies under specific land use types, and to highlight the importance of land-based solutions. The report seeks to target a broad audience that includes scientists, policy makers and other social actors, such as land owners, community stakeholders and small and medium enterprises (SMEs).

1.2 SLM: definition, history and relevant concepts

1.2.1 Defining SLM

According to the UN Earth Summit of 1992, SLM is "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions". Dumanski & Smyth (1993) indicated that the objective of SLM is to harmonise the complimentary goals of providing environmental, economic, and social opportunities for the benefit of present and future generations, while maintaining and enhancing the quality of land (soil, water and air) resources.

Today, SLM represents a holistic approach to achieving long-term productive ecosystems by integrating biophysical, socio-cultural and economic needs and values (Holling, 2001; Schwilch et al., 2009).

ALONG WITH REHABILITATION AND RESTORATION, SLM FORMS ONE OF THE MAIN MECHANISMS TO ACHIEVE LAND DEGRADATION NEUTRALITY (LDN) (Orr et al., 2017).

SLM encompasses soil, water and vegetation conservation measures, and is based on the key principles of enhancing the productivity and protection of natural resources, while being economically viable and socially acceptable (Schwilch et al., 2014).

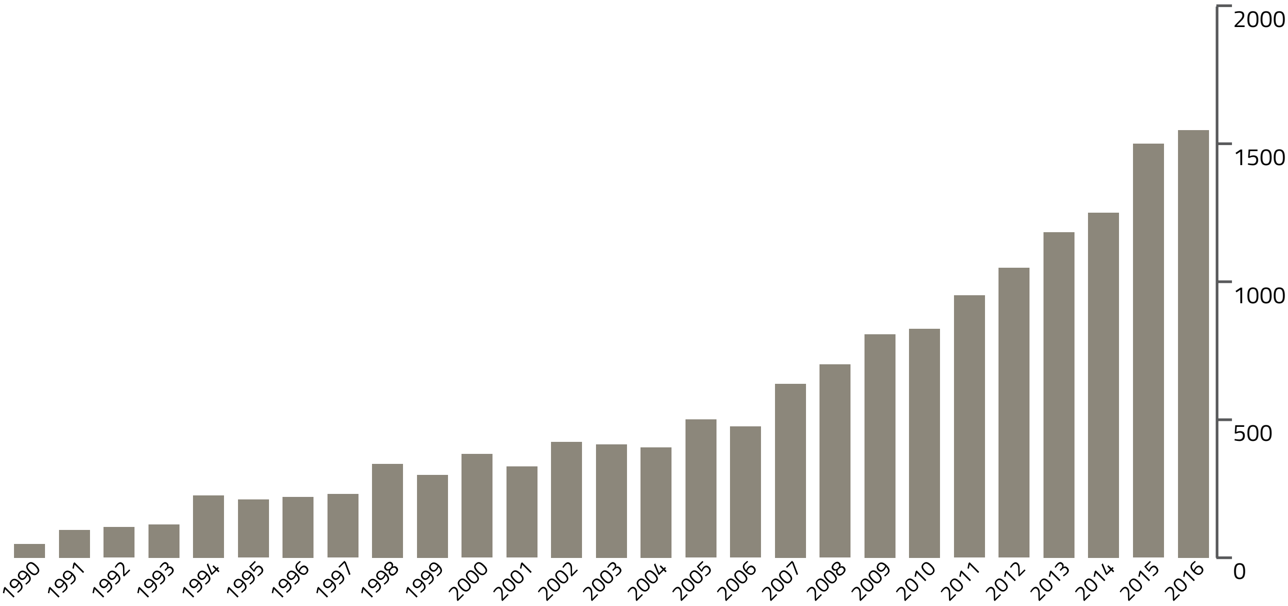

FIGURE 2:
Number of publications (X axis) included in the Web of Science (WoS) on the topic SLM between 1990-2016 (Y axis).

The potential multiple benefits provided by SLM practices are widely accepted and documented within the scientific community (e.g. Novara et al., 2013; Batjes, 2014; Schwilch et al., 2014; Tejada & Benítez, 2014; Garcia-Franco et al., 2015; Giger et al., 2015; Mekonnen et al., 2015; Ndah et al., 2015; van Leeuwen et al., 2015; Almagro et al., 2016; Kust et al., 2016). However, in order to increase the success of SLM, recent studies indicate that considering non-linear ecosystem dynamics and the financial viability of investments, as a pre-requisite for SLM design and implementation, will be fundamental (Sietz et al., 2017).

1.2.2 SLM history

The concept of SLM emerged more than twenty years ago[7] and has been promoted ever since, as illustrated by the increased number of publications on this topic (Figure 2). SLM was introduced to address technical, ecological and biophysical aspects, as well as economic and socio-cultural dimensions (Dumanski & Smyth, 1993; FAO, 1993; Hurni et al., 2006; IAASTAD, 2008). In addition, it encourages an integrated, holistic perspective of land management, including environmental, economic and socio-cultural aspects (Schwilch et al., 2011).

7 In this paper, the terms 'sustainable land management' and "land degradation" apply globally, not only restricted to drylands.

At an international scale, the Millennium Ecosystem Assessment reviewed SLM options available to dryland communities (MA, 2005), and the World Overview of Conservation Approaches and Technologies (WOCAT) documented and evaluated SLM options, building on, and sharing, local knowledge between comparable contexts around the world (Liniger et al., 2007; Schwilch et al., 2009; Schwilch et al., 2011).

1.2.3 Other approaches

In order to reflect on the historical background of SLM, it is important to note that the concept of sustainability in the context of natural resources management has been considered through several definitions, characterised by specific objectives or priorities of organizations or initiatives over time. The majority of actions taken on land degradation and climate change were designed to address one or few of the ecosystem services provided by land systems. For example, climate change mitigation actions aim primarily to enhance climate regulation. However, it is critical to preserve ecosystem functionality as a whole to ensure that all its services will be maintained. Related to this, a number of new concepts and paradigms have appeared during the last decade, related directly or indirectly to land-use, such as: ecosystem services (MA, 2005, Figure 1); ecosystem-based approach (CBD); ecosystem-based adaptation; ecosystem-based mitigation; land-based (adaptation, mitigation) approach (IPCC, 2007); integrated land management; integrated landscape management; landscape approach (Sayer et al., 2013); nature-based solutions (Balian et al., 2014). All these concepts, while still considered for different purposes, converge towards striving for a sustainable interaction between natural and human systems.

The integrated management of the natural capital of land, water and living resources can help policy makers and other stakeholders to successfully implement a series of coordinated and integrated SLM practices. This might be achieved through a combination of "ecosystem adaptation approaches", "landscape approaches" (synonymous with "integrated landscape management") or "land-based adaptation and mitigation approaches". These should aim to simultaneously increase food security and livelihoods, protect or enhance biodiversity, enable adaptation to climate change and contribute to climate change mitigation. In the late 1980s, it was identified that the imposition of top-down ideas and practices failed to adequately take the issues of contextual specificity and local knowledge into account while working on development programmes (Scott, 1998).

HOWEVER, IN ORDER FOR INTEGRATED MANAGEMENT TO BE SUCCESSFUL, TRANS-DISCIPLINARY EFFORTS AND LEADERSHIP IS REQUIRED AT ALL LEVELS OF DECISION-MAKING, FROM GLOBAL POLICY MAKERS TO COMMUNITY LEADERS, AND FROM SCIENTISTS TO FARMERS.

Engaging private sector investments, networking and partnership-building is required, as well. Not only top-down, but also more bottom-up approaches are necessary. For example, Community-Based Adaptation (CBA) and Nature-Based Solutions (NBS) at a local level could be options for preserving and recovering ecosystem services, and therefore also for addressing land degradation and climate change causes and impacts at this scale.

SLM is commonly considered as the main approach to prevent, mitigate and reverse land degradation, but it can also serve as an integral climate change adaptation strategy, being based on the statement that the more healthy and resilient the system is, the less vulnerable and more adaptive it will be to external changes and forces, including climate. In that regard, SLM can be considered a land-based approach, which includes the concepts of both Ecosystem-Based Adaptation (EBA) and Community-Based Approach (CBA).

1.2.4 LDN concept

Although the principles and practices of SLM are well known and SLM has been widely promoted through many land-use projects in different countries, land degradation is still growing and becoming a major global threat. The UNCCD considered that the problem of slow adoption of SLM could be addressed by inclusion of LDN as a Sustainable Development Goal (Lal et al., 2012). The concept of LDN[8] was first raised at the Rio+20 conference of the United Nations, and recorded in the resulting document "The Future We Want" (UN article 206, 2012): "We recognized the need for urgent action to reverse land degradation. In view of this, we will strive to achieve a land-degradation neutral world in the context of sustainable development." The LDN goal can serve as a target for SLM and overall indicator for the success of SLM (Kust et al., 2016).

1.2.5 LDN and SDG targets

On the 25th of September 2015, the Sustainable Development Goals (SDGs) were formally adopted by the UN General Assembly. SDG 15 explicitly stresses to "sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" (Box 1.). The centrality of land in addressing a number of sustainable development challenges was politically recognised, including challenges relating to poverty, food, water and energy security, human health, migration, conflict tackling climate change and biodiversity loss (Thomas et al., 2012).

The 2030 goal for the LDN set by political decision-makers is less than 15 years away, leaving a challenging timeframe for action. One important step towards LDN has been taken by the UNCCD in decisions adopted at its twelfth Conference of the Parties (COP) in 2015. Parties decided to integrate LDN into the implementation process of the UNCCD, noting that: "striving to achieve SDG target 15.3 is a strong vehicle for driving the implementation of the UNCCD" (UNCCD, 2015a, decision 3). At the same time, SDG target 15.3 is relevant to the other Rio Conventions as well.

Achieving LDN through SLM underpins and catalyses the achievement of SDG 15 and 13 and their related targets (see Figure 3). For example, SDG 13 on climate change is particularly relevant to the UNFCCC, while multiple relationships and feedbacks between land and climate systems are noted in literature (e.g. Reed & Stringer, 2016).

8 See Chapter 4, LDN conceptual framework

BOX 2:

Sustainable Development Goal (SDG) target 15.3

SDG 15 includes the target 15.3 to "combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world" by 2030 (UNGA, 2015a).

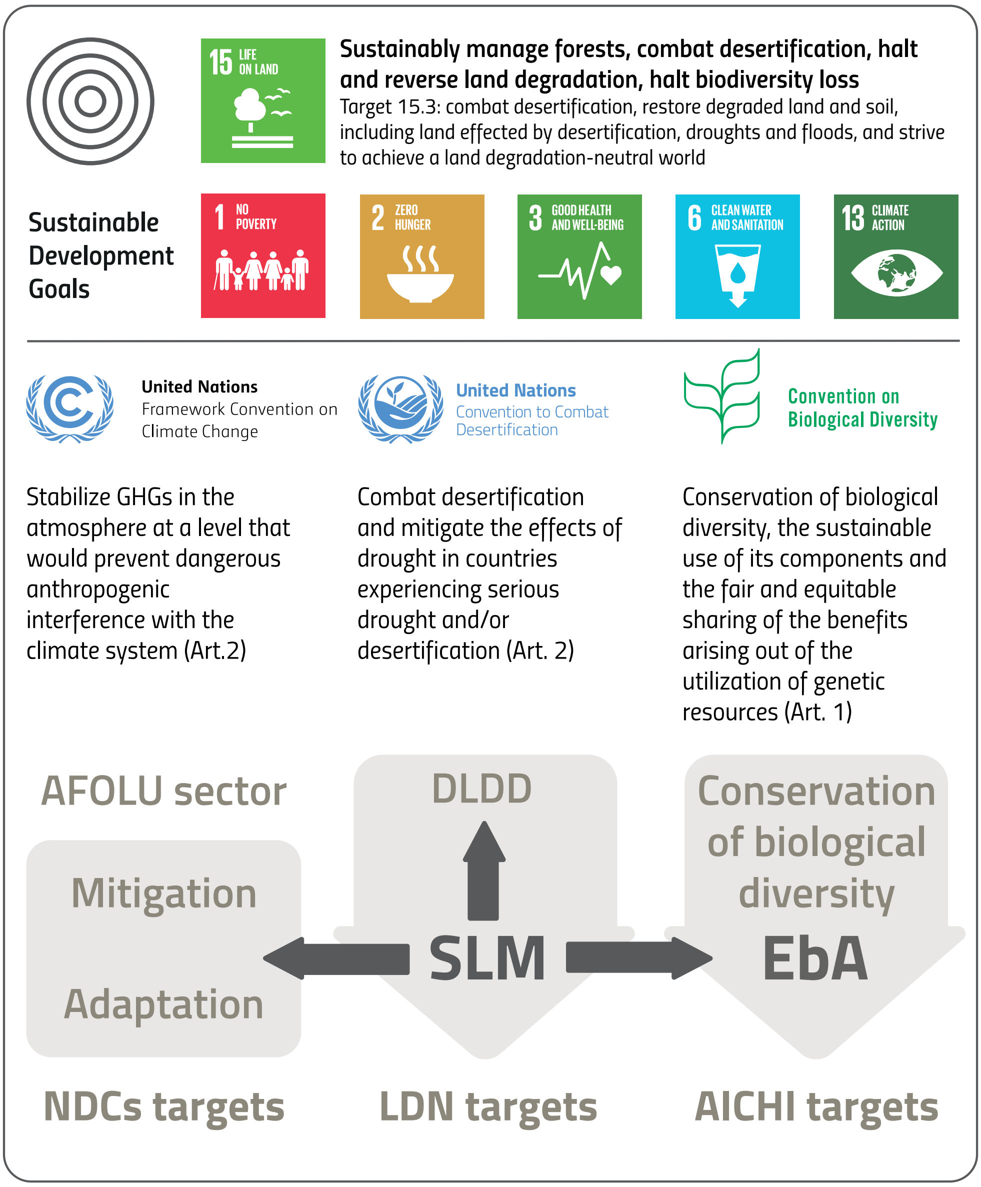

FIGURE 3:

SLM as a holistic vehicle to achieve the objectives of the three Rio Conventions, and the SDG 15 (15.3) and SDG 13 primarily, but also relevant for SDG 1, 2, 3, 6 and SDG 13.

Biodiversity-related targets under SDG 15 show clear links to the CBD, with biodiversity supporting many of the processes that underpin the ecosystem functioning of land. Developing interconnected actions that span the interests of the Rio Conventions will be vital in moving towards LDN, especially at national level, where cross-compliance in actions across different conventions will be necessary. Such interplay creates a number of challenges and opportunities, many of which are well-reflected in existing literature. In addition to contributing to achieve LDN, SLM can contribute to SDG2 (zero hunger) and SDG6 (clean water and sanitation), to some extent.

Harnessing possible synergies could lead to a pragmatic, integrated framework of complementary rehabilitation, restoration and SLM measures to achieve LDN. It could also stimulate actions at a national level that enhance human well-being. Developing such synergies will be vital in the post-2015 development context as countries seek both policy alignment and cost-effective action (Akhtar-Schuster et al., 2016). However, this requires careful assessment and evaluation, since sometimes trade-offs may already exist or emerge between different environmental, economic and socio-cultural objectives (see, for example, Cowie et al., 2011).

1.3 Climate change: the role of land-use and SLM in the context of Nationally Determined Contributions (NDCs)

Despite two decades of effort to curb emissions of CO_2 and other greenhouse gases (GHGs), emissions grew faster during the 2000s than in the 1990s (Le Quéré et al., 2013), and by 2010 had reached ~50 Gt CO_2 equivalent (CO_2eq) yr^{-1} (Peters et al., 2013a). The continuing rise in emissions is a growing threat for meeting the international goal of limiting warming to less than 2 °C in comparison with the pre-industrial era. The objective of UNFCCC's Paris Agreement is to strengthen the global response to climate change by keeping a global temperature rise this century well below 2 °C above pre-industrial levels, and to pursue efforts to limit the temperature increase even further, to 1.5 °C. Delivering this level of ambition requires immediate and dramatic emissions cuts in all sectors. The Agreement establishes a binding obligation to all Parties to put forward nationally determined contributions (NDCs) that formulate a country's mitigation strategies and goals. To have more than fifty percent chance of limiting warming below 2 °C, most recent scenarios from integrated assessment models (IAMs) require large-scale deployment of negative emissions technologies (Smith et al., 2016). In that context, the land sector has significant mitigation potential through increasing carbon stocks in biomass and soil and reducing GHG emissions. Moreover, and most importantly, the land sector is central to ensuring a secure livelihood and food sovereignty, and to maintaining ecosystem integrity.

According to the IPCC (2014), and broadly confirmed by more recent analysis of the IPCC datasets (Tubiello et al., 2015) and Food and Agriculture Organization of the United Nations (FAO) data (Federici et al., 2015), net emissions from land-use changes represented ≈ 10–12% of total GHG emissions around the year 2005. Beyond the mitigation potential related to reducing emissions from land-use changes, the Land-use, Land-use Change and Forestry (LULUCF) sector also provides a relevant contribution through the conservation and enhancement of carbon sinks (e.g. cropland management, grazing land management, forest management, forest expansion) and through the provision of renewable energy and materials. Soil carbon stock is the largest potential sink, mitigating ~1.2 $GtCO_2e\ yr^{-1}$ in 2030 at USD 20/ tCO_2e (Smith et al., 2014; Williamson, 2016), although its effects are easily reversed with intensive tillage or soil disturbance, and there are still important uncertainties about long-term stability of soil organic carbon and possible saturation effects. Reducing the land-use change for the benefit of expanding agricultural lands worldwide has the potential to mitigate 1.71–4.31 Gt $CO_2\ yr^{-1}$ by 2030, at a price of USD 20/tCO_2e (Carter et al., 2015). Historically, global LULUCF net emissions decreased from 1.54±1.06 $GtCO_2e\ yr^{-1}$ in 1990 to 0.01±0.86 $GtCO_2e\ yr^{-1}$ in 2010 (Grassi et al., 2017)

In preparation for the COP21 in Paris, by 15 December 2015, 187 countries[9] (representing around 95% of global GHG emissions in 2010) had submitted their emission reduction targets in the Intended Nationally Determined Contributions (I-NDCs). Of those countries, more than 100 of them explicitly mention a mitigation role of the Land-use, Land-use change and Forestry (LULUCF) sector (Admiral et al., 2015; Forsell et al., 2016). The NDC bottom-up approach, grounded in country leadership, was vital to producing a successful outcome at COP21, where INDCs were turned into Nationally Determined Contributions (NDCs). Unless a Party specifies otherwise, its INDC will become its first NDC upon submitting its instrument of ratification for the Paris Agreement. (I) NDCs outline countries' climate change priorities for the post-2020 period.

Parties are expecting a significant contribution from LULUCF in meeting the individually proposed NDC mitigation targets. According to Grassi et al., (2017) the full implementation of announced NDCs would turn the LULUCF sector globally from a net source during 1990-2010 (1.3±1.1 $GtCO_2e\ yr^{-1}$), to a net sink by 2030 (up to -1.1±0.5 $GtCO_2e\ yr^{-1}$). A wide range of LULUCF mitigation options are being put forward by the Parties to reduce emissions and increase removals from the LULUCF sector. Options such as reducing deforestation, increasing afforestation, improving sustainable forest management, and enhancements of forest carbon stock are mentioned. It should also be noted that a number of Parties have provided joint commitments for the LULUCF and agricultural sector (e.g. Mauritania, Namibia). As these two sectors are highly interlinked, Parties have to carefully consider cross-sectoral implications when implementing mitigation options, as well as in developing projections that are consistent and feasible for both sectors.

The Food and Agriculture Organization of the United Nations (FAO) has analysed the INDCs and found that the agricultural sectors (crops, livestock, fisheries and aquaculture, as well as forestry) feature prominently in meeting national mitigation goals (FAO, 2016) by June 2016 (see Box 3).

9 160 Parties to the UNFCCC, as the EU submitted one INDC on behalf of its 28 Member States

BOX 3:
Agriculture and LULUCF in NDCs: an analysis by FAO.

Agriculture and land-use, land-use change and forestry (LULUCF) are among the most frequently included sectors in countries' mitigation contributions (targets and/or actions). When considered together, 89 percent of countries cover agriculture and/or LULUCF. When countries that mention bioenergy as a mitigation strategy are included, this percentage increases to 92 percent.

The mitigation potential of agriculture and/ or LULUCF is prominently acknowledged at all levels of socio-economic development and among developing countries in all regions. Eighty-six percent of the developing countries, 88 percent of the countries in transition, and 98 percent of developed countries include agriculture and/or LULUCF in their mitigation contributions. Among developing countries, both sectors together are featured most prominently in Eastern and South-Eastern Asia (100 percent), SSA (96 percent), LAC (91 percent) and Southern Asia (89 percent). In Northern Africa, Western Asia and Oceania, 69 percent and 50 percent of the developing countries include both sectors in their mitigation contributions.

In total, 148 countries include agriculture (crops, livestock) in their mitigation contributions. Seventy-one percent of the developing countries, 88 percent of the economies in transition and 98 percent of the developed countries include agriculture in their mitigation contributions. Countries that include agriculture collectively account for 92 percent of global agricultural GHG emissions. Among all developing countries, agriculture is featured most prominently in SSA (84 percent), Southern Asia (78 percent), Eastern and South-Eastern Asia (77 percent), LAC (72 percent) and Northern Africa and Western Asia (69 percent). In Oceania, 21 percent of the developing countries include agriculture in the mitigation contributions.

In total, 157 countries include LULUCF in their mitigation contributions. 80 percent of the developing countries, 75 percent of the countries whose economies are in transition and 98 percent of the developed countries consider LULUCF within their mitigation contributions. Among all developing countries, LULUCF is featured most prominently in Sub-Saharan Africa (94 percent). LULUCF is also included in the mitigation contributions of many developing countries in South Asia (89 percent), Latin America and the Caribbean (88 percent), Eastern and South-Eastern Asia (85 percent). The corresponding figures are more modest in Northern Africa and Western Asia (44 percent) and Oceania (43 percent).

Countries rarely include quantified sector-specific targets for agriculture and/or LULUCF. Nevertheless, forestry is the second most-referenced sector for Non-GHG targets. Many countries consider mitigation in agriculture and/or LULUCF as part of an economy-wide GHG target.

Several countries include specific **policies and measures** when outlining how to achieve their intended mitigation contributions. Policies and measures put forward by countries in **agriculture and LULUCF** focus, in particular, on cropland management, livestock management, grazing land management forest management and restoration, afforestation/reforestation and reducing deforestation.

Interestingly, the agriculture and LULUCF sectors are most often referred to in the NDCs as providing adaptation-mitigation synergies, as well as socio-economic and environmental co-benefits (FAO, 2016). Up to 57 countries endorse or even prioritise actions based on the potential synergies between mitigation and adaptation. Thirty-two countries (including 40 percent of the LDCs) refer to climate-smart agriculture in their INDCs. One-fourth of the countries mention social, economic and environmental co-benefits, particularly rural development and health, poverty reduction and job creation, and conservation of ecosystems and biodiversity. With regard to gender equality, agricultural sectors are highlighted – more so than any other sector – as providing opportunities for empowering women and reducing their vulnerability to climate change.

Scientific evidence shows that SLM practices, if widely adopted, help to prevent, reduce or revert land degradation and achieve LDN, contribute to climate change adaptation and mitigation, protect biodiversity, achieve multiple sustainable development goals, and increase human well-being globally.

More than one hundred SLM technologies can avoid, reduce and/or reverse land degradation and desertification while contributing to climate change mitigation and adaptation.

Chapter 2

SLM practices addressing DLDD, climate change mitigation and adaptation

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2.1 Introducing SLM technologies

Many SLM practices are suitable vehicles to simultaneously address the causes and consequences of land degradation, desertification and climate change in managed systems. Principles and SLM solutions from a scientific and technical perspective are well-known. In practise, guidance for identification and implementation of SLM practices is being provided by different organisations and initiatives, using similar but different criteria, in accordance with their specific objectives and area of implementation. Table 1 includes the criteria used by some of the most prominent ones: World Overview of Conservation Approaches and Technologies (WOCAT) database, the World Bank, TerraAfrica and FAO. All of them are considering technologies and approaches or strategies for SLM implementation, generally guided by few principles. Monitoring and evaluation of the implemented SLM practices and technologies in different stages (short-, medium- and long-term) for each system and for appropriate representative indicators of progress, is crucial to assess the effectiveness of the intervention within each specific socio-ecosystem. However, often only scant quantitative information is available on actual impacts at different spatial and temporal scales.

Based on previous efforts to identify and systematically describe and share SLM practices to address land degradation and climate change adaptation and mitigation globally (i.e. WOCAT database; World Bank SLM source book) and regionally (i.e TerraAfrica), this report identifies more than one hundred SLM technologies from literature and existing databases (such as the WOCAT database), to illustrate the most common technologies or strategies to address DLDD and climate change adaptation and mitigation in different land-use types. Special attention when identifying the SLM practices is given to drylands, due to the importance of desertification in those lands. For the assessment of SLM practices, in this report, all SLM practices are associated with five major land-use types (WOCAT, 2002; see Box 4): cropland, grazing land, forestland, mixed land and others. These land use types correspond broadly to the land-use categories that the IPCC 2006 Greenhouse Gas (GHG) Inventory Guidelines (IPCC, 2006) used and they are the basis for the GHGs Inventories that countries regularly report to the UNFCCC (Forest lands, croplands, grasslands, wetlands, settlements, other lands) (see Box 4).

TABLE 1:

Sustainable Land Management: principles and technologies/strategies by World Overview of Conservation Approaches and Technologies (WOCAT), the World Bank, TerraAfrica.

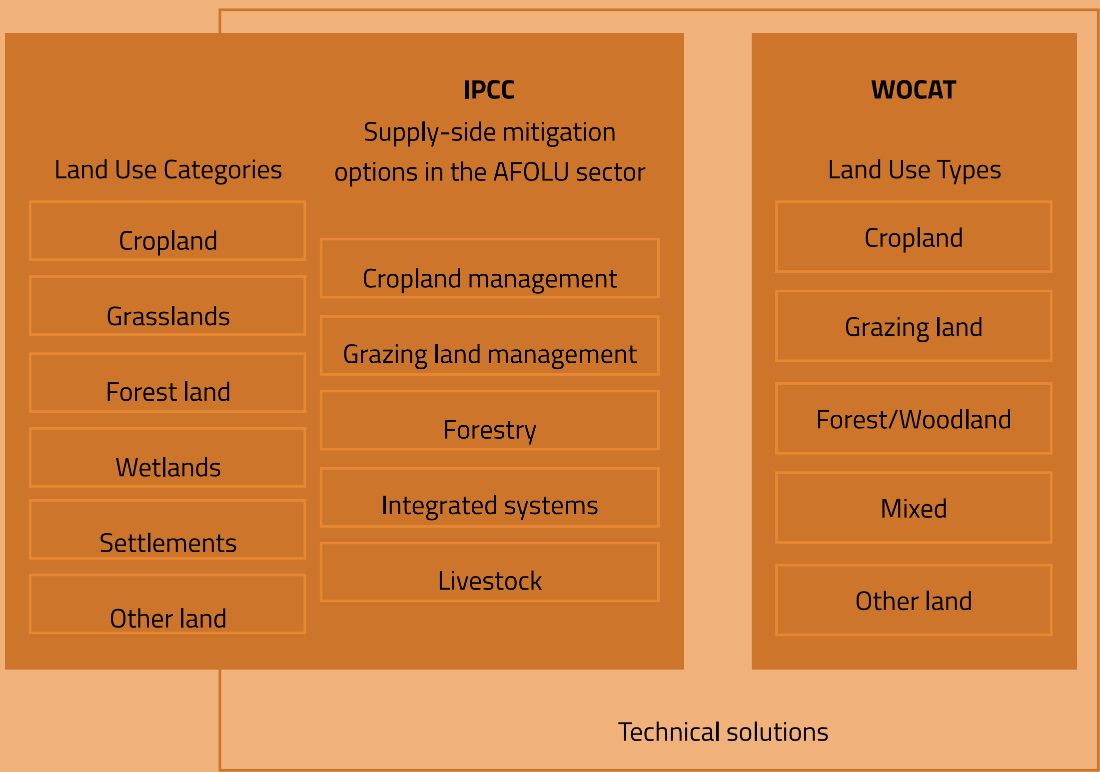
Source	Criteria
World Bank **Sustainable Land Management Sourcebook. The International Bank for Reconstruction and Development / The World Bank. 2008**	Principles: ▪ Buildup of soil organic matter and related biological activity ▪ Integrated plant nutrition management ▪ Better crop management ▪ Better rainwater management ▪ Improvement of soil rooting depth and permeability ▪ Reclamation Strategies: ▪ Intensify existing farm production patterns through increased use of inputs or better quality inputs. ▪ Diversify production, with emphasis on greater market orientation and added value, involving a shift to new, generally higher-value products. ▪ Increase farm size (an option limited to a few areas where additional land resources are still available). ▪ Increase off-farm income to supplement farm activities and provide financing for additional input use. ▪ Exit from agriculture, in many cases by migrating from rural areas Technologies: Improvement of plant varieties; Conservation farming practices; Minimum tillage; Organic farming: Integrated pest management; Precision agriculture; Fertilizer use.
WOCAT **Where the land is greener** **Wocat.net**	▪ SLM technologies are agronomic, vegetative, structural and management measures that control land degradation and enhance productivity in the field. ▪ SLM approaches are ways and means of support that help to introduce, implement, adapt and apply SLM technologies in the field.
TERRAFRICA **http://www.terrafrica.org/sustainable-land-management-platform/**	Principles: ▪ land-user-driven and participatory approaches ▪ integrated use of natural resources at ecosystem and farming systems levels ▪ multilevel and multi-stakeholder involvement ▪ targeted policy and institutional support SLM technologies that aim to increase productivity, improving livelihoods and enhancing ecosystems broadly grouped into 8 categories: Integrated Soil Fertility Management; Conservation Agriculture; Cross-Slope Barriers; Rainwater Harvesting; Smallholder Irrigation; Agroforestry; Sustainable Forestry; Range and Pasture Management.

BOX 4:

Five major land use types definition according to WOCAT (adapted from WOCAT 2002)

Cropland: annual cropping, perennial cropping, tree and shrub cropping.
Grazing land: extensive and intensive grazing lands.
Forest/woodland: natural forest, forest plantations, other.
Mixed: agroforestry (cropland and forest), agro-pastoralism (cropland and grazing land), agro-silvo-pastoralism (cropland, grazing land and forest), silvo-pastoralism (forest and grazing land), other.
Other land: mines and extractive industries, settlements, roads, infrastructure network, others (wastelands, deserts, glaciers).

The following figure illustrates different land use types and categories that are documented in the literature and existing data bases and platforms in land use.



Fourteen groups of SLM (see box 6, tables 2 to 6 and Annex 1) technologies were identified, based on existing initiatives and databases (WOCAT, TerraAfrica, World Bank SLM Source Book, CSA FAO, IPCC Assessment Reports and peer-reviewed papers cited in the sub-chapter below), and are described in the next sub-chapter. These SLM technologies can avoid, reduce, and/or reverse land degradation and desertification to different degrees, and in many cases, they also correspond to broad supply-side mitigation options (Smith et al., 2014; see Box 5), and climate change adaptation options suggested by the IPCC (Noble et al., 2014)[10]. Furthermore, they assist in mitigation activities that were defined under the Kyoto Protocol (Kyoto Protocol, 1997: Article 3.3. and Article 3.4) (i.e. afforestation, reforestation, forest management, cropland management, grazing land management and revegetation), whose definitions and accounting rules were adopted by the UNFCCC COP[11]. As stated in Chapter 1, the objective of this report is not to give an exhaustive classification of current SLM technologies and practices, or to propose new ones. Instead, the report aims to illustrate the potential of different groups of SLM technologies under specific land use types to address land degradation, desertification and climate change adaptation and mitigation.

10 Land-based adaptation options, such as Ecosystem-based Adaptation and water management. Adaptation options are less narrowly defined by IPCC than mitigation options.

11 Accounting of LULUCF activities under the Kyoto Protocol refers to applying the guidance contained in decision 16/CMP.1: (in the first commitment period) or decision 2/CMP.7: (in the second commitment period).

BOX 5:

Types of supply-side mitigation options in the AFOLU sector (Smith et al., 2014)

Forestry: reducing deforestation, afforestation / reforestation, forest management, forest restoration
Cropland management: plant management, nutrient management, tillage/residues management, water management, rice management, rewet peatlands drained for agriculture, set-aside and land use change, biochar application.

Grazing Land Management: plant management, animal management, fire management, revegetation, organic soils—restoration, degraded soils—restoration, bio solid applications.

Livestock: livestock feeding, livestock breeding and other long-term management, manure management.

Integrated systems: agroforestry (including agro-pastoral and agro-silvo-pastoral systems), other mixed biomass production systems.

For the purpose of this report, and in order to make better use of SLM technologies in each circumstance, while also considering the time dimension in the intervention, avoiding implies the employment of SLM measures that maintain natural resources and their environmental and productive function on the land that may be at risk of degradation. Reducing implies interventions intended to reduce ongoing degradation. This comes at a stage when degradation has already begun. The main aim then is to halt further degradation, and to start improving resources and their ecosystem functions. Reduction impacts tend to be noticeable in the short- to medium-term; the observed impact then provides a strong incentive for further efforts. Reversion, for example through rehabilitation, is required when the land is already degraded to such an extent that the original use is no longer possible. In this situation, the land has become practically unproductive and the ecosystem is seriously disturbed. Rehabilitation usually implies high investment costs with medium- to long-term benefits.

2.2 Evaluated SLM technologies

Although most SLM technologies are rather specific to a certain land-use type, i.e., animal management only relates to grazing lands, other groups can apply to different land use types, i.e., managing soil fertility and vegetation management can be related to croplands and grazing lands. In implementing SLM technologies, the interrelationship and interdependence of biophysical factors, such as soil quality, water availability, weather and climate change, biodiversity changes (losses or gains) have to be carefully looked into at different scales[12]). Moreover, economic and socio-cultural factors, such as traditional values or land use rights, have to be taken into account, as well. In this chapter, the technical appraisal of identified technologies applied to address land degradation and climate change in the context of different land-uses is explored, while the socio-economic and policy context is explored in subsequent chapters.

2.3 Croplands

Inappropriate agricultural practices on vulnerable soils and marginal production areas are a common cause of soil degradation, causing compaction, loss of organic matter and nutrients, surface capping, erosion, acidification or secondary salinization[13]. This is even more problematic in the case of drylands, where land degradation, nutrient deficiencies, and increasing water scarcity and drought represent further constraints.

The most common SLM technologies to address land degradation in croplands are related to preventing soil erosion (soil erosion control and cross-slope barriers), soil deterioration (integrated soil fertility management, minimum soil disturbance by tillage), improving

12 Implementation of certain SLM practices in a catchments headwater can affect water availability in downstream parts positively and negatively

13 Soil salinization occurs when water-soluble salts accumulate in the soil to a level that has an impact on agricultural production, environmental health, and economics. In the early stages, salinity affects the metabolism of soil organisms and reduces soil productivity, but in advanced stages, it destroys all vegetation and other organisms living in the soil, consequently transforming fertile and productive land into barren and desertified lands

productivity and biodiversity (vegetation management, pest and disease control, use of sustainable irrigation systems, drainage and water harvesting). Broadly, these SLM technologies correspond to land-based mitigation options driven by agricultural demand (cropland management: plant management, rice management, nutrient management, biochar and bio-solids application, tillage/residue management and plant water management) (Smith et al., 2014; see table 2). Enhanced physical (water retention) and chemical (fertility and carbon sequestration) soil properties have a positive effect on preventing land degradation, while enhancing mitigation and adaptation to climate change for agroecosystems.

Erosion control and water harvesting in southern Spain © Carolina Boix Fayos

TABLE 2:

Number of SLM technologies per technology group considered for croplands in relation to climate change land-based mitigation options, as defined by IPCC.

Croplands		Nº
SLM technology group	**Land based mitigation options (Cropland management)**	54
Soil erosion control	Plant management and water management	19
Minimum soil disturbance	Tillage/residues management	5
Integrated soil fertility management	Nutrient, rice and water management, and bio-solid and biochar application	8
Vegetation management	Plant management and water management	8
Pest and diseases control	Plant management	5
Water harvesting	Water management	9

2.3.1 Soil erosion control

Soil erosion by wind or water leads to the loss of surface soil layers, rich in organic and mineral nutrient pools, resulting in partial or complete loss of soil horizons and possible exposure of growth-limiting subsoil, and can cause off-site impacts, such as damage to private and public infrastructure, reduced water quality and increased sedimentation of rivers, deltas and reservoirs. The process of soil erosion is accelerated by human activities, resulting in less soil covered by crops, natural vegetation or crop residues, tillage and other field operations, and reduced soil stability, leading to soil creep and landslides.

GLASOD (Global Assessment of Human-induced Soil Degradation from: ISRIC, 1991) figures show that almost 40% of the agricultural land sector was affected by human-induced soil degradation. A review by Ravi et al. (2010) asserts that soil erosion is the most widespread form of land degradation in drylands, with wind and water erosion contributing to 87% of the degraded land. Technologies for mitigating soil erosion are well-known and have been proven to be effective in experimental plots, but their adoption requires fine-tuning at local scales (Lal, 2001). However, erosion rates on agricultural lands are still high across much of the world today, related to the lack of economic incentives for today´s farmers to conserve the soil resource for future generations (FAO and ITPS, 2015) and the lack of farmers and other community stakeholders' awareness of the importance of preserving soils (Schwilch et al., 2012b).

Soil erosion control is the practice of preventing or controlling wind or water erosion. Soil erosion, defined as the detachment, transportation and re-deposition of soil particles by wind or water, can be reduced or prevented by technologies that decrease both wind and runoff velocities. Water erosion control measures often require reduction of surface runoff through structural and/or vegetative barriers, and/or by increasing soil cover (e.g., cover crops, mulching), and are important techniques in preventing water pollution, soil loss and human property loss. Cross-slope barriers are measures on sloping lands in the form of earth or soil bunds, stone lines, and/or vegetative strips for reducing runoff velocity and soil loss, thereby contributing to soil, water and nutrient conservation. These measures reduce steepness and/or length of slope. While cross-slope barriers are primarily intended to reduce soil erosion, they also enable or ease cultivation between the barriers, which are usually sited along contours, and enhance infiltration, thus increasing water harvest. Likewise, wind erosion can be reduced or prevented by technologies that decrease wind velocity (windbreaks and wind barriers), change the roughness of the topsoil layer (maintain stable aggregates or clods on the soil surface, mulching with vegetation residues, crop covers, etc), or reshape land to reduce erosion on knolls where converging wind flows cause increased velocity (Tibke, 1988).

Vegetative measures to prevent or control soil erosion can be used alone or in combination with one another, and include: grass strips; shrub and tree buffers; riparian vegetation; grassed waterways that can be established along contours, at the edge of crop fields or along streams or other water bodies to reduce runoff velocity and sediment transport and to enhance sediment deposition (Mekonen et al., 2015). The benefits of soil erosion control have been demonstrated by multiple studies. For example: using tree or shrub buffers as vegetative barriers between farmlands and rivers traps and prevents transported sediment from reaching nearby streams and waterways (Leguedois et al., 2008; Zhang et al., 2010); planting new hedges (Mutegi et al., 2008; Donjadee & Tingsanchali, 2013); creating grassed waterways enhances infiltration and reduces sediment transport and gully formation by decreasing flow velocity (Bracmort et al., 2004; Fiener & Auerswald, 2006; Dermisis et al., 2010). Field shelterbelts using trees can provide extra protection against wind erosion no matter which cropping system is used, avoiding top soil losses by reducing the wind velocity for distances up to 30 times the height of the trees and trapping snow in cold regions, which increases soil moisture. This measure might increase crop yields that can compensate the yield losses associated with taking land out of crop production for shelterbelt plantings. In some cases, emergency controls for wind erosion are applied, which involve increasing the surface roughness of a field or covering the soil with straw or manure. Another positive side effect of such vegetative soil erosion control technologies, especially if they provide nectar (via flowering plants), is that they can increase the number of pollinators, and thus enhance crop production (especially if these fields are not subject to the use of pesticides; IPBES, 2016). Such vegetative barriers can also support the re-establishment and maintenance of biodiversity, while helping – if suitable synergies occur – to control pest and diseases of the main crop.

Structural measures include bench terraces, sloping terraces, bunds and banks, and graded and level ditches. A global synthesis on terracing practices (Wei et al., 2016) suggests that diverse terracing practices play a positive role in erosion control, as well as runoff reduction, biomass accumulation, soil water recharge, and nutrient enhancement.

Since all erosion control technologies involve the retention of soil, these techniques could have an effect not only on preventing on-site soil erosion, but also on avoiding carbon losses, promoting water recharge, and increasing productivity. In addition, the establishment of perennial woody vegetation (shrubs and trees) or grasses also increases SOC and carbon sequestration in woody biomass, and involves other co-benefits (such as increases in biodiversity, including insects and plant species). On the other hand, there is still scientific discussion on the net effect of soil erosion on carbon dynamics at larger scales, including deposition and possible long-term burial of eroded carbon and dynamic replacement of carbon at eroded sites (Wang et al., 2017), Annex 1 lists some case study examples illustrating SLM technologies, including:

Structural measures: soil bund with contour cultivation; semi-circular bunds (for crops and forest/rangeland; vegetated earth-banked terraces; soil/stone bunds; progressive bench terrace; rockwall terracing; terracing and check-dams in watersheds; traditional cut-off drain; haraghie stone bund; stone lines and stone walls.

Vegetative measures: vegetative strips; paved and grassed waterways; tree rows and grass strips to sustain filtering; shelterbelts and windbreaks; live hedges; living fences and windbreaks.

Combined or integrated: gully control and catchment protection; integrated runoff water management; river bank stabilisation; water-spreading weirs.

2.3.2 Minimum soil disturbance

Conventional tillage often implies completely inverting the soil profile by using a mouldboard plough, or frequent ploughing with cultivators, discs, chisels, or other ploughing equipment. Depending on the combination of climatic and soil characteristics, conventional tillage can have a positive or negative effect on soil moisture status and its availability for crops. Conventional tillage has proven to be effective for weed and pest control, but has a detrimental impact on the soil's physical quality, incrementing soil erosion and degradation (Poesen et al., 1997; Stavi, 2013; Martínez-Mena et al., 2008). Regarding climate change mitigation, despite potentially increasing crop yields in the short run, conventional tillage often tends to limit crop productivity in the long run, increase soil organic matter mineralisation, and thus CO_2 emissions from soils, (Smith et al., 2008) and compromise soil water retention.

All minimum soil disturbance technologies, often implemented to maintain or increase soil quality (i.e., soil organic matter, soil biological activity) can often also contribute to soil erosion control and are considered climate change adaptation and mitigation options. Although these technologies have advantages such as improving productivity, providing long term application, increasing soil organic carbon (SOC) storage in depleted and degraded agricultural lands, off-setting anthropogenic emissions, and improving the environment (Lal, 2015), they can also have disadvantages such as incrementing pesticide use. These technologies are agronomic measures and vary between zero tillage (No-till), reduced (minimum) tillage, mulch tillage, ridge tillage and contour tillage. Controlled traffic farming reduces disturbance – especially compaction – by farm machinery by restricting machinery to permanent tracks. No tillage (NT) is a soil cultivation system in which seeds are deposited directly into untilled soil. To do so, narrow slot trenches or bands of sufficient width and depth are opened to obtain proper seed coverage. Minimum tillage implies a reduced level of soil manipulation, avoiding soil inversion through shallow ploughing or by reducing the number of passes per year. In mulch tillage systems, the soil is prepared or tilled in such a way that the crop or plant residues are left to cover the soil surface to a maximum extent. Ridge or strip tillage involves planting crops in rows. Contour tillage refers to ploughing and/or seeding along the slope following its elevation contour lines.

Non-tillage or reduced tillage systems, if well-implemented, generally show higher yields than conventional tillage systems, especially in well-drained soils prone to surface runoff and accelerated erosion (Zhang et al., 2009; Moraru & Rusu, 2013). However, there are also examples of significant reductions in yields, particularly within the first years after conversion from conventional tillage to non-tillage due to poor establishment, nitrogen (N) deficiency, herbicide-resistant weeds, disease harboured in stubble, lower soil temperature, allelochemicals and volatile fatty acids released from decomposing stubble in wet soils (anaerobic conditions) among others (Farina et al., 2011; Soler et al., 2011; Verhulst et al., 2011; Martínez-Mena et al., 2013). Several recent studies, including a meta-analysis (Vicente-Vicente et al., 2016) on Mediterranean agroecosystems indicate that conversion from conventional tillage to reduced tillage, combined with green manure, is suitable for increasing soil carbon stocks without enhancing GHG emissions from soils in woody and non-woody crops (Guardia et al., 2016; Sanz-Cobena et al., 2016; Almagro et al., 2017; Pardo et al., 2017). Of note is the fact that soils were only sampled to a depth of 30 cm or less across these studies, even though crop roots often extend much deeper, which could explain the consistent accrual of SOC. On the contrary, in studies in which soils have been sampled deeper, no consistent accrual of SOC between soil depth layers was observed between conventional and reduced tillage systems. While Baker et al. (2007) observed higher organic carbon concentrations in the top soil (first 30 cm) in non-tilled soil, the opposite occurred in deeper soil layers (below 30 cm) for conventional tillage, suggesting that the distribution of SOC can change with depth depending on the tillage system. Therefore, more research is needed on soil carbon accumulation at deeper depths under different tillage regimes (Kravchenko & Robertson, 2010), and special attention should be paid when comparing SOC stocks under different tillage intensity levels (especially when no tillage is considered) because this should be performed on an equivalent soil mass-depth basis (Ellert & Bettany, 1995) and should not be limited to the superficial soil layers. Apart from CO_2, other greenhouse gases (GHGs), notably nitrous oxide (N_2O) and methane (CH_4), have been reported to be influenced by tillage regimes (Busari et al., 2015). Some authors also indicate that adopting reduced or no-till may also decrease emissions of N_2O, but the effect should not be overemphasised, as it may depend primarily on soil types and climatic conditions (Marland et al., 2001). In addition, there is still conflicting scientific evidence as to how no-till affects the flux of N_2O and CH_4 from soils (Kaharabata et al., 2003; MacKenzie et al., 1998; Ussiri et al., 2009). It may have some positive effects, such as reduced soil erosion (see Chapter 5) while improving water conservation and carbon accumulation in some cases, but it is likely to support the further spread of industrialised large-scale agriculture. For example, no-tillage when considered in conventional large agricultural operations today is associated with the typical and well-known environmental impacts of industrial agriculture with high external inputs, including the use of herbicides and expensive machinery. Geographically, the potential of no-till agriculture is limited in drought-prone areas, particularly in the semi-arid tropics where annual rainfall is less than 800 mm and the dry season lasts for over five months (Gattinger et al., 2011).

Cover crops (including when used as green manure) and mulching are important soil management options used for increasing soil quality, water content and organic carbon stocks in agricultural systems, and in some cases for increasing biodiversity. A meta-analysis that recently quantified the potential for cover crops to enhance SOC for the first time, found a mean annual SOC sequestration of 0.32 ± 0.08 Mg ha^{-1} yr^{-1} reaching a total mean accumulation of 16.7 Mg ha^{-1} (Poeplau & Don, 2015). Almagro and Martínez-Mena (2014) demonstrated the potential of green manure incorporation in semi-arid Mediterranean woody crops as an efficient tool for recovering previous soil organic carbon losses derived from land-use change. Kaye & Quemada (2017) estimated that widespread adoption of cover crops might mitigate 10 % of agricultural GHGs emissions. Recent field observations also indicated that cover crops resulted in the stabilisation of sandy soils against wind erosion (Kuwait Institute for Scientific Research, 2017).

These technologies of minimum disturbance and cover crops can be implemented on their own, or be easily combined to promote synergies in addressing land degradation and climate change adaptation and mitigation. In this regard, since the late 1990s, there has been greater emphasis on a system approach to non- or minimum-tillage farming, called "conservation agriculture" (CA). CA encompasses a system of practices: retaining crop residues as surface mulch, including cover crops in the rotation cycle, causing minimal or no soil disturbance, and improving soil fertility. This integrated vision (system of practices) of combining several minimum soil disturbance technologies, including improved soil fertility in poor soils (That can be also achieved by providing three to five years for soil restoration phase while converting from long-term conventional tillage to conservation agriculture), could minimise soil erosion risks, conserve soil water, sequester carbon and promote sustainable intensification. However, there are also several studies, in drylands in particular, where a consistent and measurable increase in SOC under CA has not been observed. A sufficient quantity of crop residue mulch, use of a cover crop (preferably leguminous with a deep root system), adequate soil fertility, and proper crop rotations are essential components of a complete CA package[14] (Lal, 2015).

Examples are included in Annex 1 to illustrate the application of the technologies, and include:

- *Non-tillage or reduced tillage*: direct planting; no-till technology; strip tillage.
- *Cover crops and mulching*: mulching in croplands; permanent soil cover.

14 For example, the amount of biomass carbon required to maintain the SOC at the antecedent level differs between soils, climates, management systems, etc.

2.3.3 Integrated soil fertility management

Integrated soil fertility management combines different methods for managing nutrients and water. The emergence of fertilizers in agriculture has dramatically increased global agricultural productivity and has simplified management by providing crops with readily-available nitrogen. Studies have found that continuous nitrogen additions to soils in agricultural systems decrease soil microbial activity (Ramirez et al., 2012) and increase the turnover of the labile soil carbon pool (Neff et al., 2002). Nitrogen applied in fertilizers and manures is not always used efficiently by crops. Improving this efficiency can reduce emissions of N_2O generated by soil microbes with nitrogen surplus. In many places around the world, overuse of synthetic nitrogen fertilizers is causing soil acidification, eutrophication of surface waters and increased decomposition of soil organic matter, leading to loss of soil function in over-fertilized soils (Tian et al., 2012).

Nutrient management that combines the use of chemical and organic soil additives (Integrated soil fertility management) has a moderate impact on overall soil quality, soil erosion control, water retention and accumulation of soil organic carbon. It also reduces N leakage into the environment, reduces N pollution and mitigates greenhouse gas emissions (Stavi et al., 2016). A recent review of integrated nutrient management studies (see Table 3) indicates that nutrient management can lead to significant increases in crop yields, while substantially reducing reactive N losses and GHG emissions, becoming a "win–win" opportunity that simultaneously increases crop production and reduces environmental impact (Wu & Ma, 2015). However, the review also emphasises that the methodology is site-specific and must be tailored to local circumstances. Furthermore, integrated soil fertility management (organic fertilizers versus synthetic fertilizers) and the form of the applied fertilizers (for example, liquid organic fertilizers) could lead to variations in GHG emissions. For example, an increase in the use of slow-release N synthetic fertilizers may reduce N_2O emissions (Smith et al., 1997).

TABLE 3:

Examples of effects of integrated nutrient management (INM) on crop performance.

Reference	Effects	Country
Prasad et al. (2002)	Rice/groundnut: INM significantly increased grain yield of rice by 1.3 t ha^{-1}, and pod yields of groundnut by 0.3 t ha^{-1}	India
Jagathjothi et al. (2011)	Finger millet: INM markedly increased grain (3.3 t ha^{-1}) and straw yield (5.9 t ha^{-1}) over all other	India
Singh (2002)	Cluster bean/wheat: INM increased cluster bean seed yield by 0.6 t ha^{-1} and grain yield of succeeding wheat crop by 0.3 t ha^{-1}	India

Precision agriculture and nutrient budgeting, by facilitating more efficient use of fertilizers, can reduce emissions associated with excess application (Vitousek et al., 2009) as well as reduce cost. Practices that improve N-use efficiency include: adjusting application rates based on precise estimation of crop needs (e.g., precision farming); using slow-release fertilizer forms or nitrification inhibitors; avoiding time delays between N application and plant N uptake (improved timing); placing the N more precisely into the soil to make it more accessible to crops roots; avoiding excess N applications, or eliminating N applications where possible (Cole et al., 1997; Dalal et al., 2003; Paustian et al., 2004; Robertson, 2004; Monteny et al., 2006). However, precision agriculture, often by using synthetic fertilizers, does not replenish organic matter stocks and therefore results in less soil quality. Although the economic and management constraints on biochar additions are not as well known (Wolf et al., 2010), the global technical potential for climate change mitigation are estimated to lie in the range of 1–1.8 Pg CO_2e yr^{-1} (Paustian et al., 2016).

Also, adding plant-derived carbon from external sources, such as composts and biochar, can be considered a land-based mitigation option where amendments are applied for improved management of nitrogen, increased water retention and soil carbon stocks. Among the organic soil-nutrient additives, livestock manures are predominant. Aguilera et al., (2013) found that, for a large range of Mediterranean copping systems, there was a higher carbon sequestration gain with compost than with raw manure. The study also finds that carbon accumulation leads to an improvement in soil quality and protection against erosion, which are especially important benefits in desertification-prone Mediterranean agroecosystems. In addition, direct N_2O emissions from the soil could possibly be lower for organic than for synthetic fertilizers under Mediterranean conditions (Aguilera et al., 2013). Recent developments suggest that biochar, obtained from the pyrolysis of crop residues or other biomass, can consistently increase crop N-use efficiency while greatly (over 25%) reducing direct N_2O emissions from N fertilizers (Liu et al., 2012; Huang et al., 2013), as well as enhance soil fertility (Woolf et al., 2010) and water retention (Obia et al., 2016).

Examples to illustrate the technologies are included in Annex 1, and include:

- *Precision agriculture* (changing fertilizer application rate, fertilizer type, timing, and precision application, inhibitors, micro-fertilization and seed priming);
- *Production and use of organic fertilizers* (compost, bio-humus, green manure-straw)
- *And biochar:* application of organic fertilizers; production and application of bio-humus; biochar soil amendment to increase biomass productivity and sequester carbon; composting using indigenous microorganism and application; planting pits for soil fertilization and moisture improvement; straw retention in rice paddies.

2.3.4 Vegetation management

Crop production over recent decades was increased by enlarging crop areas, but also by increasing harvest frequency through several vegetation management practices (i.e., crop rotation, intercropping and multi-cropping). However, increasing harvest frequency or annual crop rotations can either reduce or increase soil quality (i.e., soil organic matter), depending on the effectiveness of the management practices followed. Soil organic matter content can be increased through: better crop varieties (or grassland) species mixtures with greater root mass or deeper roots (Kell, 2012); improved crop rotations where carbon inputs are increased over a rotation (Burney et al., 2010); greater residue retention (Wilhelm et al., 2004); use of cover crops during fallow periods to provide year-round carbon inputs (Burney et al., 2010; Poeplau & Don, 2015) and use of green permanent covers (Vicente-Vicente et al., 2016). In addition, some practices, such as green covers, protect the soil against erosion while increasing water availability and retention (Celano et al., 2011; Palese et al., 2014; Almagro et al., 2016) and increasing biodiversity (Plaza-Bonilla et al., 2015). In this regard, some estimates point to SOC increases between 44% and 85% in topsoil (0–15 cm) in olive groves after 100 years of cover crop management (Nieto et al., 2013), and preliminary estimations suggest an increase in soil carbon sequestration of around 1 tonne carbon ha^{-1} yr^{-1} in olive orchards under Mediterranean conditions due to the adoption of plant covers (Vicente-Vicente et al., 2016).

Some case examples are included in Annex 1 to illustrate the technologies, including choice of species/variety, multiple- and intercropping, crop rotation and set-aside/long-fellow periods, perennial woody crops, green permanent soil cover and improved seed survival (see Annex 1): choice plant species/varieties; crop rotation; traditional shifting cultivation; multiple cropping; intercropping; long-term fallow or set-aside; perennial cropping systems; green cover in perennial woody crops; seed priming.

BOX 6:

Crusting and surface sealing in the African sub-tropics croplands

Crusting and surface sealing are widespread in the African sub-tropics and can be readily ameliorated, opening up the possibility for significant increases in food production in the region.

It is caused by the following factors (Morin, 1993): the generally low organic matter contents of the soils, resulting from high temperature and cultivation; the heavy raindrop impact that commonly occurs during intensive rainstorms; the weak topsoil structure of most cultivated soil types; widespread destruction of the vegetation cover, which protects the soil surface from the impact of heavy rain.

Effective management to overcome crusting depends heavily on a local community's infrastructure, culture and means. Western methods cannot simply be copied and applied under African conditions. Agricultural development to increase food production should be gradual and handled wisely, while preserving the local community life. Developing effective management systems for specific local conditions demands a quantitative, in-depth understanding of particular soil restrictions of which crust formation and surface sealing are key aspects. Management technologies for crusted soil are based on three methods for augmenting infiltration (Morin, 1993): conservation farming; the use of soil amendments; tillage management. These methods may be used separately or be combined.

(Smith et al., 2014)

2.3.5 Integrated Pest Management

Integrated pest management is defined by the simultaneous and flexible use of a range of means, including tillage, mechanical (installing insect traps), and cultural (variety selection, fallowing, crop rotation, inter-cropping, vegetation strips, cover cropping, etc.) measures (Pretty & Bharucha, 2015). Integrated pest management effectively controls weeds and pathogens that can affect crop yields. At the same time, depending on the combination or selection of means, integrated pest management could have a synergistic effect on overall soil quality, soil erosion control, soil organic carbon pool, environmental quality or greenhouse gas emissions, and soil biodiversity (e.g., by introducing herbaceous and/or tree buffer strips to host beneficial insects).

Some case examples are included in Annex 1 to illustrate the technologies, and include: trees as buffer zones; application of biological agents to increase crop resistance; biological pest control; integrated production and pest management; use of phyto-pesticides.

2.3.6 Water management

Improving soil moisture management is crucial for the sustainable improvement of food production and water supply (Shaxson & Barber, 2003). Better water management, coupled with improved soil and crop management, can increase agricultural productivity in rainfed areas with currently low yields by more than double. With climate change and increasing food prices, even more emphasis needs to be placed on addressing water management in rainfed agriculture as a key determinant for agricultural production and productivity (ETWWA, 2010).

Reduction of a soil's capacity to accept, retain, release and transmit water reduces biomass productivity, regardless of whether they are crops, pasture species, shrubs or trees. In arid and semi-arid conditions, sustainable irrigation systems can result in adaptation to droughts[15] and economic benefits by water savings, while contributing to reduce soil CO_2 emissions by decreasing microbial activity in response to decreased soil moisture levels (Butenschoen et al., 2011; Arroita et al., 2013; Zornoza et al., 2016). Water efficiency can be improved through management practices that reduce water requirements and evaporation from the soil (such as adding mulch as ground-cover, which could also reduce soil erosion; see Box 7.) and include: more precise irrigation scheduling and rates, fixing leaks in dryland irrigation systems, improving application technologies (e.g., drip irrigation; sub soil drip irrigation; irrigation at night to avoid evaporation losses) and using intermittent irrigation in rice paddies. Improving water efficiency can therefore be seen as both a climate change adaptation and a mitigation measure. Some irrigation systems, however, can increase soil salinity in dry regions with high salt content in the subsoil (Setia et al., 2011). Rain water collection could increase supplemental irrigation at critical crop growth stages by harvesting rainwater in structures such as small dams (Akhtar et al., 2016), or retention structures in fields (ponds and small ditches). Energy savings through the design of the irrigation systems, including where water is not limited, is also indirectly contributing to mitigating climate change.

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15 For effective drought management, it is necessary to develop region-specific drought management actions. For different climatic regions:In Arid areas (Frequency is once every 2 to 3 years. Persistence / successive droughts: -2-3 consecutive yrs.). Mitigation options: Intensive rain water harvesting/ water conservation; Recycling of wastewater, particularly for supplemental irrigation; Micro-irrigation (sprinkler/ drop systems); Measures for evaporation reduction from tanks/reservoirs; subsoil drip irrigation systems; Inter-basin water transfer

- In Semi-Arid areas (Frequency is once every 4 to 5 years. Persistence droughts: 2-3 consecutive yrs.). Mitigation actions: Creation of water storages (tanks/reservoir); Intensive water conservation/ rain water harvesting (key lines; swales); Ground water Recharge; Inter-basin water transfer; Recycling of waste water to use in irrigation/other.
- In Sub-humid areas (Frequency is once every 6 to 9 years. Persistence/ successive droughts: 2-consecutive yrs.): Mitigation actions: Increase in Water storages (Carryover storage); Water conservation/ in-situ water retention through gully checks and stop dams; Ground water Recharge; Within stream water storages and Water diversions; Recycling of waste water to use in irrigation/ other (Dr. Rajendra Prasad Pandey)

Water storage and flood moderation technologies provide for management of excessive water supply caused by rainfall, overuse of irrigation water, canal seepage or floods. Water retention capability can affect an entire landscape, e.g., increasing water storage capacity with man-made structures that increase flood storage capacity. The water retention capacity of an agricultural landscape can be improved by: checking and rebuilding old drainage systems; establishing a variable water flow regime; rehabilitating and reconstructing/adapting morphological structures in rivers; adopting ad hoc crop rotations and association and agricultural practices (tillage systems, soil cover management, etc.); setting up flood control reservoirs, typically with large capacity and designed to only take up water levels that have been reached.

Some case examples are included to illustrate the technologies (Annex 1):

Use of sustainable irrigation systems: Cascading Rock Irrigation Channel, Micro-irrigation systems, Spate irrigation, Spiral water pumps.

Water harvesting: Water harvesting, recharge of groundwater; water collection to enable off-season irrigation, water harvesting from concentrated runoff for irrigation purposes.

Drainage: Sub-surface drainage, mid-season rice paddy drainage.

BOX 7:

Techniques to minimizing water stress and improving water resources

Improving restricted rainfall infiltration: Improving the infiltration capacity of the soil surface, Using surface residue covers to increase infiltration and reduce runoff, Mechanisms by which surface residue covers enhance rainwater infiltration, Surface residue covers, Fallowing under cover crops or natural vegetation, Temporary closure of grazing lands and subsequent protection, Increasing the period for infiltration by detaining runoff with physical structures.

Contour field operations: Surface irregularities formed by contour field operations, Conditions favouring the adoption of contour field operations, Narrowly-spaced contour planting ridges and tied ridges, Impermeable and permeable contour barriers at discrete intervals downslope, Permeable cross-slope barriers, Bench-type terraces, Deep tillage to increase subsoil porosity and permeability.

Reducing water losses from evaporation and excessive transpiration: Minimising evaporation from the soil surface, Reducing excessive transpiration, Subsoil drip irrigation systems and/or irrigation at night, Weed control, Windbreaks, Conditions favouring the adoption of windbreaks, Shade.

Reducing rainwater drainage beyond the rooting zone: Increasing available water capacity of soil, Dry planting, Improving plant nutrition for early root development, Introducing deep-rooting crops.

Improving soils with restricted rooting: Mechanical disruption of shallow root-restricting layers, Mechanical disruption of moderately deep root-restricting layers, Mechanical disruption of very deep root-restricting layers in the subsoil, Chemical solutions to restricted root growth.

Maximising usefulness of low and erratic rainfall: Use of drought-resistant and drought-escaping crops and varieties, Increasing crop water-use efficiency, Selecting water-efficient crops, Adjusting plant population to expected rainfall, Applying fertilizers, Weed control, Seed priming, Early planting, Accumulating moisture from one season to the next, Water harvesting, Zaï pits or Tassa, Half-moons , Contour stone lines, Contour earth ridges and bunds, Retention ditches, Retention pits, Retention basins, Farm ponds, Floodwater harvesting and Water spreading.

Collaborative stakeholder participation

(Shaxson & Barber. 2003)

2.4 Forest/Woodland

According to FAO (2015), in 2010, forests covered about 31 percent of the world's total land area and provided livelihoods for more than 1 billion people. Forest loss is therefore not only of concern to conservationists. According to the World Bank, around 1 billion people in the developing world either directly or indirectly depend on goods and services from forests, which provide an essential safety net to many of the world's poorest people (Mansourian et al., 2005). Recent estimates based on official country data and international methodologies that quantified the overall net emissions from forests over the period 1991–2015 for the first time (1.52 Gt CO_2 yr^{-1}), highlighted the significant role of deforestation as a net source (4.04 Gt CO_2 yr^{-1}) and the importance of remaining forests as a net sink (-2.52 Gt CO_2 yr^{-1}; Federici et al., (2015), of global CO_2.

It is well known that forests play a crucial role in: water protection and reducing water-related risks (i.e., local floods and droughts and helping to prevent desertification and salinezation); soil protection and conservation; conservation of biodiversity; climate change mitigation and adaptation; food, fibre and energy supply and other ecosystem services. However, the world's forests continue to decline as human population grows and demand for food and land increases. However, the rate of net forest loss has been cut by over 50 % (FAO, 2015), and forests and forest management have changed substantially. Deforestation affected an estimated 13 million hectares per year between 2000 and 2010, but thanks to afforestation and natural expansion, the net forest loss was 5.2 million hectares per year (FAO, 2015). Notwithstanding, not only land use conversions are leading to forest loss; other drivers such as fire, windstorms (Lindroth et al., 2009), pests and climate change are also significantly contributing to loss of forests around the world. Reversing this damage is a huge and complex challenge. Despite the fact that many drivers of forest loss (deforestation) are outside the forest (i.e., need of land for agriculture, extractive activities, infrastructures) (Kissinger et al., 2012), the drivers inside the forest must be addressed, as well. Sustainable Forest Management (SFM) constitutes a set of practices that can also be considered within the realm of SLM. Adaptive SFM approaches will help to reduce forest vulnerability and maintain forest productivity, and specific management practices can also be adopted to help mitigate climate change. In addition, establishing new forests in former arable or pasture lands or re-establishing former forests on degraded lands are also contributing to SLM practices.

The most common SLM technologies to address land degradation in forest and woodlands are related to preventing soil erosion (afforestation/reforestation, soil protection, grazing pressure management, drainage and infiltration) and improving productivity and biodiversity (forest management and restoration, pest and disease control) (Table 4). Broadly, these SLM technologies pertain to forestry-driven mitigation options (reducing deforestation, forest management, forest restoration and afforestation/reforestation). Despite the adaptive capacity of the forest to climate change without human intervention, it can be enhanced (Bolte et al., 2009) by conserving or improving forest stand structures and forest composition for forest functioning and composition, in a way that the resulting forest is better-adapted to climate change impacts.

2.4.1 Reducing deforestation

Humankind's development from Neolithic until recent times had been largely based on the increase of agricultural lands, at the expense of natural ecosystems. Since the Neolithic onset, the world's forest surface was reduced by 40% (Shvidenko et al., 2005). Deforestation has

Taibilla catchment, Spain © Joris de Vente

TABLE 4:

Number of SLM technologies per technology group considered for woodlands/forest in relation to climate change land based mitigation options as defined by IPCC.

Forest / Woodland		Nº
SLM technical solution	**Land-based agriculture mitigation options (Forestry)**	26
Reducing deforestation	Reducing deforestation	2
Afforestation/Reforestation	Afforestation/Reforestation	5
Sustainable forest management	Forest management	9
Forest restoration	Forest restoration/Forest management	1
Fire, pest and diseases control	Reducing deforestation	2
Soil erosion control	Afforestation/Reforestation, forest restoration, forest management, reducing deforestation	6
Water management; Drainage	Afforestation/Reforestation	1

(Smith et al., 2014)

caused the release of large quantities of CO_2 into the atmosphere. SLM practices aiming to reduce deforestation may have the greatest potential to mitigate climate change by reducing emissions of GHGs, but also by protecting soils, preserving biodiversity, providing food security and making forest-dependent communities more resilient.

Some case examples are included to illustrate the technologies (Annex 1): establishment of protected forest areas; reducing slash and burn agriculture.

2.4.2 Afforestation/Reforestation

Throughout the history of agriculture, over cropping and/or poor agricultural practices have led to land degradation in agricultural lands and abandonment. Abandoned agricultural lands could naturally recover through forests (natural regeneration) or through artificial plantations (afforestation). Afforestation increases biomass accumulation (both above ground and below ground), soil organic carbon accumulation, and the related increase in soil biological activity, ecosystem biodiversity (including soil biodiversity) and derived ecosystem services, such as soil and water conservation, carbon sequestration potential, and often aesthetic and cultural values.

Because arable soils usually have a much lesser SOC content than forests or grasslands, changes in land use through afforestation will lead to a gradual accumulation of SOC that will depend on the species and planting techniques. This is the case of afforestation by natural colonisation after abandonment of arable lands in temperate regions (Poulton et al., 2003). In many cases, reductions in N_2O emissions can also appear due to the cessation of external fertilization after conversion. However, an accurate selection of arable lands where afforestation can be implemented is essential for the success of the activity and to avoid perverse outcomes.

In Europe, long-term afforestation projects in Southern Europe were assessed for their degree of success and the provision of ecosystems services (Bautista & Alloza, 2009). In a case of afforestation in extremely degraded lands in a semi-arid climate undergoing ecological restoration measures, ten years after restoration, the provision of ecosystem services (e.g., soil and water conservation, nutrient cycling, carbon sequestration and biodiversity) was significantly improved in comparison with the degraded ecosystem (Valdecantos et al., 2016).

Some examples of SLM technologies are provided in Annex 1: afforestation with species mix at different scales; reforestation in former forest lands; forest establishment in semi-arid land; reintroduction of forest cover after wildfires; land reclamation by introducing native forest species.

2.4.3 Sustainable forest management

Sustainable forest management involves policies and technical standards for the responsible management of natural and planted forests. Principles of forest management combine both forest productivity and forest conservation.

According to FAO[16]: "Managing forests sustainably means increasing their benefits, including timber and food, to meet society's needs in a way that conserves and maintains forest ecosystems for the benefit of present and future generations". However, forest exploitation (i.e., logging) often conflicts with the basic principle of sustainability, and thus, planted forests can play an important role in relieving the pressures from goods and services provided by indigenous forests (Evans, 2009).

Logging and fire are the major causes of forest degradation in the tropics (Bryan et al., 2013). Logging practices may negatively affect soil physical properties and nutrient levels (soil and litter), both in tropical (e.g., Olander et al., 2005; Villela et al., 2006; Alexander & Cruz, 2012) and in temperate forests (Perez et al., 2009). Forest fires affect many physical, chemical, mineralogical and biological soil properties to different degrees, depending on fire regime (Certini, 2005). The increased frequency of fires in the same forest contributes to land degradation and reduces the resilience of the biomes to natural disturbances. A meta-analysis of 57 publications (Nave et al., 2011) showed that wildfires caused a significant decrease in soil carbon and N, whereas prescribed fires caused smaller reductions in carbon and N storage. Moreover, the recovery of both nutrient pools in the soil was generally faster. Forest fires produce charcoal, or black carbon, some of which can be preserved over centuries and millennia in soils. In addition, the increased frequency of fires results in a decrease in soil fertility, especially in labile organic matter fractions, that persists over the long term (Mayor et al., 2016).

A large field study in the Amazon (225 forest plots) focused on the effects of anthropogenic forest disturbance (selective logging, fire and fragmentation) on soil carbon pools, showed that the first 30 cm of the soil pool did not differ between disturbed primary forests and undisturbed areas of forest, suggesting a resistance to impacts from selective logging and understory fires (Berenguer et al., 2014). Impacts of disturbances on the soil carbon are of particular concern in tropical forests located on organic soils and on steep easily eroded slopes.

An integrative adaptive forest management concept is suggested by Bolte et al., (2009) that should combine actions on different spatial scales, due to their interaction regarding GHG mitigation and forest adaptation. The stand level interventions suggested by them relate to the conservation of the forest structures even against successional pressure; active use of silvicultural methods (i.e., thinning, changing rotation periods) to change stand structures and composition (i.e., choice of species) better-adapted to the changing climatic conditions.

Some examples of SLM technologies are provided in Annex 1: selective logging; adjust forest plantations rotation periods; short rotation biomass production from forest; fuel-wood production; forest irrigation and fertilization; woodlots for biomass production; reducing logging waste.

16 (http://www.fao.org/forestry/sfm/en/)

2.4.4 Forest restoration

It is difficult to define "Restoration" in a way that encompasses all situations found in the literature and proactive. Generally, restoration is seen as synonymous with degradation: an undisturbed forest in a natural or historical condition can be degraded, and a degraded forest can be restored to that natural or historical condition (Santurf, 2005). A variety of approaches can be used to overcome forest degradation (Lamb & Gilmour, 2003):

- Restoration is used for situations where the intent is to bring an ecosystem as close as possible back to its original state. The site then contains most of the original plant and animal species, and has a structure and productivity as was originally present.
- Rehabilitation is used to enhance environmental services, with a focus on provision of goods and services, rather that ecosystem integrity. In this regard, the main objective is to regain the original productivity or structure, but not all the original biodiversity. This might be because commercial imperatives demand the use of certain agricultural or timber species to justify the rehabilitation effort, or because the site has become unsuitable for some of the original species;
- Reclamation is used for situations where productivity or structure is regained, but biodiversity is not. In fact, native species may not be used at all. In such cases, there are few, if any, benefits to landscape biodiversity, but there may be social or economic advantages or functional gains, such as improved watershed protection.

The three approaches differ in the extent to which they enable the original biodiversity to be regained. They are similar, however, in that they all seek to establish a productive and stable new land use. Ecosystem integrity is promoted more by restoration than by rehabilitation. Forest landscape restoration is also defined as a process that aims to regain ecological integrity and enhance "human well-being" (Mansourian et al., 2005). This approach helps to achieve a balance between human needs and those of biodiversity by restoring a range of forest functions within a landscape and accepting the trade-offs that result. The term "human well-being" is necessarily broad, and covers not only benefits such as the market value of forest products (e.g., timber or non-timber forest products) and other ecological services, such as watershed protection, but also a broader range of benefits that flow from them. The term "forest landscape restoration" incorporates both ecosystem integrity and human well-being (Lamb & Gilmour, 2003).

Some examples of assisted regeneration are provided in Annex 1.

2.4.5 Fire, pest and diseases control

Each year, wildfires destroy 6 to 14 million hectares of fire-sensitive forests worldwide (Rowell and Moore, 2000), a rate of loss and degradation comparable to that of destructive logging and agricultural conversion. At the same time, many fire-adapted forest ecosystems are fire-starved. Humans are altering natural fire regimes around the world. Page et al., (2002) estimated that 0.81 and 2.57 Gt of carbon were released into the atmosphere in 1997, as a result of burning peat and vegetation in Indonesia. This is equivalent to 13–40% of the mean annual global carbon emissions from fossil fuels, and contributed greatly to the largest annual increase in atmospheric CO_2 concentration detected since records began in 1957. The role of fire varies among different types of forest: in tropical dry forests, boreal forests and some types of conifer forests, a certain amount of fire is an essential factor in the maintenance of forest structure, function and plant and animal composition; in tropical moist forest, fire is usually always detrimental (Moore et al., 2003).

Pests can also be affected by climate change and lead to important CO_2 emissions. A recent unprecedented case is the pine beetle outbreak in British Columbia, where Kurz et al., (2008) estimated that the cumulative impact in the affected region (374,000 km^2 of forest) during 2000–2020 was 270 Mt of carbon (or 36 g C m^{-2} yr^{-1}) emitted into the atmosphere. The need for pest control treatments can often be minimised through experience-based forest management and long-term forestry practices. The pest control method(s) chosen will depend upon the kind and amount of control necessary, balanced with costs and benefits within legal, environmental and other constraints. There is considerable evidence that climate change will alter pest outbreak dynamics, but it is difficult to generalise overall consequences. Although there are examples of damaging pest outbreaks triggered by climate change, there are also examples of outbreaks that have been diminished by climate change. Given the unpredictability of future climate change on insect outbreak dynamics, there is currently little useful advice on the direction that forest pest management should take in the future in anticipation of climate change (Liebhold, 2012).

Some case examples are included in annex 1 to illustrate the technologies: management for forest fire prevention; controlling anthropogenic disturbances, such as fire and pest outbreaks; control of wildfires in peatlands.

2.4.6 Soil erosion control

Erosion is a risk for soil fertility, and foresters usually prevent it with adapted management practices. Under forest conditions, surface runoff and soil erosion are generally low because of the surface litter cover. Hydraulic conductivities are in excess of 15 mm hr^{-1}, and erosion rates are generally less than 0.1 mg ha^{-1} (Elliot et al., 1996). If the litter layer is disturbed, then runoff and erosion rates can increase by several magnitudes (i.e., by forest fires or litter extraction). Soil erosion, combined with other impacts from forest disturbance, such as soil compaction and forest fires, can reduce forest sustainability and soil productivity. Because the highest concentrations of nutrients and biota, and the maximum water-holding capacity are in the uppermost horizons, incremental removal of soil near the surface is more damaging than subsoil losses. Productivity may inevitably decline on most shallow forest hilly soils as erosion causes root-restricting layers to be nearer the surface, and as organic matter is washed away. Consequently, the largest declines in productivity are most likely to occur in marginal, dry environments (Elliot et al., 1996). Wind erosion is also a degradation risk, particularly in coastal sandy environments where dunes can be stabilised through forest establishment (Bernabé et al., 2004).

Global changes, particularly climate change, and changes in practices and demand for energy, increase or modify soil erosion risk. Models predict a higher frequency of extreme rainfall events, which are by far the primary drivers of soil erosion. High-intensity rainfall events are more damaging when soils are dry, and show low permeability and sparse vegetation cover. The forecasted higher occurrence and duration of heat waves and droughts during the summer season will increase the risk of heavy rainfall events, when soils are dry during the autumn season. This risk is particularly high in areas that encounter violent autumn storms, such as those in Mediterranean climates. It will also multiply the combination of these strong rainfalls with episodes of forest decline and fires (Ventier et al., 2014). The adoption and combination of SLM practices, e.g., trees for watershed management and the establishment of protected forest areas (see Annex 1), assists on preventing soil erosion risk.

Some examples of the SLM technologies are included in Annex 1: landslide prevention using drainage trenches lined with fast growing trees; trees for watershed management; trees on mountain slopes together with moisture accumulating trenches; afforestation and hillside terracing; hydro-mulching; mulching after forest fires.

2.4.7 Water management; Drainage

The removal of excess water, either from the ground surface or from the root zone, is called drainage. Excess water may be caused by rainfall or by using too much irrigation water, but may also have other origins, such as canal seepage or floods.

Trees for bio-drainage illustrate the technologies (see Annex 1).

2.5 Grazing lands

Grasslands on every continent have been degraded due to human activities, with about 7.5% of grasslands having been degraded because of overgrazing (Conant, 2012). Production in pastoral systems is constrained by over-grazing, land degradation, climate variability, and gaps in feed supply. These constraints are very pronounced in dryland grasslands (see Box 8.).

BOX 8:

Types of grazing lands

For the purpose of this report, **grasslands** are lands where grass or grass-like vegetation grows and is the dominant form of plant life, used interchangeably with the term grazing lands. It is a broader term that covers pasture, savannah, steppe, rangelands and hayfields.

Pasture: a field covered with grass or herbage and suitable for grazing by livestock.

Savannah: a flat grassland in tropical or subtropical regions with scattered trees.

Steppe: a temperate or tropical grassland that only has trees near lakes and rivers; located in places including southern Russia, central Asia, southern South America, the central United States and western Canada.

Hayfield: a field where grass or alfalfa are grown to be made into hay.

Rangelands are distinguished from pasture lands because they grow primarily native vegetation, rather than plants established by humans.

The most common SLM technologies to address land degradation in grasslands (synonymous with pastoral lands) are related to preventing soil erosion and deterioration (integrated soil fertility management, grazing pressure management), and improving productivity and biodiversity (animal waste management, vegetation management and the use of irrigation). Broadly, these SLM technologies correspond to the land-based agricultures' demand-driven mitigation options in grazing land (grazing land management: animal, plant and fire management) (Table 5).

Silvopastoral farm in Matiguas, Nicaragua © CIAT / Shadi Azadegan

TABLE 5:

Number of SLM technologies per technology group considered for grazing lands in relation to climate change land-based mitigation options as defined by IPCC.

Grazing lands		Nº
SLM technical solution	**Land-based mitigation options (Grazing land management)**	16
Grazing pressure management	Animal management	6
Integrated soil fertility management	Plant and soil management	2
Vegetation management	Plant and fire management	7
Animal waste management	Animal management	1

(Smith et al., 2014)

2.5.1 Grazing pressure management

Sustainable grazing management determines the carrying capacity meaning the maximum livestock or wildlife population that a habitat or ecosystem can support on a sustainable basis, and manages the timing and severity of grazing to ensure that the carrying capacity is not exceeded. In livestock production, the concept has been applied mainly to the management of arid and semi-arid rangeland regions of the world, such as pastoral systems in Africa where livestock are primarily dependent on grazing resources for feed supply. This may involve the establishment of total grazing pressure fencing, strategic placement of watering points or time-controlled rotational grazing.

Soil carbon dynamics in pastures highly depend on their management, with soil carbon increases or reductions observed for different combinations of animal densities and grazing frequency (Conant, 2012; Machmuller et al., 2015). Under certain conditions, grazing can lead to increased annual net primary production over un-grazed areas, particularly with moderate grazing in areas with a long evolutionary history of grazing and low primary production, but this does not always lead to an increase in soil carbon (e.g. Badini et al., 2007); grazing, like crop harvest, fundamentally leads to the rapid oxidation of carbon that would otherwise be eventually transferred to the soil. Henderson et al., (2015) estimated that the optimisation of grazing pressure could globally sequester 148 Tg CO_2 yr^{-1}.

Some case examples are included to illustrate the technologies (annex 1): stocking density; area closure to grazing; communal grazing management; eco-graze practices; rotational grazing, rangeland resting.

2.5.2 Integrated soil fertility management

As for croplands, carbon storage in grazing lands can be improved by a variety of measures that promote productivity. For instance, alleviating nutrient deficiencies with fertilizers or organic amendments increases plant litter returns and, hence, soil carbon storage (Conant et al., 2001; Schnabel et al., 2001). Adding nitrogen, however, may stimulate N_2O emissions (Conant et al., 2005) thereby offsetting some of the benefits. Similarly, irrigating grasslands can promote soil carbon gains (Conant et al., 2001). Practices that tailor nutrient additions to plant uptake, similar to precision agriculture, can reduce emissions of N_2O (Dalal et al., 2003), but may be complicated in terms of separation of faeces and urine from livestock.

Some examples of the SLM technologies are included in Annex 1: nutrient management; manure separation to better distribute organic matter technologies.

2.6 Vegetation management

Introducing grass species with higher productivity or carbon allocation to deeper roots has been shown to increase soil carbon. For example, the establishment of deep-rooted grasses in savannahs has been reported to yield very high rates of soil carbon accrual, up to 1 m in depth (Fisher et al., 1994), although the applicability of these results has not been widely confirmed (Davidson et al., 1995; Conant et al., 2001). Introducing legumes into grazing lands can promote soil carbon storage (Soussana et al., 2004) by enhancing productivity from associated N inputs, while reducing N_2O emissions from soils if the biological N_2 fixation reduces the need for N fertilizer. However, care has to be taken when introducing non- native species, particularly, with exotic invasive grass species, because although a substantial increase in net primary productivity is generally observed in the system, they reduce native plant diversity and can drive rapid shifts in the soil environment from surrounding native communities (Gibbons et al., 2017).

Lands used for grazing also emit GHGs from the livestock, notably CH_4 from ruminants and their manures. Reducing the frequency or intensity of fires in grasslands typically leads to increased tree and shrub cover, resulting in higher landscape carbon density in soil and biomass (Scholes & van der Merwe, 1996). Nonetheless, the effectiveness of this practice might vary depending on the environmental context where implemented. While this woody plant encroachment mechanism has a high initial impact, it saturates after 20–50 years. After that time, CH_4 and N_2O emissions are still avoided, and for as long as the fires are suppressed.

Some case examples are included in Annex 1 to illustrate the technologies: range pitting and reseeding; grazing land rehabilitation with shrubs plantation; improved use of fire for sustainable grassland management; improved fodder production on degraded pastureland; cut-and-carry fodder production; creation of a perennial grass seed area; off-season irrigation of fields and pastures.

2.6.1 Animal waste management

Animal Waste Management Systems are designed for the proper handling, storage, and utilisation of wastes generated from animal confinement operations, which include a means of collecting, scraping, or washing wastes from confinement areas into appropriate waste storage structures, and management of storage and application to reduce gaseous emissions and nutrient loss.

To illustrate the technologies, Annex 1 describes improved cattle shed for urine collection.

Intercropping, Sidama, Ethiopia © ILRI / Kettema Yilma

2.7 Mixed

In the present report, the systems that combine trees with crops and/or animals as productive systems are considered mixed systems (agroforestry systems and agro-pastoral systems). Broadly these SLM technologies are mitigation options in the AFOLU sector (Smith et al., 2014; see Table 6).

Agroforestry, argan trees and barley fields, Sidi Ifni Province, Morocco © IRD / Geneviève Michon

TABLE 6:

Number of SLM technologies per technology group considered for mixed in relation to climate change land-based mitigation options as defined by IPCC.

Mixed		Nº
SLM technical solution	**Integrated systems (Agroforestry)**	5
Agroforestry systems	Agroforestry (including agro-pastoral and agrosilvopastoral systems)	4
Agri-pastoral systems	Agroforestry (including agro-pastoral and agrosilvopastoral systems)	1

(Smith et al., 2014)

2.7.1 Agroforestry systems

According to the World Agroforestry Centre, agroforestry is defined as land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals within the same land management unit [17]. Agroforestry practices, according to Nair (1993), range from simple forms of shifting cultivation to complex hedgerow intercropping systems; systems including varying densities of tree stands, ranging from widely-scattered trees in dryland cereal fields, to the high-density multistoried home gardens of the humid tropics or in an oasis; systems in which trees play a predominantly service role (e.g., windbreaks) to those in which they predominantly provide commercial products (e.g., intercropping with plantation crops) (Nair 1993). Depending on the combinations of trees, animals and crops, they are often classified into (Nair, 1985): Agri-silviculture (crops, including shrubs/vines combined with trees); silvo-pastoral (pasture/animals and trees); and agro-silvo-pastoral (crops, pasture/animals and trees). Agroforestry land-use is a common practise worldwide and a great variety of systems and practices exist under different climatic conditions, from tropical to hyper-arid areas. For example, the traditional *Acacia senegal*-based agroforestry system for gum arabic production was recognised and considered as one of the most successful forms of natural forest management in the tropical drylands, and regarded as sustainable in terms of its environmental, social and economic benefits (Gaafar et al., 2006). Another example in temperate regions are the so-called "*dehesas*" (in Spain) and "*montados*" (in Portugal), which consist of combining oak trees with animal grazing or cereal crops. Inter-cropping and home gardens in oasis and river valleys are a common practice in hyper-arid climate zones.

When properly managed, agroforestry systems can be very beneficial for land users and their environments (Marques et al., 2016). One of the most widely-acclaimed advantages of agroforestry is its potential for conserving the soil and maintaining its fertility and productivity, while ensuring subsistence and/or providing market products. This is particularly relevant in the tropics, where soils are generally inherently poor and less productive than in the temperate zones (Nair, 1984; Young, 1989). To some extent, forest cover (natural or through proper arrangements, such as hedgerows) can: i) reduce erosion to low levels; ii) maintain or increase the soil organic matter; iii) improve water retention; and iv) intercept, absorb, and recycle nutrients in the soil that would otherwise be lost, through leaching by the tree root systems (Nair, 1993). The inclusion of trees in agroforestry systems (e.g., N-fixing leguminous), may specifically enhance SOC storage. However, SOC sequestration rates observed are highly variable, and only a very limited number of field experiments have been specifically designed to rigorously test the effects of agroforestry practices on SOC (Lorenz & Lal, 2014). However, depending on the species, effects such as nutrient and moisture competition with crops and grasses can emerge. It remains to be studied whether agroforestry systems can be specifically designed and managed to maximise belowground carbon sequestration, by exploring the carbon storage potential in the entire mineral soil profile through the inclusion of trees and their associated root-derived carbon inputs (Lorenz & Lal, 2014).

17 e.g. Agroforestry system dominated by Acacia senegal, developed through protection of all naturally regenerating trees with improvement of soil properties through presence of trees, application of manure and a fallow rotation (https://qt.wocat.net/qt_summary.php?lang=english&qt_id=619

Silvo-arable systems (trees and crops) have the potential to contribute to the increased sustainability of agriculture and enhancement of biodiversity, whilst preserving landscapes that are both culturally important and aesthetically pleasing (Eichhorn et al., 2006; Mosqera et al., 2012). There may be environmental benefits to silvo-arable systems at the regional scale. Increased tree planting could absorb greater amounts of carbon, and therefore mitigate future increases in atmospheric CO_2 (Herzog, 1994). The search for alternative energy sources has led to consider silvo-arable systems as a source of bio-fuels (Herzog 1994; Hall, 1997). The use of trees for fodder production and as a means of combating erosion in fields previously sown purely with annual fodder crops is also increasing (Dupraz & Newman, 1997). Also in Africa, agroforestry in general may increase farm profitability through the improvement and diversification of output per unit area of tree/crop/livestock, by protecting against the damaging effects of wind or water flow, thereby substantially contributing to climate change adaptation and mitigation (Mbow et al., 2014). In India, as in many other countries, agroforestry is also seen as a unique opportunity to combine the twin objectives of climate change adaptation and mitigation (Dhyani et al., 2016).

In order to optimise agroforestry for climate change adaptation and mitigation, there is a need for more integrated management approaches to increase benefits and reduce negative impacts on climate (Figure 4). In addition, agroforestry systems can meaningfully reduce the pressure on natural forests for energy needs. On the other hand, uncertainties related to future climates, land use and land cover, soil fertility in drier environments and pests and diseases, pose challenges to the geographical expansion of agroforestry practices.

FIGURE 4:

Examples of positive or negative implications of agroforestry practice for adaptation to or mitigation of climate change.

Mitigation

		Positive	Negative
Adaptation	Positive	Soil carbon sequestration, improved water holding capacities, use of manure instead, mixed agroforestry for commercial products, income diversification with trees, reduced nitrogen fertilizer, fire management.	Dependence on biomass energy, overuse of ecosystem services, increased use of mineral fertilizers, poor management of nitrogen and manure, over extraction of non-timber products, timber extraction.
	Negative	Integral protection of forest reserves, limited rights to agroforestry trees, forest plantation excluding harvest.	Use of forest fires for pastoral and land management, tree exclusion in farming lands.

(Mbow et al., 2014)

Some case examples are included in Annex 1 to illustrate the technologies: plantation crop combinations; multi-purpose trees on crop lands; animal draft zero-tillage; home gardens; orchard with integrated grazing and fodder production (Silvo-pastoralism); traditional *Acacia senegal*-based agroforestry system.

2.7.2 Agri-pastoral systems

This is a diversified form of pastoralism that integrates crop farming in different forms. Pastoralism is an economic and social system frequently adopted where severe conditions for agriculture exist, such as in drylands or steep slope areas in temperate climates. It is characterised by a complex set of practices and knowledge that has permitted the maintenance of a sustainable equilibrium among pastures, livestock and people. The types of livestock kept by pastoralists varies according to climate, environment, water and other natural resources, and geographical area, and may include cattle, camels, goats, sheep, yaks, horses, llamas, alpacas, reindeer and vicunas. These practices often encompass grazing or feeding of crop residues and grazing of fallow land (agro-pastoralism), which includes nomads and transhumant (agro)-pastoralist communities.

These agri-pastoral systems are particularly wide-spread in drylands; with a long tradition in Africa and the Mediterranean Basin; less wide-spread in Asia (mostly restricted to roadside and fallow grazing, and rice straw feeding) and Latin America, although these areas show an increase in the trend. These systems are facing constraints (such as access to land and water points, market access, growing population pressure) and new challenges (such as conflict avoidance, expansion of trade and growing demand of proteins over the world, equitable access to land, including protection of customary services; Rota & Sperrandini, 2009).

In remote and degraded areas, or under harsh climates, this breeding plays a crucial role in the farming economy, thanks to its ability to exploit marginal areas. Along with the limited labour and capital required for their growth, this is the only possible primary activity capable of preventing land abandonment, especially in south-eastern Mediterranean regions (Enne et al., 2004). Grain-based feedlot forages are often produced on less suitable lands for crop production (Peters et al., 2013b). For example, sheep and goats play a crucial role in the farming economy of the Mediterranean basin, thanks to their ability to exploit marginal areas, and as well for the limited labour and capital requirements for their management. Yet overgrazing (Enne et al., 2004) and changes in soil bulk density and soil nutrient profiles are a major concern of dryland grain producers considering grazing sheep on cereal stubble fields. Some scientific studies' results show no detrimental impact of grazing sheep on small grain residue (e.g. Hatfied et al., 2007), suggesting a strong potential for grazing sheep on grain stubble without adversely impacting soil bulk density or nutrient profiles. However, additional research must be done to determine optimum stocking rate, season of grazing, and environmental conditions, particularly soil moisture, to determine when grazing should occur without negatively impacting soil bulk density.

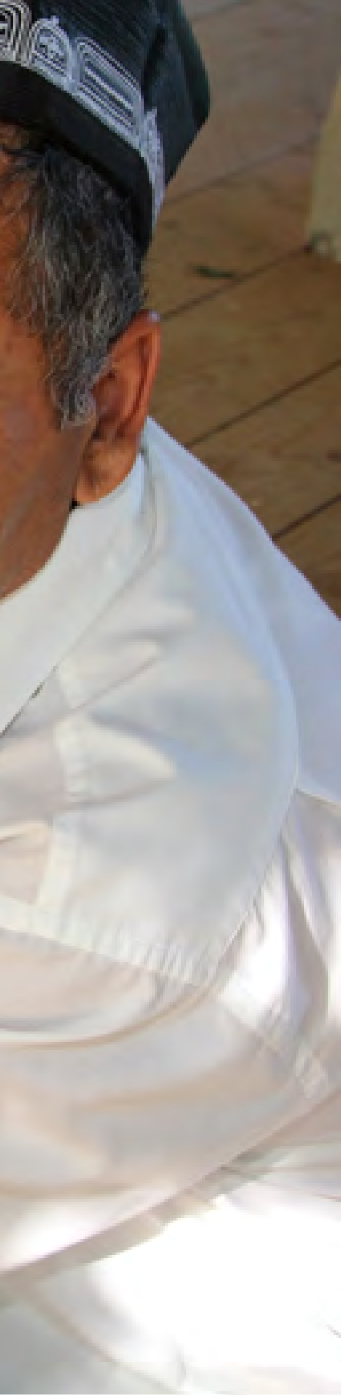
There is a tendency towards sustainable intensification of forage-based systems as a measure to mitigate GHG emissions from livestock production, while providing a number of co-benefits, including increased productivity, reduced erosion, improved soil quality and nutrient and water use efficiency; however, ex-situ environmental costs and benefits vary widely with respect to GHG emissions and impacts on biodiversity and water (Peters et al., 2013c). To best select agro-pastoral practices, assessing environmental impacts, land suitability for grazing, and estimating the optimal stocking rate is essential.

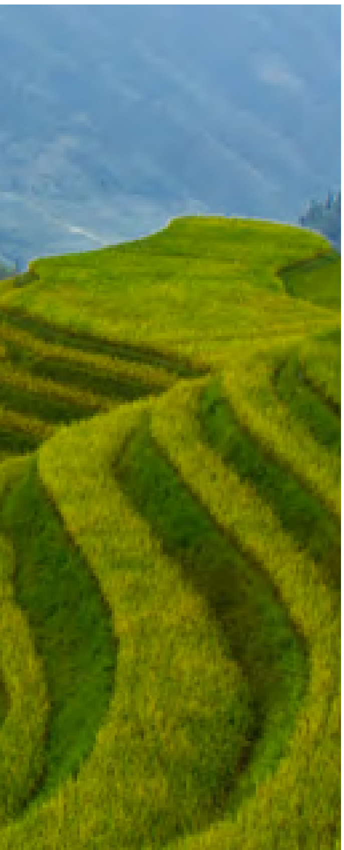
The Annex 1 illustrates technologic examples: incorporating sheep into dryland grain production systems.

More than one hundred SLM technologies can avoid, reduce and/ or reverse land degradation and desertification while contributing to climate change mitigation and adaptation.

A selected set of variables to qualitatively compare the impacts of groups and/or individual SLM practices.

Chapter 3





Synergies between SLM practices to address desertification, land degradation, drought, climate change adaptation and mitigation

3.1	Qualitative evaluation of SLM technologies and practices	77
3.2	Qualitative assessment results	79
3.3	Technically-promising technologies	96

Many overviews and assessments of SLM have focused on specific technologies like water harvesting techniques, and yield improvement strategies or specific impacts, such as enhanced soil quality; climate change adaptation or mitigation, etc. However, there is a need for more comprehensive and multi-objective assessments, including those that consider co-benefits and trade-offs. As indicated already in Chapter 2, technologies aiming to address land degradation (prevent, reduce or revert) can often improve resilience (contributing to adaptation to climate change), increase carbon stocks and reduce GHG emissions (contributing to climate change mitigation). This chapter attempts to qualitatively and simultaneously assess the positive relative impacts of the SLM technologies and practices considered (see Chapter 2) in addressing DLDD, climate change adaptation, climate change mitigation and safeguarding biodiversity, including a qualitative indication of their cost. While trade-offs are considered, they are not systematically included in the qualitative assessment. Although this exercise is limited due the selection of the SLM technologies considered in this report, it is noteworthy to highlight that thirty-five percent of the practices considered in Annex 1 are commonly implemented in drylands.

3.1 Qualitative evaluation of SLM technologies and practices

3.1.1 Approach

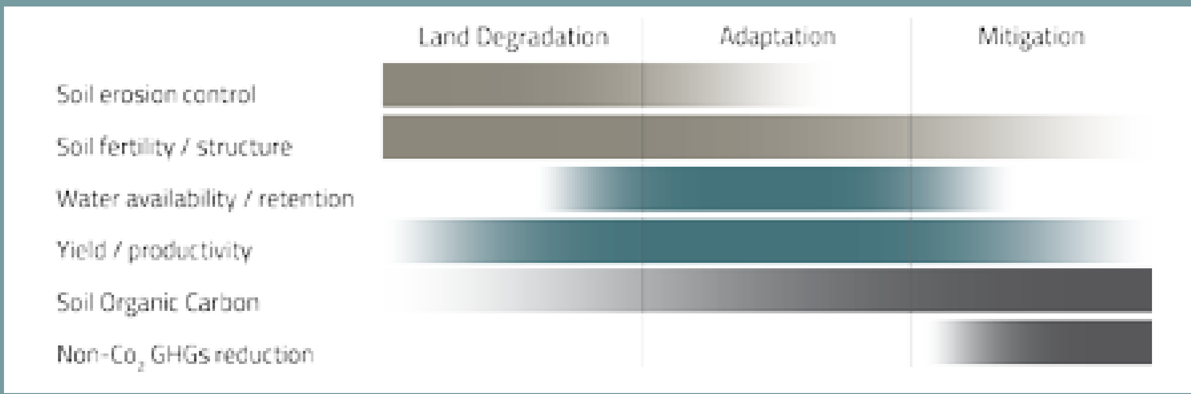
For the qualitative assessment, a set of "variables" (Box 9) were selected, considering the assessments undertaken by Smith et al., (2013), Kanter et al., (2016), Marques et al., (2016), and Stavi et al., (2016) in relation to land degradation, climate change adaptation and mitigation, incling impact on biodiversity as a co-benefit[18]. The qualitative assessment presented below should be seen as providing initial and general guidelines informing on how to approach technical choices when specific practices are looked at in specific cases.

FOR EACH GROUP OF PRACTICES (TABLES 7 TO 10), SCORES OF INDIVIDUAL TECHNOLOGIES CONSIDERED ARE AVERAGED TO ASSIGN AN INDICATIVE SCORE TO THE GROUPS THAT ARE PRESENTED IN POLAR GRAPHS (FIGURES 5 TO 8).

18 Although biodiversity also can contribute to addressing land degradation and climate change adaptation and mitigation, up to some extent.

BOX 9:

Variables and scoring considered in the qualitative assessment of the SLM technologies

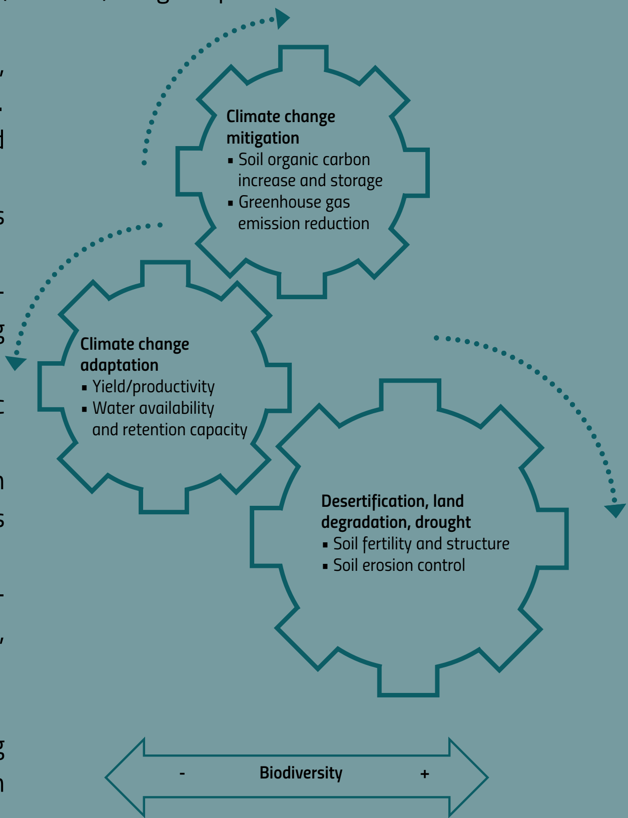


Specific variables or qualities are selected (and grouped with colours) to indicate the degree to which the SLM technology can contribute in addressing DLDD, climate change adaptation and mitigation, as well as its impact on biodiversity.

In each case levels assigned are: 1 (in figures) or * (in tables) = low or non-impact; 2 (in figures) or ** (in tables) = medium impact; and 3 (in figures) or *** (in tables) = high impact.

- Soil fertility and structure: sustaining plant growth, creation and storage of soil organic matter is favored.
- Soil erosion control: prevention of loss, retention and protection of soil.
- Yield/productivity: productivity increase, this relates to food security.
- Water availability and retention capacity: water retention capacity and availability is increased, including resilience to droughts.
- Soil organic carbon increase and storage: soil organic carbon levels are increased or preserved.
- Greenhouse gas emission reductions: non-CO_2 green gases emissions are decreased, in particular nitrous oxide and amethane.

In addition: increased or protected biodiversity, including plants, animals and/or soil fauna; cost indication (low, moderate or high) for implementation.



A score for each technology is assigned by considering the scientific literature referred to in Chapter 2.2 for each group of technological solutions and land-use type information, the examples included in Chapter 2.2, Annex 1, and the team of authors' expert judgement. The score does not prejudge, nor can it be applied directly to specific circumstances; rather, it constitutes an indication based on the information considered (specific assessments should be conducted for specific applicability in particular cases beyond the present report).

This is beneficial for comparative purposes, giving an idea of how technologies compare in SLM, although it also has some limitations. This is because technologies are assessed individually, while combinations of technologies are not considered in the assessment. Individual SLM technology scores referred to the variables associated (Box 9) with DLDD, climate change adaptation and mitigation, and biodiversity, and are shown in the tables. All the tables for individual technologies include an indication of the relative cost for their establishment in terms of low, medium or high costs, based on the literature and indicative information in consulted databases (WOCAT).

3.2 Qualitative assessment results

3.2.1 Croplands

Group of technologies (Figure 5)

When considering SLM technologies, vegetation management and soil fertility management have moderate to high impact on soil structure and fertility. soil erosion control and on climate change adaptation (in particular, increasing yield) and mitigation (by increasing soil organic carbon). Soil fertility management, however depending on the technology and how it is applied, could lead to an increase or decrease in non-CO_2 GHGs (see Chapter 2). Soil erosion control technologies, primarily indicated for avoiding losses in top soil, score high for soil erosion control, with a moderate score in yield/productivity, but have a lower impact on soil fertility/structure, water availability/retention and soil organic carbon. However, combined with green cover, their mitigation potential could increase.

Minimum soil disturbance technologies have a high impact on erosion control and score moderate to high in soil fertility/structure, and also seem to have less impact on climate change mitigation than soil fertility management and vegetation management technologies. Their lower score on mitigation is due to the disparate results in soil organic carbon increase by non-tillage and green cover practices. In the case of pest and disease control practices, they have a moderate impact on climate change mitigation and on yield productivity (adaptation), but low or no impact on land degradation (soil erosion control and fertility). Specific cases scored moderate to high for water availability/retention, although this was not explicitly recognised in the literature. Water management technologies considered (irrigation and drainage) have low to moderate impact on some aspects of climate change adaptation and mitigation, since soil organic carbon cannot be increased by increasing yield/productivity. However, non-CO_2 gases can increase or decrease depending on the circumstances (see Chapter 2). While in this group drainage can have a positive impact on GHGs, this aspect still requires careful assessment, since drainage may reduce CH_4 emissions, but can increase N_2O. The above can change if new technologies are included, for example, flooding control technologies.

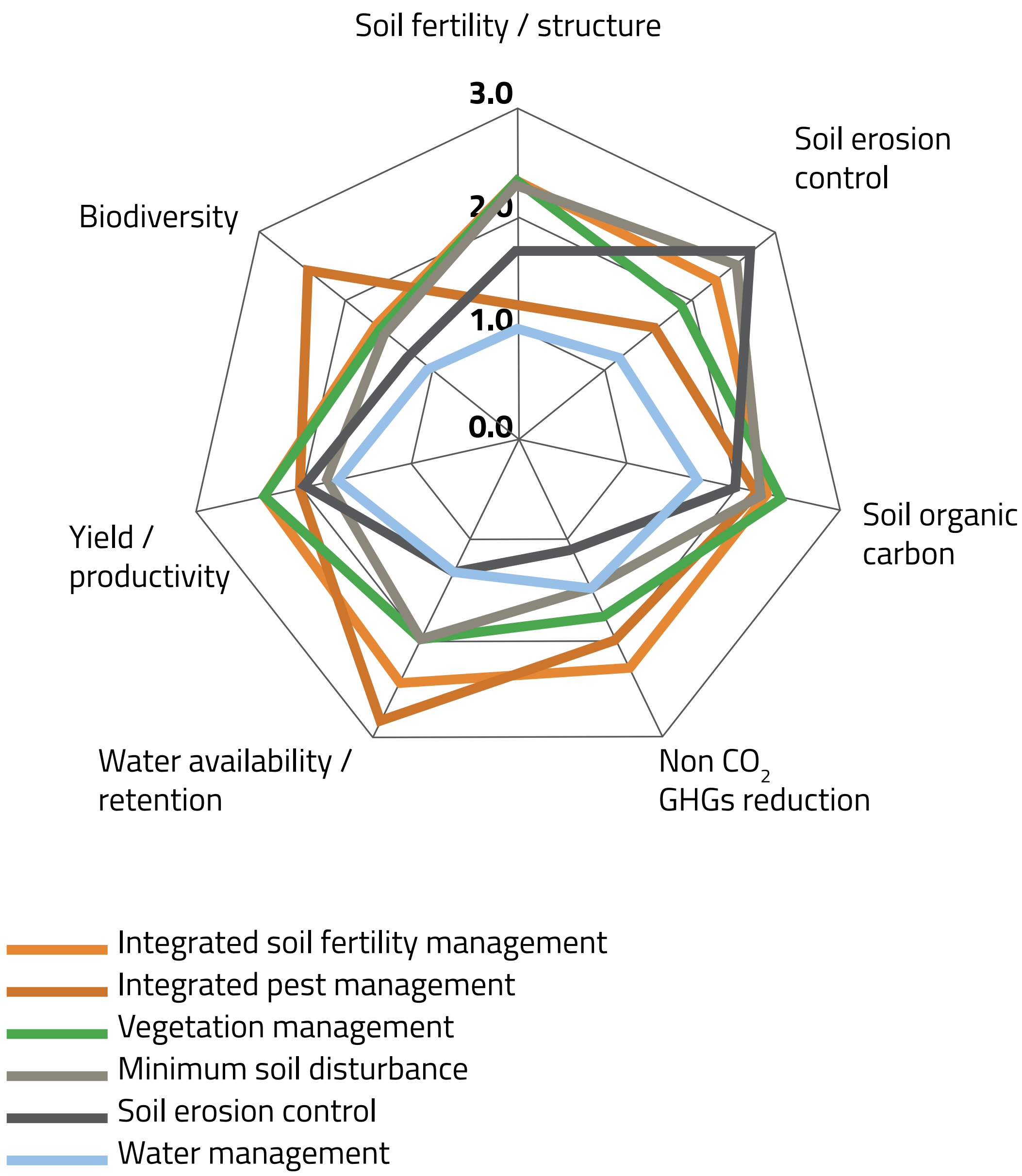


FIGURE 5:

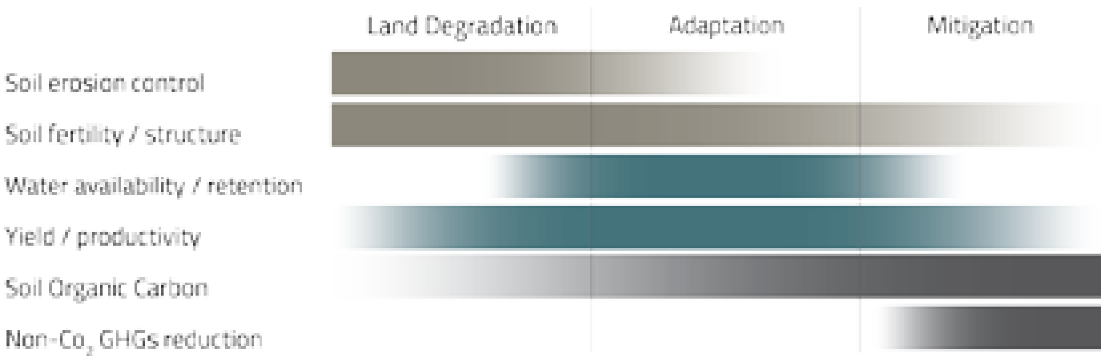
Qualitative assessment of SLM groups of technologies in croplands. A scale for positive impact from one to three (1: low or none; 2: moderate; 3: high) is used to qualify each of the SLM practices considered (Chapter 2.2 of this report) for each of the aspects selected above.

Individual practices

Within the groups' technologies, some practices contribute more than others to addressing land degradation and climate change. Other co-benefits could be considered, a possible additional benefit being conservation of biodiversity or increasing biodiversity in low biodiversity systems. In Table 7, each practise is qualitatively assessed. Technologies that have a high impact on at least two aspects (land degradation, climate change adaptation and mitigation) in most cases also have a positive impact on biodiversity (Table 7). This is especially true if these technologies are implemented after less sustainable or more conventional technologies, such as intensive mono-cropping technologies with overuse of mineral fertilizers, as was found for Mediterranean cropping systems (Aguilera et al., 2013; Aguilera et al., 2015), including semi-arid areas (de Vente, 2012; Almagro et al., 2016). They encompass: i) soil fertility management (application rate, type and time of fertilizers, in particular, organic fertilizers); ii) vegetation management technologies (permanent soil covers, such as green covers in perennial crops, crop rotation, multiple and inter-cropping, and the choice of species) and iii) minimum soil disturbance (non-till or different forms of reduced till, green covers and mulching).

TABLE 7:

SLM technologies in croplands clustered in six groups of technologies reflected in Chapter 2.2. Addressing land degradation (LD), climate change adaptation and mitigation, co-benefits (biodiversity), and cost (investments): Low (1), moderate (2), high (3).



CROPLAND	Soil fertility/ structure	Soil erosion control	Soil Organic Carbon	Non CO_2 GHGs reduction	Water availability/ retention	Yield/ Productivity	Biodiversity
Integrated soil fertility management	**2,3**	**2,3**	**2,3**	**2,3**	**2,4**	**2,3**	**1,6**
Aplication of organic fertilizers	3	3	3	2	1	2	2
Biochar soil amendment to increase biomass productivity, and sequester C	3	2	2	2	3	2	1
Changing fertilizer application rate, fertilizer type, timing, precision application, inhibitors	1	2	2	3	3	3	1
Composting using Indigenous Microorganism	3	2	2	2	3	2	3
Microfertilization	1	2	2	3	3	3	1
Planting pits for soil fertilisation and moisture improvement	2	3	2	2	1	2	1
Production and application of biohumus	3	2	3	2	3	2	2
Minimum soil disturbance	**2,3**	**2,5**	**2,3**	**1,5**	**2,0**	**1,8**	**1,5**
Direct planting	3	2	2	1	2	1	1
Mulching in croplands	2	3	3	1	2	2	1
No-till technology	3	3	2	2	3	2	2
Strip Tillage	1	2	2	2	1	2	2
Intgrated Pest Management	1,2	1,6	2,2	2	2,8	2	2,4
Application of biological agents to increase crop resistance	1	1	2	2	3	2	3
Biological pest control	1	1	2	2	3	2	3
Integrated production and pest management	2	2	2	2	3	2	2
Trees as Buffer Zones	1	3	3	2	2	2	3
Use of phytopesticides	1	1	2	2	3	2	1
Water management	**1**	**1,1**	**1,6**	**1,5**	**1,3**	**1,6**	**1**
Micro-irrigation systems	1	1	2	2	1	2	1
Mid-season paddy Water management; Drainage in rice paddies	1	1	1	2	3	1	1
Spate irrigation	1	2	2	1	1	2	1
Spiral water pumps	1	1	2	1	1	2	1
Subsurface drainage	1	1	1	2	1	1	1
Water harvesting from concentrated runoff for irrigation purposes	1	1	2	1	1	2	1

TABLE 8:

(cont.) SLM technologies in croplands clustered in six groups of technologies reflected in Chapter 2.2. Addressing land degradation (LD), climate change adaptation and mitigation, co-benefits (biodiversity), and cost (investments): Low (1), moderate (2), high(3).

CROPLAND	Soil fertility/ structure	Soil erosion control	Soil Organic Carbon	Non CO_2 GHGs reduction	Water availability/ retention	Yield/ Productivity	Biodiversity
Soil erosion control	1,7	2,7	2,0	1,1	1,3	1,9	1,2
Gully control and catchment protection	2	3	2	1	1	2	1
Haraghie Stone Bund	1	2	2	1	2	2	1
Integrated runoff water management	2	3	2	2	1	2	1
Living fences / windbreaks	2	3	2	1	2	2	2
Paved and grassed waterways	1	2	1	1	1	2	1
Progressive bench terrace	2	3	2	1	1	2	1
River bank stabilization	2	3	2	2	1	1	1
Rockwall Terracing	1	3	2	1	2	2	1
Semi-circular bunds (for crops and forest/rangeland)	2	3	2	1	1	2	1
Shelterbelts and windbreaks, live hedges	2	3	2	1	2	2	2
Soil /stone bunds	1	2	2	1	2	2	1
Soil Bund with Contour Cultivation	2	2	2	1	1	2	1
Stone lines and Stone walls	1	3	1	1	1	2	1
Terracing in watershed	2	3	2	1	1	2	1
Traditional cut-off drain	2	3	2	1	1	2	1
Tree row and grass strip to sustain filtering	2	3	2	1	1	2	2
Vegetated earth-banked terraces	2	3	3	1	2	2	1
Vegetative strips	2	3	3	1	1	2	2
Water-spreading weirs	1	1	2	1	1	2	1
Vegetation management	2,3	1,8	2,4	1,7	2	2,3	1,5
Choice plant species/varieties	2	2	3	2	2	3	2
Crop rotation	2	1	2	2	2	3	1
Green cover in perennial woody crops	3	3	3	2	2	3	2
Long term fallow or set-aside	2	1	2	2	2	2	1
Multiple Cropping, intercropping	3	2	3	2	2	3	2
Perennial cropping systems	3	2	3	1	2	1	2
Permanent soil cover	3	3	3	2	1	2	2
Seed priming	2	2	2	2	3	2	1
Traditional Shifting Cultivation	1	1	1	1	2	2	1

A recent review on using cover crops to adapt and mitigate to climate change (Kaye & Quemada, 2017) showed that mixed, rather than single species cover could be more resilient to climate change; however the introduction of permanent covers could lead to extra cost for farmers, and its introduction might therefore require subsidies. On the other hand, care should be taken when introducing exotic species as permanent covers since they might threaten local biodiversity (i.e. invasive exotic species).

Soil erosion control technologies and water management technologies that showed moderate to low impact on land degradation and adaptation and mitigation of climate change might require extra investments by farmers and, unless the state provides subsidies, their adoption may be limited. Other studies also found similar results in a limited number of cases looking into i) the impacts on soil quality, water availability and biodiversity (Marques et al., 2016); ii) soil health and its benefits and trade-offs (Key et al., 2016); and iii) potentials for mitigation and other environmental co-benefits (Smith et al., 2014). Technologies identified as beneficial for building soil quality, such as through nutrient management, cover crops, and crop rotation, are well-established and have been used for centuries, all likely resulting in positive impacts on carbon storage in the soil and water retention while improving crop yields.

Technologies can also be applied in combination, as is the case in conservation agriculture, organic farming and integrated farming systems. For example, minimum tillage and soil protection may be combined with vegetation residues and rotation, and micro water-harvesting techniques may even be combined with micro fertilization. In the case of semiarid areas in Africa, Marques et al., (2016) found that results were positive for these combinations of technologies. Overall, the most effective approach to SLM in arable agriculture should consider the implementation of a variety of complementary SLM measures involving the whole community or watershed. However, trade-offs in some cases will need to be considered carefully. For example, the possibility of reduced yields if pests cannot be controlled efficiently in the absence of chemical agents. Stavi et al., (2016), in comparing conventional and conservation agricultural systems, found that moderate-intensity and integrated farming systems are expected to provide satisfactory conditions for crop production, sustaining soil fertility and controlling erosion, and contributing to the mitigation of climate change and to food security and environmental quality, while conservation systems may sometimes result in lower yield. Stockmann et al., (2013) pointed out that, despite the potential for carbon storage increase of some technologies in the long-term, soil carbon sequestration cannot continue indefinitely, although the rates of sequestration can be high until a system reaches an equilibrium, which can vary from 0.05 to 0.6 t C $ha^{-1}yr^{-1}$, depending on the prevailing climate and land-use.

3.2.2 Grazing lands

Group of technologies (Figure 6)

Among the four groups of SLM technologies considered for grazing lands, vegetation management and the management of carrying capacity practices lead to moderate positive impacts overall. Vegetation management leads to a higher impact in the case of soil organic carbon increase and yield productivity. Regarding integrated soil fertility management, SLM practices seem to have the highest impact on soil organic carbon increase among all the groups of practices considered. It is well-known that grassland management to enhance production (through sowing improved species, irrigation or fertilization), minimising the negative impacts of grazing or rehabilitating degraded lands, can each lead to carbon sequestration, with suggested averages of 0.35 t C $ha^{-1}yr^{-1}$ (Conant et al., 2001), and between 0.02 and 0.8 t $Cha^{-1}yr^{-1}$ (Stockmann et al., 2013), depending on the climatic region. SLM technologies that sequester carbon in grassland soils tend to maximise vegetative cover, reducing wind and water-induced erosion (Follett et al., 2001), and can lead to higher biodiversity (Bekessy & Wintle, 2008; Marques et al., 2016).

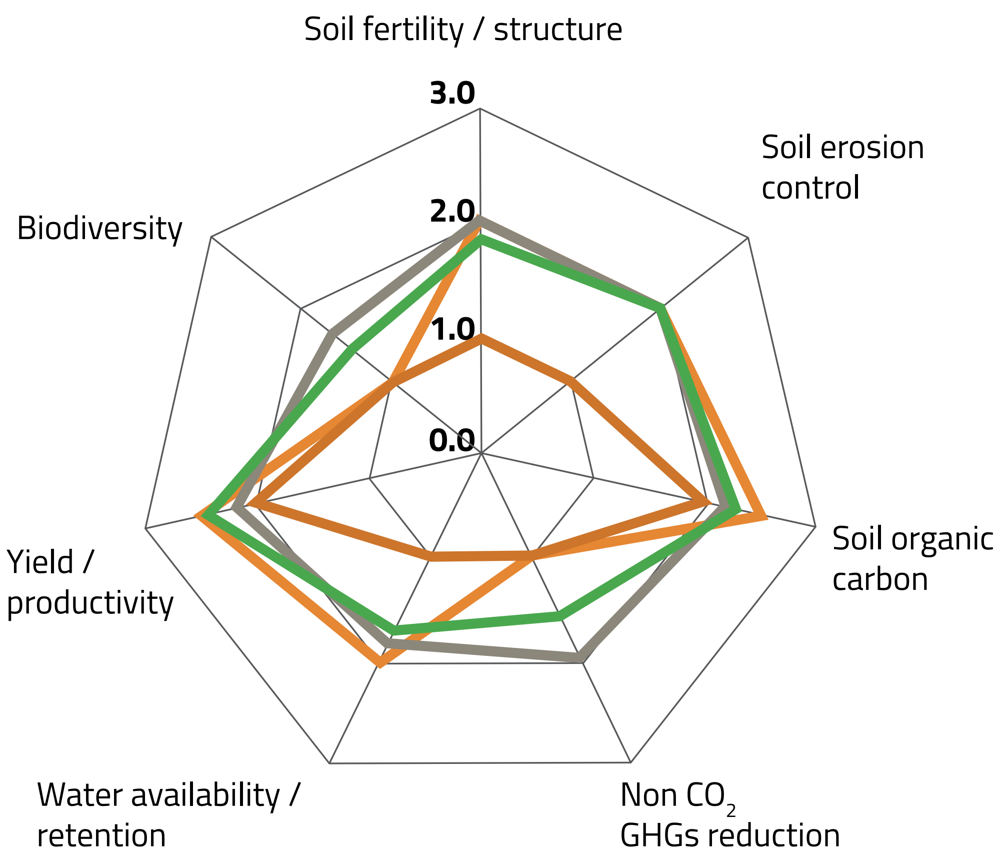


FIGURE 6:

Qualitative assessment of SLM groups of technologies in grazing lands. A scale for positive impact from one to three (1: low or none; 2: moderate; 3: high) is used to qualify each of the SLM practices considered (Chapter 2.2 of this report) for each of the aspects selected above.

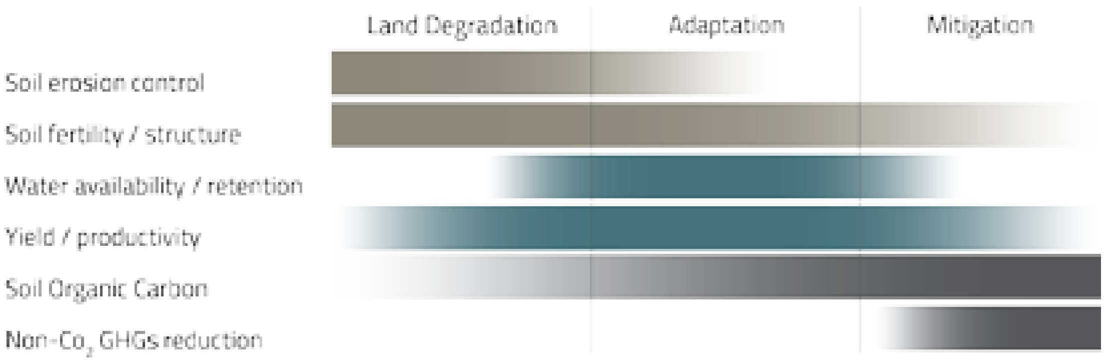
Animal waste management may result in zero or negative impact on non-CO_2 GHGs emissions reductions, but could indirectly result in benefits when the manure is later used for fertilizing. Yet, quantifying the impacts of SLM practices on rangelands is challenging insofar as contrasting results in various ecosystem services is concerned (Marques et al., 2016).

Individual practices

Seeding and rehabilitation with shrubs, followed by nutrients management, seem to be the most beneficial technologies for land degradation prevention and reversion, as well as for climate change mitigation by increasing carbon storage (see Table 9). These practices also generally imply positive impacts on biodiversity, although they might imply extra cost. However, some trade-offs are being observed, such as the introduction of non-native invasive grass species in pasture lands, which might result in legacies that affect soil-microbial associations of native gasses and inhibit their growth in invaded communities (Jordan et al., 2012), and can also cause environmentally-invasive weeds beyond pasture lands (Driscoll et al., 2014). Prevailing or historical land use often needs to be considered; for example, the introduction of new grazing practices may displace traditional existing practices (balance between grazers versus browsers in southern African prairies).

TABLE 9:

SLM practices in grazing lands considered clustered in four groups of technologies reflected in Chapter 2.2. Addressing land degradation (LD), climate change adaptation and mitigation, co-benefits (biodiversity), and cost (investments): Low (1), moderate (2), high (3).



GRASSLAND	Soil fertility/ structure	Soil erosion control	Soil Organic Carbon	Non CO_2 GHGs reduction	Water availability/ retention	Yield/ Productivity	Biodiversity
Animal waste management	**1,0**	**1,0**	**2,0**	**1,0**	**1,0**	**2,0**	**1,0**
Improved cattleshed for urine collection	1	1	2	1	1	2	1
Grazing pressure management	**2,0**	**2,0**	**2,2**	**2,0**	**1,8**	**2,2**	**1,7**
Area closure to grazing	2	2	3	2	2	2	3
Communal grazing management	2	2	2	2	3	2	1
Ecograze	2	2	2	2	1	3	2
Rangeland resting	2	2	2	2	1	2	1
Rotational grazing	2	2	2	2	1	2	2
Stocking density	2	2	2	2	3	2	1
Integrated soil fertility management	**2,0**	**2,0**	**2,5**	**1,0**	**2,0**	**2,5**	**1,0**
Manure separation to better distribute organic matter	2	2	2	1	3	2	1
Nutrient management	2	2	3	1	1	3	1
Vegetation management	**1,9**	**2,0**	**2,3**	**1,6**	**1,7**	**2,4**	**1,4**
Creation of a perennial grass seed area (CACILM)	3	3	3	2	2	3	2
Cut-and-carry fodder production	2	2	2	1	1	2	1
Grazing land rehabilitation with shrubs plantation	2	3	3	2	2	3	2
Improved fodder production on degraded pastureland	2	2	2	2	2	3	1
Improved use of fire for sustainable grassland management.	1	1	2	1	2	2	1
Off-season irrigation of fields and pastures as a mechanism for pasture improvement	1	1	2	1	1	2	1
Range pitting and reseeding	2	2	2	2	2	2	2

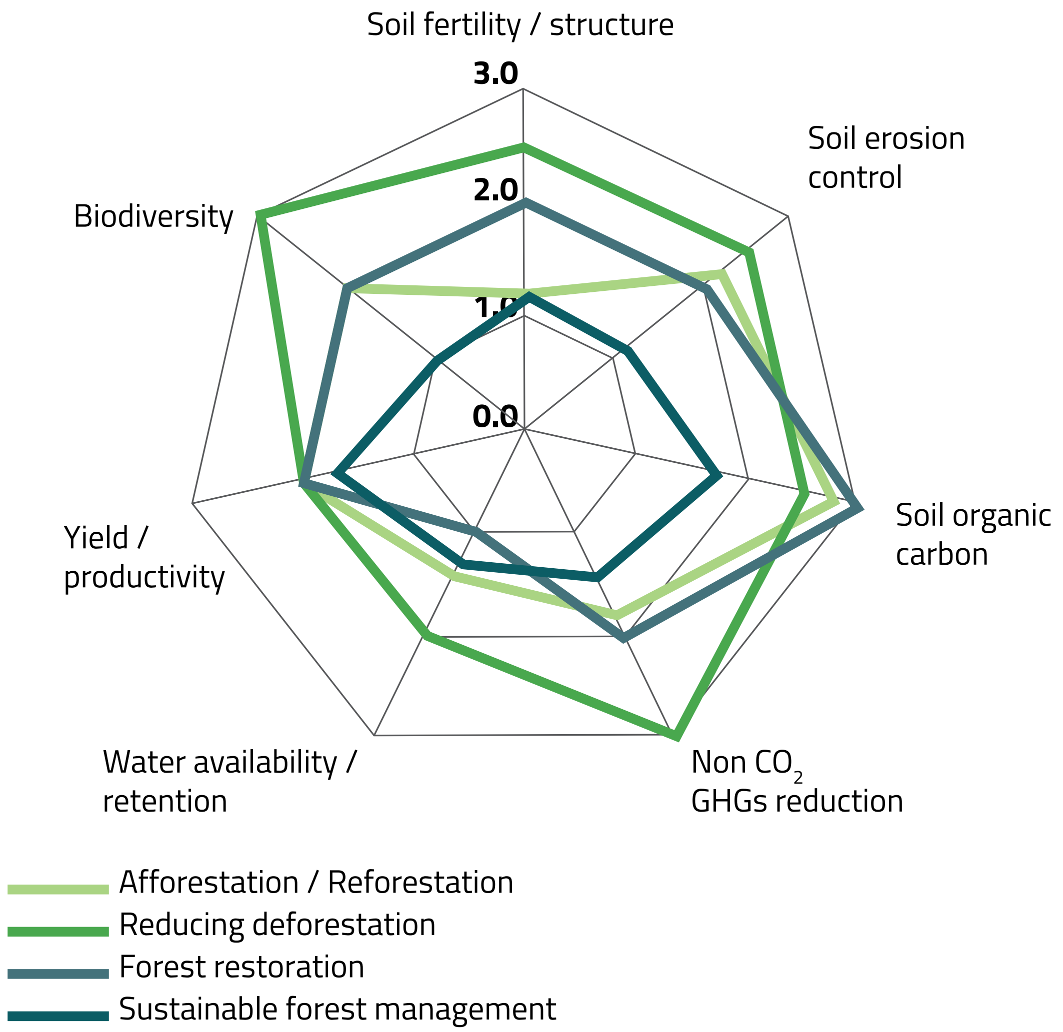
Rotational grazing, eco-graze, lowering stocking density, rangeland resting and communal grazing that combine these practices have a moderate impact on degradation and on contribution to climate change adaptation and mitigation. This is in line with the findings of Papanastasis et al., (2015) in Mediterranean rangelands, which show that effective rehabilitation can be achieved if grazing management is adjusted from heavy to moderate grazing, without depriving these areas from livestock use which may otherwise have led to social unrest.

The use of grazing-free periods is a traditional practise that used to be respected by cattle holders, but is no longer common. In addition, according to reports, grazing-free periods also led to an increase in fodder production, and provided other ecological benefits, particularly related to soil organic matter, increases in biodiversity, and reduced erosion (Marques et al., 2016). In West Africa, grazing management (including rotational grazing, adjusting socking densities and controlled grazing) had positive impacts on mitigation and adaptation to climate change, as well as on food security (Amole & Ayantunde, 2016). In this case, forage conservation (cut and carry fodder production) resulted in moderate to high impacts on food security and climate change adaptation, and moderate impact on mitigation. While nutrient management implies an increase in productivity and soil quality, in particular when organic fertilizers and manure are used, it may result in a trade-off in non-CO_2 GHG emissions (while off-site emission reductions will need to be carefully considered).

3.2.3 Forest / woodlands

Group of technologies (Figure 7)

Among the seven groups of technologies considered, the groups related to protecting forests, such as reducing or avoiding emissions from deforestation, lead to high or moderate impacts on all three aspects considered, in particular, in relation to climate change mitigation, and have strong co-benefits in conserving biodiversity. This is followed by forest restoration and afforestation/ reforestation. While sustainable forest management practices, including fire and pest control, lead to moderate impacts in most aspects, due to higher emissions of CO_2 and non-CO_2 GHGs, fire control has a high impact on climate change mitigation. In some cases, pest control could be very relevant to prevent carbon losses (see Chapter 2). The groups of practices related to soil erosion control have a higher impact on preventing or reversing land degradation and climate change adaptation when compared with climate change mitigation.


Soil fertility / structure
3.0
2.0
0.0
Soil erosion control
Soil organic carbon
Non CO_2 GHGs reduction
Water availability / retention
Yield / productivity
Biodiversity
Afforestation / Reforestation
Reducing deforestation
Forest restoration
Sustainable forest management

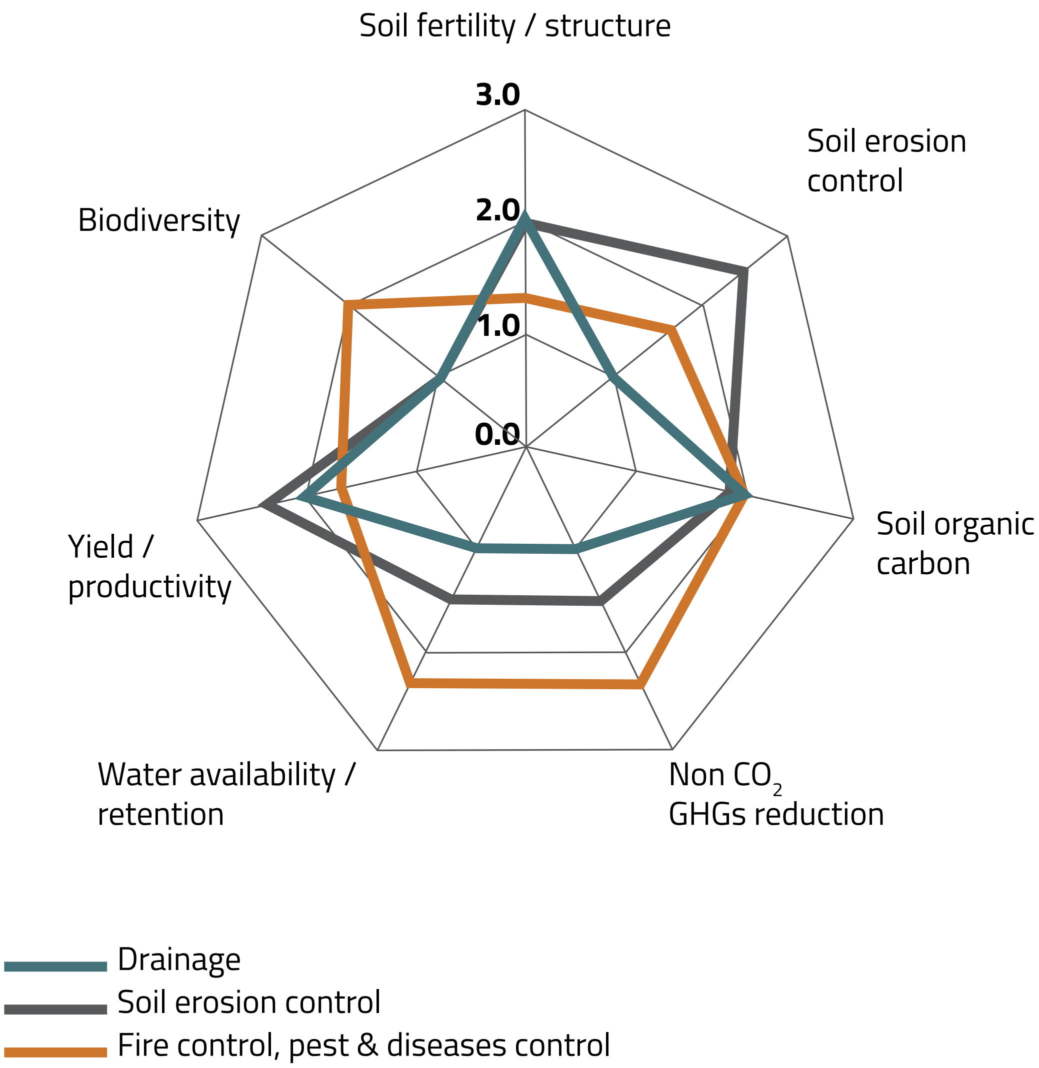


FIGURE 7:

Qualitative assessment of SLM groups of technologies in forest/woodlands. A scale for positive impact from one to three (1: low or none; 2: moderate; 3: high) is used to qualify each of the SLM practices considered (Chapter 2.2 of this report) for each of the selected aspects above.

Individual practices

Interventions to reduce deforestation and forest degradation have the largest and most immediate carbon stock impact in the short term per ha and per year globally (Smith et al., 2008). This is due to the fact that large carbon stocks (about 350–900 tCO_2/ha) are not emitted when deforestation is prevented. SLM practices aiming to reduce deforestation can have the greatest potential for land-based climate change mitigation. Furthermore, practices can also protect soils and biodiversity, and provide food security and resilience to forest-dependent communities. The most effective option is the protection of natural forests (preventive measures), in particular in the tropics, as these may have a high impact on land degradation prevention and land-based climate change mitigation and adaptation, as well as on biodiversity conservation. The costs of reduced deforestation depend on the cause(s) of deforestation (timber or fuelwood extraction, conversion to agriculture, settlement, or infrastructure), the associated returns from non-forest land-use, the returns from potential alternative forest uses, and any compensation paid to the individual, institutional landowner or community to change land-use practices (Smith et al., 2014). These causes, however, vary among countries and regions (Sathaye et al., 2007; Wolosin et al., 2016). In some cases, providing alternative options for small farmers to reduce slash and burn agriculture is a promising practise to reduce deforestation, although it may reduce their access to food from subsidence agricultural practices. Forest restoration practices, such as assisted natural regeneration, provide an opportunity for reversing land degradation and recovering biodiversity, forest functions and services, particularly if implemented at landscape scale (forest landscape restoration) (Uriarte & Chazon, 2016). Restoration methods based on, or which consider, natural regeneration also provide low-cost opportunities for conserving biodiversity (Latawiec et al., 2016), sequestering carbon (Mukul et al., 2016), and protecting soils and watersheds (Locatelli et al., 2015). Such measures could be very relevant in the case of dry forests.

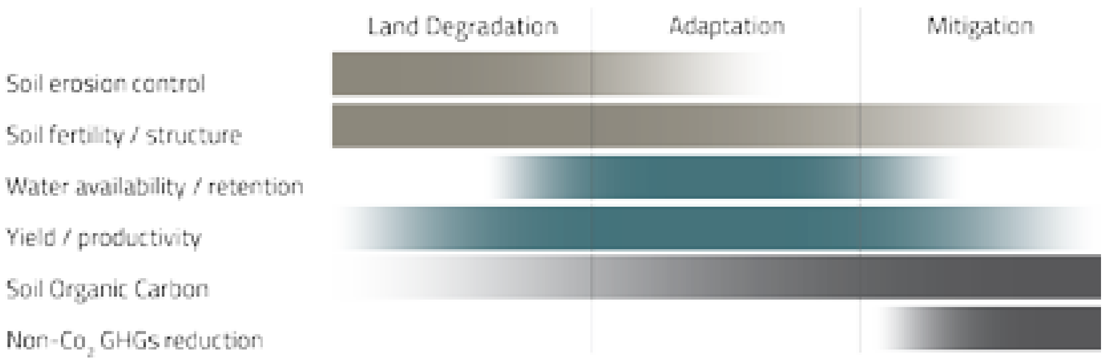
In general, afforestation and reforestation has the potential to increase carbon storage and provide goods in all cases. However, depending on the planting and soil preparation, it might result in soil degradation and poor biodiversity; for example, biomass clearing and site preparation prior to afforestation may lead to short-term carbon losses on that site. Afforestation might be foreseen in degraded agricultural lands, which limit the introduction of certain species and could result in low-success practices. However, in some cases, such as afforestation with a species mix at different scales, reforestation that considers the reintroduction of native forest species and the reintroduction of forest cover after wildfires, can lead to better soil quality and erosion control, as well as improved water retention capacities (Maestre et al., 2004; Martinez-Palacios et al., 2015). In highly degraded dry forests, active restoration approaches, such as multi-species planting and nurse tree methods (Medawatte et al., 2004) may be more appropriate than reforestation interventions based on conventional mono specific plantations. The same applies to afforestation measures (Marques et al., 2016). However, such active restoration approaches are costly and require sufficient ecological knowledge for their effective implementation (Lamb et al., 2005), preventing those practices from being adopted, and leading to a continuation of land degradation (Vilagrosa et al., 2009).

Forest management activities that increase stand-level forest carbon stocks may include harvest systems that maintain partial forest cover (such as selective logging, thinning, etc.), thereby minimising losses of dead organic matter or soil carbon by reducing soil erosion, and by avoiding slash burning and other high-emission activities (Nabuurs et al., 2008). Adjusting rotation periods and planting after harvest or natural disturbances accelerate tree growth and reduce carbon losses relative to natural regeneration. Often, these practices include an increased use of fertilizers that cause higher N_2O emissions. Adopting integrative adaptive forest management (Bolte el al., 2009) could make forests more resilient to climate change, and indirectly, to a greater extent than if it were not adopted, mitigation in the long term (see Table 12).

Fire and pest control can also provide high mitigation benefits, especially in areas where fires are a frequent part of forest dynamics. Drainage of forest soils, and specifically of peatlands, may lead to substantial carbon loss due to enhanced respiration, but moderate drainage, for example by using bio drainage, can lead to increased peat carbon accumulation (Minkkinen et al., 2002).

TABLE 10:

SLM practices in forests/woodlands considered clustered in seven groups of technologies reflected in Chapter 2.2. Addressing land degradation (LD), climate change adaptation and mitigation, co-benefits (biodiversity), and cost (investments): Low (1), moderate (2), high (3)



FOREST / WOODLAND	Soil fertility/ structure	Soil erosion control	Soil Organic Carbon	Non CO_2 GHGs reduction	Water availability/ retention	Yield/ Productivity	Biodiversity
Afforestation/Reforestation	**1,2**	**2,2**	**2,8**	**1,8**	**1,4**	**2**	**2**
Afforestation with species mix at different scales	1	2	3	2	2	2	2
Forest establishment in semi-arid land	2	3	2	1	1	2	1
Land reclamation by introdcing forest native species	1	2	3	2	1	2	3
Reforestation in former forest lands	1	2	3	2	2	2	2
Reintroduction of forest cover after wildfires	1	2	3	2	1	2	2
Drainage	**2,0**	**1,0**	**2,0**	**1,0**	**1,0**	**2,0**	**1,0**
Trees for bio-drainage	2	1	2	1	1	2	1
Fire control, pest and diseases control	**1,3**	**1,7**	**2,0**	**2,3**	**2,3**	**1,7**	**2,0**
Control of wildfires in peatlands	2	2	2	3	1	1	2
Controlling anthropogenic disturbances such as fire and pest outbreaks	1	1	2	1	3	2	2
Management for forest fire prevention	1	2	2	3	3	2	2
Forest restoration	**2,0**	**2,0**	**3,0**	**2,0**	**1,0**	**2,0**	**2,0**
Assisted regeneration	2	2	3	2	1	2	2
Reducing deforestation	**2,5**	**2,5**	**2,5**	**3,0**	**2,0**	**2,0**	**3,0**
Establisment of protected forest areas	3	3	3	3	2	2	3
Reducing slash and burn agriculture	2	2	2	3	2	2	3
Soil erosion control	**2,0**	**2,5**	**1,8**	**1,5**	**1,5**	**2,3**	**1,0**
Afforestation and Hillside Terracing	2	3	2	2	1	2	1
Hydromulching	2	2	1	1	2	2	1
Landslide prevention using drainage trenches lined with fast growing trees	2	3	2	2	2	2	1
Mulching after forest fires	2	2	2	1	1	2	1
Trees for watershed management	2	2	2	1	1	3	1
Trees on mountain slopes together with moisture accumulating trenches	2	3	2	2	2	3	1
Sustainable forest management	**1,1**	**1,1**	**1,7**	**1,4**	**1,3**	**1,7**	**1,0**
Adjust forest plantations rotation periods	2	2	3	1	2	2	1
Forest irrigation and fertilisation	1	1	3	1	1	3	1
Fuelwood production	1	1	1	2	1	1	1
Reducing logging waste	1	1	2	2	1	1	1
Selective logging	1	1	1	1	2	1	1
Short rotation biomass production from forest:	1	1	1	1	1	2	1
Woodlots for biomass production	1	1	1	2	1	2	1

3.2.4 Mixed

Group of technologies (Figure 8)

Agroforestry systems embrace a wide range of practices that can improve land productivity providing a favourable micro-climate, permanent vegetative cover, improved soil structure and organic carbon content, increased infiltration and enhanced fertility (Branca et al., 2011).

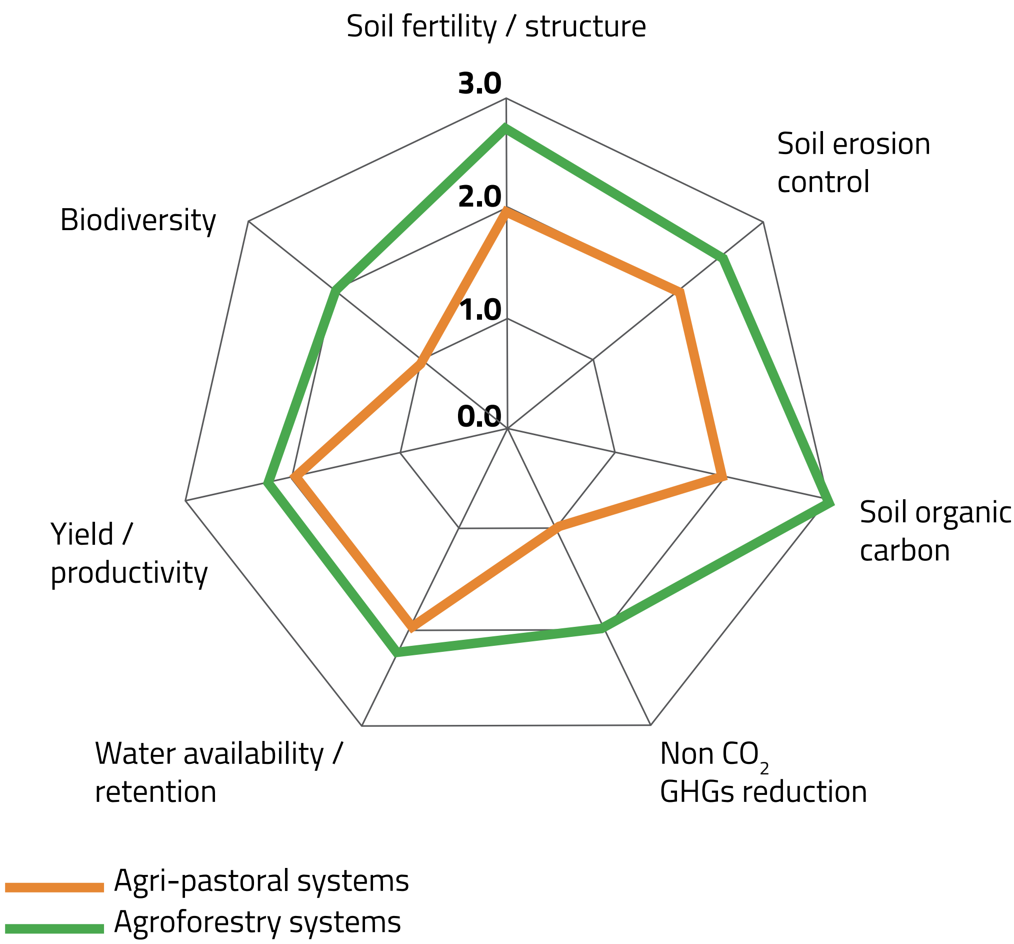


FIGURE 8:

Qualitative assessment of SLM groups of technologies in mixed systems. A scale for positive impact from one to three (1: low or none; 2: moderate; 3: high) is used to qualify each of the SLM practices considered (Chapter 2.2 of this report) for each of the selected aspects above.

Agri-pastoral systems result in moderate impact. They can indirectly enhance resilience and land-based climate change mitigation by reducing grazing pressures elsewhere.

Individual practices

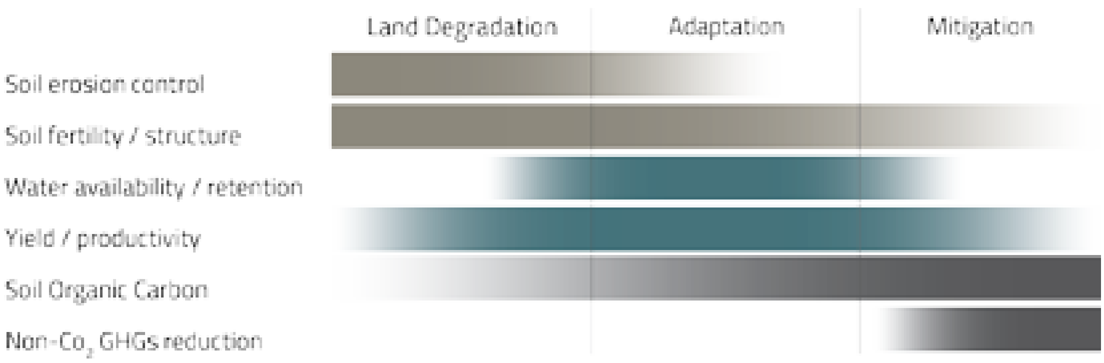
This might be rephrased as: "Agroforestry practices that highly affect soil quality and control soil erosion, such as planting crop combinations under multipurpose tree[19] systems, and that can support carbon sequestration and provide food and income to communities, thus making them more resilient to climate change. In general, all agroforestry practices considered can have relatively significant positive impacts on all aspects considered in Table 10.

Incorporating sheep into dryland grain production systems, such as sheep-cereal farming, is an original Mediterranean system which probably appeared in the Middle Ages, during a critical economic situation as a diversification response to reduce risk and optimise food and feed production (Correal et al., 2006). The system provides better outcomes on marginal drylands, where cereal yields are low and animal production is economically more interesting. The practice of sheep-cereal organic farming in marginal areas could both support the preservation of local cereal races and local sheep and goat breeds, which are better adapted and more productive under difficult conditions than selected races and breeds, and can also be justified by the originality and quality of their final products.

19 Trees that are deliberately grown and managed for more than one output. They may supply food in the form of fruit, nuts, or leaves; while at the same time supplying firewood, add nitrogen to the soil, or supply some other combination of multiple outputs.

TABLE 11:

SLM practices in mixed systems are clustered in two groups of technologies reflected in Chapter 2.2. Addressing land degradation (LD), climate change adaptation and mitigation, co-benefits (biodiversity), and cost (investments): Low (1), moderate (2), high (3).



MIXED	Soil fertility/ structure	Soil erosion control	Soil Organic Carbon	Non CO_2 GHGs reduction	Water availability/ retention	Yield/ Productivity	Biodiversity
Agri-pastoral systems	**2,0**	**2,0**	**2,0**	**1,0**	**2,0**	**2,0**	**1,0**
Incorporating sheep into dryland grain production systems	2	2	2	1	2	2	1
Agroforestry systems	**2,8**	**2,5**	**3,0**	**2,0**	**2,3**	**2,3**	**2,0**
Animal Draft Zero-Tillage	3	2	3	2	1	2	2
Home gardens	3	3	3	2	2	2	2
Orchard with integrated grazing and fodder production (Silvo-pastoralism)	2	2	3	2	3	2	2
Plantation crop combinations, multipurpose trees on crop lands	3	3	3	2	3	3	2

3.3 Technically-promising technologies

In croplands, SLM technologies aimed at increasing and stabilising crop productivity, in particular in developing countries, including i) agronomy (multi-cropping and inter-cropping, green cover in perennial woody crops), ii) integrated soil fertility management (production and application of bio-humus), and iii) agroforestry (in particular, multiple cropping, intercropping and green covers in perennial woody crops) can generally prove to be optimal solutions to simultaneously address land degradation and climate change adaptation and mitigation. These technologies tend to show significant adaptation potential (i.e., by maintaining or enhancing food security) in humid and in semiarid areas, but may show smaller mitigation co-benefits in drylands where addressing land degradation and adapting to climate change has higher relevance as a goal than mitigating climate change.

In grazing lands, SLM practices that increase productivity (such as perennial seed grass areas or rehabilitation of grasslands in particular, including woody vegetation) can be seen as promising solutions. In particular, they show significant potential for land-based climate change mitigation and in addressing land degradation, but also in adapting to climate change (i.e., by increasing yields). Their implementation, however, may also imply extra costs and technical knowledge, which could slow down, or even entirely prevent, their implementation in areas dependent on lower-cost practices for managing carrying capacity (for example, area closure for grazing or rotational grazing).

In forest/woodlands, SLM practices aiming to reduce deforestation of primary forest, in particular in the tropics, show significant mitigation potential, all while preventing land degradation, ensuring biodiversity co-benefits and enhancing resilience of forest-dependent communities. Finally, diverse mixed systems, such as agroforestry, including crop combinations with multipurpose trees, also emerge as an optimal solution to simultaneously address land degradation and climate change adaptation and mitigation at a relatively low cost.

In the case of croplands, second-best technology options that in general imply low investment include integrated soil fertility management by: i) applying organic fertilizer (most economically viable if the farmer has free access to organic fertilizers), ii) changing fertilizer applications (types, rates and timing) and micro-fertilization, iii) vegetation management technologies (such as choice of crop species, permanent soil cover and perennial crops), iv) mulching technologies as minimum disturbance technologies, v) trees as buffers to support pest control, and vi) soil erosion control technologies (e.g., vegetated earth-banked terraces or vegetative strips). Recent literature and studies show that some technologies, such biochar amendment may have wide geographical applicability (Paustian et al., 2016), and are becoming promising for climate change mitigation in multiple regions. In woodlands and forests, second-best options that emerged were management practices to prevent forest fire, although they might have a high cost, soil erosion control by introducing trees with moisture retention trenches that have - if established with local man power – a relatively low cost. For grazing lands, second-best options seem to rely on nutrient management at relatively low cost. In the case of mix systems, home gardens and orchard grazing are combined with fodder production, also at a low cost.

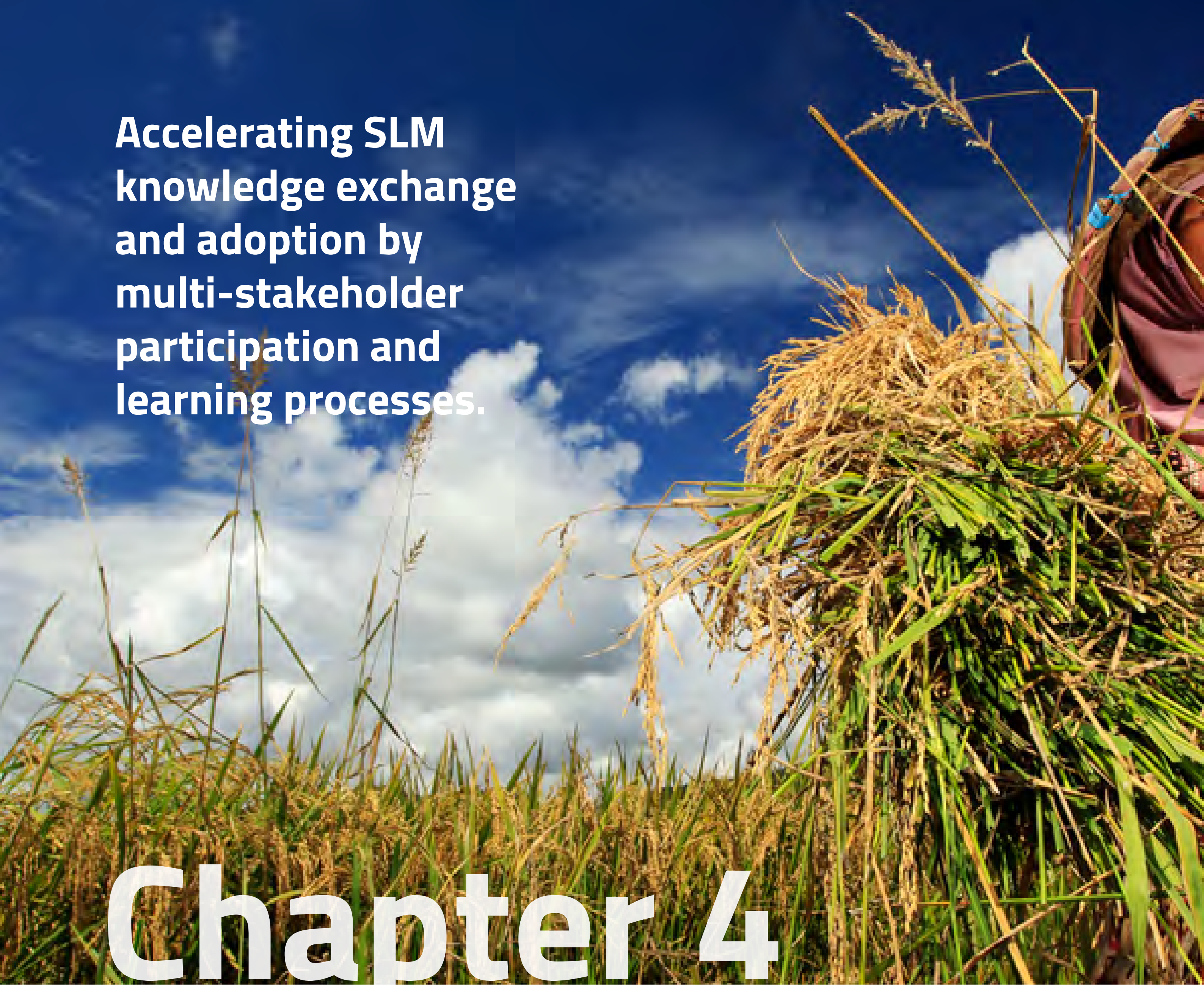
Economic considerations

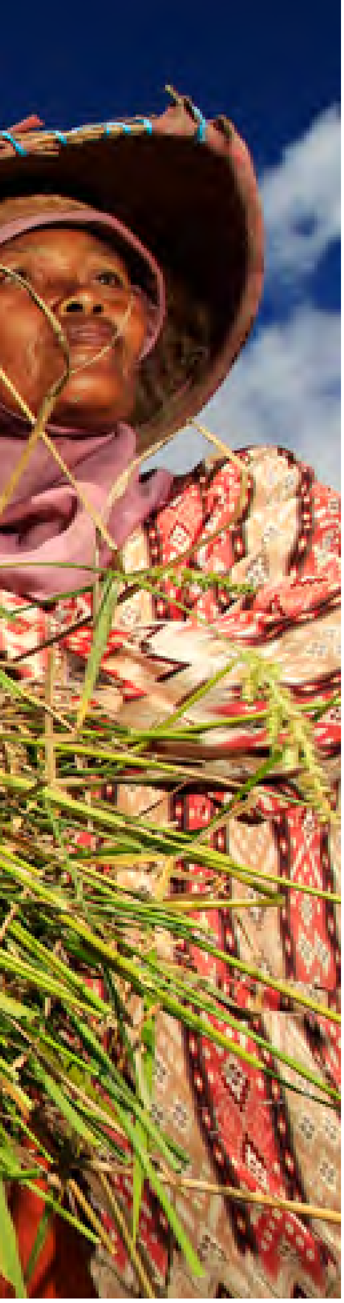
Economic reasons are key determinants in land users' decisions to adopt SLM technologies. Giger et al., (2015) evaluated the cost of 258 technologies for which these data were available in the WOCAT database and found a median cost of USD500/ha. Many of the practices imply low to moderate costs, but the amount varies considerably (less than $20 to over $5000/ha) due to the great diversity of measures and of contexts in which they are implemented. The highest median establishment costs, as well as median maintenance costs, were reported for technologies involving combined vegetative/management measures that included high-cost afforestation projects. It was also found that, in order to make investments, land users need stable economic conditions and secure tenure rights, as adoption of measures is generally a gradual process that lasts for many years. They also found that land users' most frequently mentioned motivations for adopting a given SLM technology are: i) production (24%), ii) increased profitability (20%) and iii) well-being and livelihood improvement (20%). Marques et al., (2016) observed that the most frequent weaknesses observed for SLM adoption are usually stakeholders' lack of awareness and the strong dependence on external subsidies and technical support. Therefore, it seems that economic considerations are a primary motivation for SLM implementation on the part of land users.

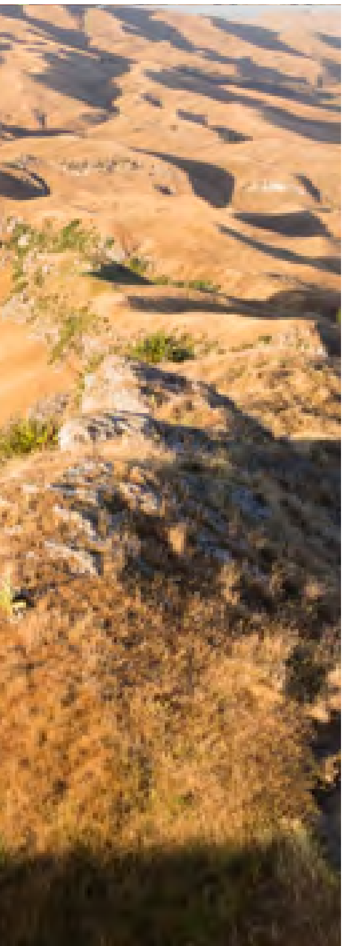
A selected set of variables to qualitatively compare the impacts of groups and/or individual SLM practices.

Accelerating SLM knowledge exchange and adoption by multi-stakeholder participation and learning processes.

Chapter 4







Creating enabling environments for the implementation of SLM practices

4.1 Opportunities and enabling conditions for upscaling SLM 106
4.2 Visualising main steps towards SLM adoption 110

The land-based SLM technologies considered in Chapter 2 are qualitatively assessed in relation to their potential biophysical and technical contribution to addressing land degradation and climate change adaptation and mitigation, including some considerations on biodiversity impacts and cost in Chapter 3. This Chapter, recognising that the adoption of SLM practices is still slow, explores general aspects related to barriers and the creation of enabling environments for SLM implementation. In addition, some general guidelines are proposed to inform the selection, promotion and enabling conditions for the implementation of SLM.

Although principles and practices of SLM are well-known, and SLM has been widely promoted through many land-use projects in different countries, land degradation is still increasing and becoming a major global threat. SLM is increasingly promoted at the policy and development cooperation level (World Bank, 2008). Its actual use, however, remains limited to a minority of innovative land users and those practising sustainable traditional systems (Critchley, 2007; Liniger et al., 2007), evidencing that there is still a wide gap between acknowledgement of the need for SLM and implementation of successful SLM practices.

This gap can be addressed when moving towards reaching adoption/implementation of SLM, by considering and promoting enabling conditions[20]; for example, through engagement of all relevant sectors of government and other stakeholder groups during the evaluation, selection, and implementation phases, thereby paying particular attention to marginalised and vulnerable populations, and also ensuring a gender-balanced approach (see below "multi-stakeholder participation and learning process" at the opportunities and enabling conditions sub-chapter). Noting that SLM targets and indicators are mostly site-, region or country-specific,

IT WILL NOT BE POSSIBLE TO EXPORT SLM SOLUTIONS FROM ONE SITE TO ANOTHER WITHOUT ANALYSING THE TECHNICAL AND SITE-SPECIFIC ENVIRONMENTAL, SOCIAL AND INSTITUTIONAL ASPECTS AND ADAPTING SLM MANAGEMENT TO THESE GIVEN REALITIES.

In this regard, developing a framework to assess co-benefits and trade-offs of SLM could allow regulators, policy-makers and land managers to deliver more coherent land-management strategies that could improve the benefits and co-benefits at the specific time and space scales considered. Recent attempts to provide such types of frameworks include general methodological frameworks for monitoring and assessment of SLM across scales (Reed et al., 2011; Schwilch et al., 2012b) and specific frameworks for drylands (Bestelmeyer et al., 2015). At the global level, the recently proposed LDN conceptual framework (Orr et. al., 2017) encourages the integration of LDN interventions into existing national land-use planning (see Box 10.)

20 Enabling environments in this context include institutional, policy and legal frameworks; awareness and capacity building; cross-sectorial collaboration; financial and material support; appropriated stakeholder participation.

BOX 10:

LDN conceptual framework

The recently proposed LDN conceptual framework (Orr et. al., 2017) encourages the integration of LDN interventions into existing national land-use planning. Furthermore, the conceptual framework proposes a response hierarchy to avoid > reduce > reverse land degradation to articulate the priorities in planning interventions at the landscape scale, thereby considering all land units of each land type and their interactions and ecological trajectories, so that LDN interventions can be optimised in order to maintain, or exceed, no net loss per land type.

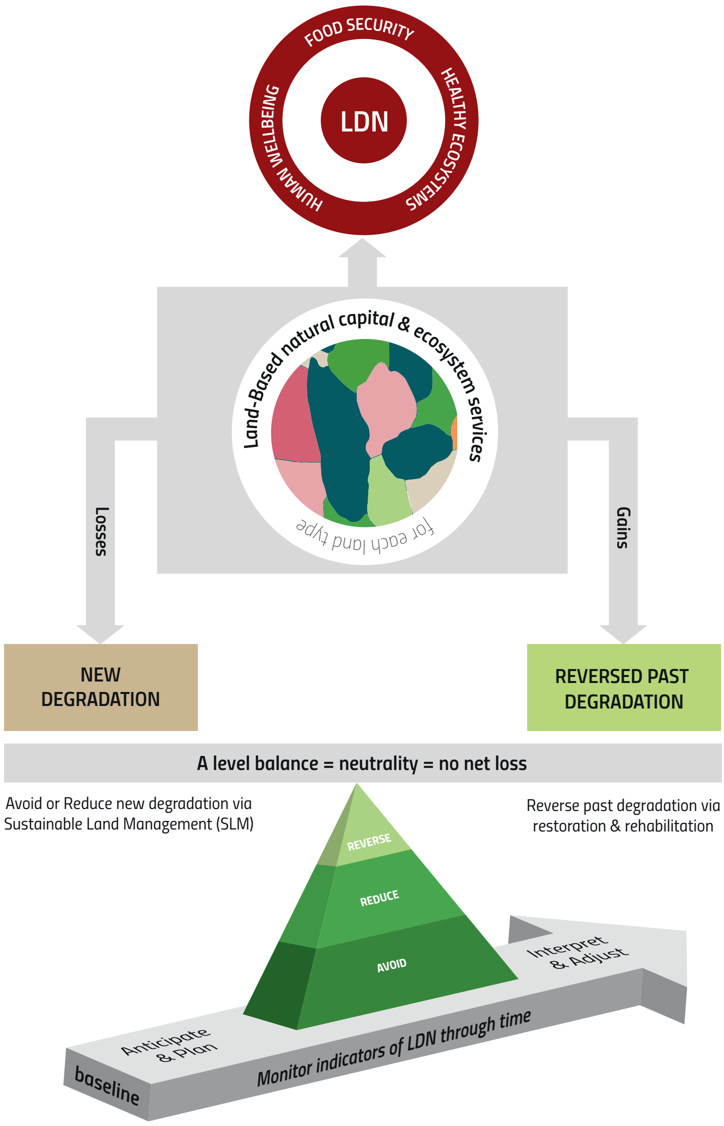


FIGURE 9:

Land Degradation Neutrality conceptual framework. (Orr et al., 2017).

Scaling up and integrating SLM technologies and practices, in the context of providing multiple ecosystem services, should become an opportunity to achieve the LDN target by addressing DLDD, all while promoting climate change adaptation and mitigation.

Barriers for implementation

Even though techniques for SLM are known, mainstreaming technically-identified best SLM practices frequently faces several barriers or bottlenecks (constraints) (Smith et al., 2008; Akhtar-Schuster et al., 2011; Reed & Stringer, 2015; Hussey et al., 2017). It can be hypothesised that the barriers for the implementation of SLM are related to technological, ecological, institutional, economic and socio-cultural aspects. Some authors also recognise that, despite significant progress in the scientific understanding and prevention of land degradation in recent years (see Chapter 2 and 3), advances in understanding the socio-cultural, institutional, sectorial, financial, legal and knowledge barriers to combating land degradation and achieving SLM, need to be further explored and understood (Akhtar-Schuster et al., 2010).

Technical barriers: SLM practices that are technically effective or possible in one specific location are not necessarily also the best option in other locations, because of different biophysical constrains or the lack of specific machinery required. For example, the inherent vulnerability of soils to degradation under various land-use options sometimes limits the level of application and success of "a priori" SLM technologies. It is therefore important to have area- and case-specific technological packages, accompanied by the necessary capacity-building measures and resources for appropriate implementation.

Ecological barriers: Availability of land and water for different uses need to be balanced, considering short- and long-term needs and planning priorities (time scales), and global differences in resource uses. Consequently, limited resources can become an ecological barrier, and the decision on how to use them needs to balance ecological integrity and societal needs (Jackson, 2009). Local environmental characteristics (climate, topography, soil quality) often determine success or failure of SLM practices. From this consideration, the potential to mitigate climate change held by some land-based options can be highly determined by specific ecological conditions, even within the same region or cropping system (Baker et al., 2007; Chatterjee & Lal, 2009).

IN THIS REGARD, INITIAL CHARACTERISATION OF BASELINE CONDITIONS WILL HELP TO SELECT THE MOST SUITABLE LAND USE AND/OR MANAGEMENT OPTION, DEPENDING ON LOCAL CONDITIONS AND CONSIDERING BOTH ON-SITE AND OFF-SITE BENEFITS.

Often, there are knowledge gaps about the ecological implications of different spatial configurations and time scales for application of potentially suitable SLM options available.

Institutional barriers: Institutional and governance issues are often major barriers that hinder the adoption of SLM practices. For example, governance structures that aggravate or inhibit decision-making at different scales do not encourage cross-sectorial planning and cause instability over time. The inability to accommodate traditional governance mechanisms and access rights recognised by indigenous people and local communities, including collective rights, can further prevent successful cross-sectorial planning (Runsten & Tapio-Biström, 2011; Shames et al., 2011; Scherr et al., 2012). Therefore, the progressive promotion of transparent and accountable governance and swift institutional establishment are very important for the implementation of SLM practices. Competent institutions, endowed with flexibility and dedicated to land planning and follow-up of the implemented SLM practices would ensure the suitability, feasibility and effectiveness of the intervention in the long term. This includes the need to promote clear land tenure and land-use rights regulations at a certain level of enforcement. Often, the lack of institutional capacity (as a means for securing creation of equal institutions among social groups and individuals) can also reduce the feasibility of certain SLM practices in the near future, especially in areas where small-scale farmers or forest users are the main stakeholders.

THERE IS A NEED TO RAISE THE NATIONAL PRIORITY ON THE EFFECTIVE IMPLEMENTATION OF LAND LAWS AND, ESPECIALLY, TO PROMOTE LAND TENURE SYSTEMS THAT WILL ENCOURAGE INVESTMENT IN SLM RELATED ACTIVITIES.

A first step towards improving land tenure regulations could be the progressive adoption of the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries, Forests (FAO, 2012).

Socio-economic and cultural barriers: SLM based on scientific knowledge alone may not be suitable for the socio-cultural context that they are needed in, and that may significantly limit their acceptability and effectiveness. Financial and economic aspects are often put forward as primary obstacles (ELD, 2015), although they can also create opportunities (see Box 11). Financial concerns include lack of access to loans and credit, high transaction costs or reduced income. Poverty is characterised not only by low income, but also by limited access to decision-making levels, social organisations, low levels of education and reduced access to resources (e.g., land or technology) and markets (Ferweda, 2015).

THE STAKEHOLDERS' PERCEPTION OF THE PROBLEMS OF DLDD AND CLIMATE CHANGE, AS WELL THE PERCEPTION OF THE IMPACTS OF SLM ALSO STRONGLY DETERMINE THEIR SOCIAL ACCEPTANCE.

Low levels of literacy, education, and language skills create barriers to valuing complex environmental goods, as well as creating difficulties for using traditional survey techniques like questionnaires and interviews. Better access to information, increasing awareness and more deliberative and participatory approaches to data collection may help to overcome these issues. Cultural (including spiritual and religious) values and social acceptance can determine the feasibility of the SLM technologies. It is sometimes necessary to adapt SLM practices to legal, political, and economic contexts in order to enable the adoption of the most economically desirable option, as well as to remove existing barriers to adoption. Removing barriers to adoption requires a good understanding of landholders' attitudes, behaviours, and incentives regarding the adoption of SLM (ELD, 2015).

BOX 11:

The Economics of Land Degradation (ELD).

The ELD Initiative has compiled financial and economic findings and recommendations from available literature, recent case studies and key ELD partners to guide the way to achieving the goals of improved food, energy, and water security. First assessments show that:

SLM approaches and techniques can reduce or even halt land degradation, and can enhance the productivity of degraded lands and provide economic benefits and higher return on investments;

Scenarios based on different development pathway options indicate that the adoption of SLM-enabling environments can provide an additional USD 75.6 trillion annually.

Source: ELD, 2015.

4.1 Opportunities and enabling conditions for upscaling SLM

SLM practices and restoration or rehabilitation measures of land have been demonstrated to be effective in many scientific projects and small-scale environmental experiments and pilots. Biophysical information has been obtained in many cases, but social capital to support its implementation is often lacking. Various implementation and research projects (GEF, 2009; Zdruli et al., 2010; Schwilch et al., 2012a) have addressed the challenge of upscaling SLM, providing numerous recommendations and possible approaches. These indicate that,

FOR SUCCESSFUL UPSCALING OF LAND MANAGEMENT, MORE ATTENTION MUST BE PAID TO THE SOCIAL SYSTEM FROM THE FIRST INVOLVEMENT STAGE, UP TO THE LONG-TERM MAINTENANCE.

Expanded training of researchers, SLM specialists, agricultural advisors, governmental staff and others may be required. SLM strategies that are adapted to the local context bear great potential for upscaling and replication.

Approaches for upscaling SLM range from sophisticated decision support systems (Ananda & Herath, 2009; Kellon & Arvai, 2011) to improved enabling environments (i.e., through land policies and subsidies focused on water, environment, and poverty) (Akhtar-Schuster et al., 2011) and promotion of social or sustainability-oriented learning processes (Leeuwis & Pyburn, 2002; Rist et al., 2006; Tàbara & Pahl-Wostl, 2007; Armitage et al., 2008; Reed et al., 2010). While all are useful and cover many key aspects, there is an apparent lack of practical, structured, yet flexible methodologies for fostering SLM in diverse contexts (Schwilch et al., 2012a). Continued monitoring and evaluation through land users and researchers will help to prove the multifaceted benefits of SLM. In this context, moving towards implementation of the LDN target could become a policy instrument to promote the implementation and upscaling of SLM, while balancing land degradation and restoration/rehabilitation/reclamation processes at global, regional, national and local levels (Kust et al., 2016), and will need to be further explored.

Cross-sectorial linkages.

GIVEN THE CONTINUING TRENDS IN INCREASING LAND DEGRADATION (MA, 2005) AND ITS PRONOUNCED LINKS WITH CLIMATE CHANGE, BIODIVERSITY LOSS, POVERTY, HEALTH, FOOD, WATER AND ENERGY INSECURITY, AS WELL AS HUMAN DISPLACEMENT, THERE IS AN URGENCY TO MAINSTREAM LAND ISSUES INTO NATIONAL CROSS-SECTORIAL POLICIES.

Integrating land degradation and SLM issues across sectors, levels and stakeholder groups, making it a consideration in policy in all related areas (e.g., water, energy, poverty), can also open new and previously inaccessible funding sources. Shifts in addressing land-use management are taking place. These consider the landscape (including institutional, policy, financial, knowledge, planning and regulatory aspects) as a whole, along with the traditionally studied biophysical and socio-economic challenges posed by land degradation. An example in the context of developing countries is provided by Akhtar-Schuster et al., (2011), who show that these holistic approaches should also take note of the different temporal (short, medium- and long-term) and spatial (local, national, regional global) scales across which land degradation, SLM and policy operate. Mainstreaming is currently hampered by the insufficient provision of scientifically-validated national monitoring and reporting, the results of which are rarely made available in a politically accessible cross-sectoral format (Akhtar-Schuster et al., 2010). There are increasing examples of generating an enabling environment by creating sustainable business cases based on sustainable development, or rehabilitation or restoration projects across sectors initiated by SMEs (see, for example, initiatives by Common land Foundation[21] or the Forest and Farm Facility[22]) and through training of future business leaders (https://www.rsm.nl/enable/about-us/).

Policy incentives for SLM implementation. Di Gregorio et al., (2017) found that effective Climate Policy Integration in the land-use sector requires i) internal climate policy coherence between mitigation and adaptation objectives and policies; ii) external climate policy coherence between climate change and development objectives; iii) vertical policy integration to mainstream climate change into sectoral policies; iv) horizontal policy integration by overarching governance structures for cross-sectoral coordination. These four characteristics are all necessary to develop enabling policy environments that facilitate climate-resilient land-use pathways that combine the aims of climate change adaptation, mitigation and sustainable development. The best way to achieve win–win situations is through a type of climate policy integration that considers both potential trade-offs and mutual benefits between adaptation and mitigation when mainstreaming climate change into land-use planning and policies (Locatelli et al., 2015). These lessons can inform broader land-use policy design to promote SLM.

Multi-stakeholder participation and learning process. Fostering structured participatory approaches, moving beyond simple promotion of SLM technologies, is necessary to maximise its benefit to human welfare demands (Nkonya et al., 2011). In this regard, transdisciplinary approaches[23] are gaining importance in development (Pohl et al., 2010; Roux et al., 2010) and sustainability (Lang et al., 2012) research.

COLLABORATING WITH LAND USERS AND OTHER STAKEHOLDERS IS CONSIDERED A PRECONDITION FOR SUCCESSFUL SLM.

While the traditional concept of knowledge and technology transfer from researchers to agricultural advisors, and then to land users, is still practised in many areas, the shortcomings of this one-way approach are increasingly recognised (Gabathuler et al., 2011). In this sense, the Department of Environmental Affairs from

21 www.commonland.com

22 http://www.fao.org/partnerships/forest-farm-facility/91934/en/

23 Involving stakeholders in the design and implementation.

the Republic of South Africa has demonstrated the importance of combining several approaches and agents (from institutional arrangement, funding, landowner's engagement and capacity building) in many successful initiatives related to Natural Resources Management (e.g., Working for Land, Working for Forest; Working for Ecosystems[24]; Working for Water, among others).

Integrating diverse stakeholder perspectives, beginning with the design of SLM projects all the way to implementation and monitoring (Gonsalves et al., 2005), thereby ensuring that their knowledge is fully integrated throughout the process (Stringer et al., 2007), will increase the likelihood for their acceptance and implementation of SLM (de Vente et al., 2017). Although still not common practise (Schwilch et al., 2012b), the crucial importance of integrating knowledge from land users, technicians, governmental and non-governmental officials and decision makers at all levels, locally, nationally, regionally and globally, is increasingly acknowledged (Hurni, 2000; Hemmati, 2002; Bouwen & Taillieu, 2004). While stakeholder involvement is clearly important and can lead to greater acceptance and adoption of SLM (de Vente et al., 2016, Figure 4.2.), it does not guarantee successful SLM practices on its own (Scott, 2011). Stakeholders must be included in the negotiation of sustainability goals, the selection of relevant SLM strategies, as well as in the selection of indicators for SLM progress monitoring. In addition, the quality of decisions made through stakeholder participation is strongly dependent on the nature of the decision-making process and the participants involved. In this regard, social learning (see Box 4.3) has gained prominence in projects and studies on sustainable agriculture and natural resource management (Armitage et al., 2008; Schneider et al., 2009).

24 https://www.environment.gov.za/projectsprogrammes

BOX 12:

Social learning: beyond simple stakeholders' participation

Reed et al., (2010) recently defined social learning as: "a change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks". Schneider et al., (2009) suggest that social learning comprises co-production of knowledge by land users, technicians, and researchers through a shared learning space that is essential for jointly moving towards more SLM. Some researchers expand the social learning concept to include people's actions, not just changes in their understanding (Garmendia & Stagl, 2010), what is widely levelled as transdisciplinary approaches. The current literature still lacks discussions on suggested ways for assessing whether, and to what extent, social learning is actually taking place (Schwilch et al., 2012a).

Reed (2008) asserts that relevant participation should be considered as early as possible and throughout the decision-making process, representing relevant stakeholders systematically. In addition, the author stresses the importance of having clear objectives from the start, and should not overlook the benefits of highly skilled facilitation. Instead, the process should be institutionalised, creating organisational cultures that facilitate decision-making. Although this may seem risky, there is growing evidence that, if well-designed, these risks may be well worth taking. Liniger et al., (2011) indicate that this will require an SLM practices selection process in three steps, where: i) stakeholders recognise that SLM solutions are available locally and that outside (technical) solutions are not always necessary; ii) these locally available solutions are carefully assessed; and iii) the interaction and learning process facilitates future collaboration and joint action. Some recommendations for the design of participatory process are provided by de Vente et al., 2016 (Figure 10) based on empirical evidence from 24 participatory processes in drylands. RAPTA guidelines (O´Connell et al., 2016) applied in the context of the Global Environmental Facility (GEF) projects provide seven iterative steps to facilitate the design and implementation of sustainable development projects: scoping, engagement and governance, theory of change, system description, system assessment, options and pathways, and learning.

Recommendations	Expected outcomes
Select your participants carefully	• Information gain and learning • Mutual gains (win-win) and sustainable solutions, goal attainment • Increased trust and acceptance
Make participation attractive and easy	• Increased problem ownership and participation • Increased trust
Foster trust among participants	• Increased trust • Increased acceptance and implementation of solutions
Provide participants with relevant information and actual decision-making power	• Information gain, learning • Mutual gains (win-win), flexible solutions • Goal attainment, increased trust
Use professional independent facilitation and structured methods of information aggregation	• Mutual gains (win-win), flexible, sustainable, and socially equitable solutions and conflict resolution • Increased trust and goal attainment
Promote long-term commitment of all participants	• Increased trust and implementation of solutions
Adapt language, location and process design to the participants	• Increased trust • Increased participation • Learning

FIGURE 10:

Summary of recommendations for the design of participatory processes in environmental management to achieve more beneficial environmental and social outcomes based on assessment of 24 dryland cases (de Vente et al., 2016).

In summary, the crucial aspects for creating the enabling environment(s) necessary for the successful design, adoption and implementation of SLM technologies and practices to support the DLDD and climate change adaptation and mitigation include: institutional, policy, and legal frameworks; awareness, capacity building, training; cross-sectoral collaboration; financial or material support; appropriated stakeholder participation at all levels of the decision-making process.

4.2 Visualising main steps towards SLM adoption

In many cases, the lack of a framework to assess co-benefits and trade-offs for identifying and promoting enabling conditions limits the ability of regulators, policy-makers and land managers to move towards more coherent SLM choices at different scales (in time and space) of implementation. Presenting information that is relevant for the analysis and delineation of possible trade-offs in a comprehensive format is critical for effective communication of results. Well-designed visualisations of multiple indicator values can be a powerful and an intuitive means of conveying large amounts of complex data, facilitating a deeper understanding of the interactions among indicators in order to support better decision-making (Marques et al., 2016).

This visualisation begins with assessment of land degradation status, climate vulnerabilities and potential for mitigation (from technical to socio-economic feasibility) of a piece of land. The next step is selection of the best SLM technologies, taking into account the socio-economic viability (of technologies on their own or in combination), and then looking for how to strengthen the enabling conditions for their implementation. The main simplified steps that could be considered in these processes are indicated below in Figure 11.

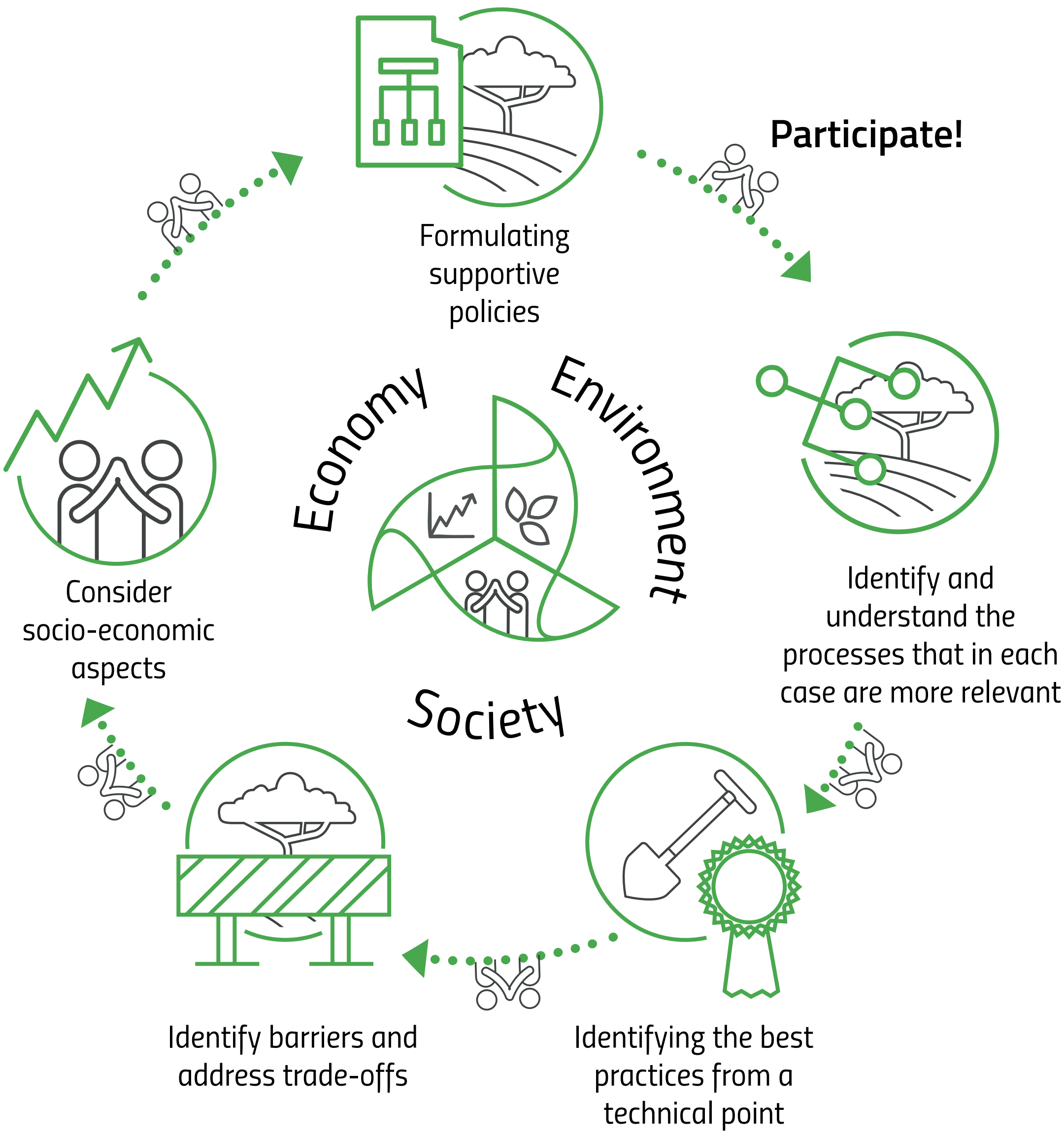


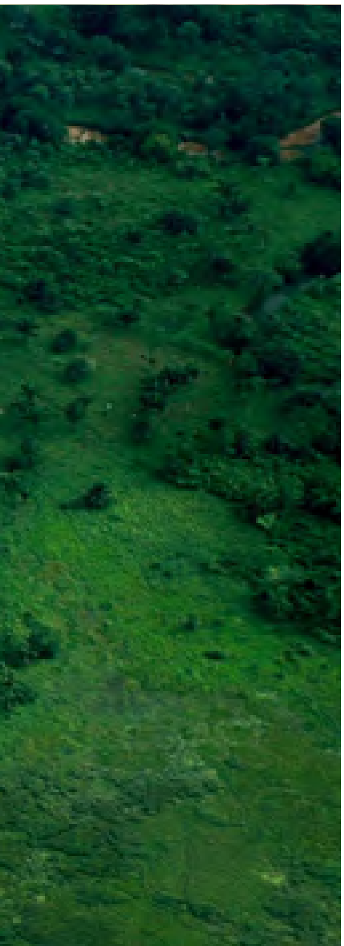
FIGURE 11:

Iterative key steps for the successful design and adoption of SLM.

Accelerating SLM knowledge exchange and adoption by multi-stakeholder participation and learning processes.

Chapter 5

Successfully addressing DLDD, climate change adaptation and mitigation requires sustaining and scaling up the implementation of SLM practices by appropriate policy instruments that enhance land users' livelihoods.



Scaling up Sustainable Land Management

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The objective of this report is to "Highlight the science-based synergistic potential of SLM practices to address DLDD, climate change mitigation and adaptation". Therefore, this report considered the linkages between SLM practices to address DLDD, climate change adaptation and mitigation, as well as the resulting synergies and trade-offs.

SLM technologies are well-known from the scientific and technical perspective, and practical guidance for identification and implementation of SLM is being provided by different organisations and initiatives, in particular at local scales. Several recent publications based on global databases, such as WOCAT and large projects made a standardised attempt to assess specific cases of SLM technologies and practices (Schwilch et al., 2012b; Liniger et al., 2017). Moreover, there are ongoing efforts (such as by the Economics of Land Degradation Initiative) to develop an approach to establishing economic valuation and cost-benefit analyses that can help identify economically desirable SLM options.

There is increasing scientific evidence of the potential advantages of adopting SLM technologies and practices as land-based solutions to simultaneously address land degradation and climate change adaptation and mitigation, while often achieving other co-benefits, such as protection of biodiversity. For example, SLM technologies aiming to address DLDD (prevent, reduce or revert) can often improve resilience, contributing to adaptation to climate change, and increase carbon stocks while reducing GHG emissions, which contributes to climate change mitigation. However, many overviews and assessments of SLM have focused only on specific technologies and single impacts (i.e., yield-improving strategies; soil quality; climate change adaption or mitigation, etc.). In this regard, this report is a first attempt to provide a more comprehensive multi-objective qualitative assessment of SLM technologies, including co-benefits, trade-offs, barriers for implementation, and enabling conditions, which is lacking to date. Although the results from the present report may be limited by the number of SLM practices or combinations of practices selected, it was proved that

SLM TECHNOLOGIES HAVE THE POTENTIAL TO SIMULTANEOUSLY ADDRESS CHALLENGES POSED BY LAND DEGRADATION, DROUGHT AND CLIMATE CHANGE ADAPTATION AND MITIGATION.

The main findings from this report are summarised in the following lines:

SLM technologies aimed at increasing and stabilising crop productivity, in particular in developing countries, including vegetation management practices (multi-cropping and inter-cropping, green cover in perennial woody crops), integrated soil fertility management (such as production and application of biohumus), can be considered technically optimal solutions to simultaneously address DLDD and climate change adaptation and mitigation with generally low investments. Although they tend to show significant adaptation potential (i.e., by maintaining or enhancing food security) in humid and in semiarid areas, it leads to smaller mitigation co-benefits in drylands where land degradation and adaptation to climate change may be of higher priority. Also, integrated soil fertility management by applying organic fertilizer and/or adjusting fertilizer applications, choice of crop species, permanent soil cover in perennial crops, mulching, some pest control practices, soil erosion control technologies (e.g., vegetated earth-banked terraces or vegetative strips) and water management (improving water efficiency and collection) can be considered technically suitable solutions to simultaneously address land degradation and climate change adaptation and mitigation with generally low investments.

SLM practices that increase productivity in grazing lands (such as adjusting grazing intensity, vegetation and animal waste management, prioritising the use of indigenous species, permanent ground cover, agroforestry, fodder crops, water harvesting or integrated nutrient management) also show significant potential for land-based climate change mitigation and for addressing land degradation. However, this may imply extra costs and require that practitioners have increasing technical knowledge. In this case, lower cost practices, such as managing the timing and severity of grazing to ensure that the carrying capacity is not surpassed (for example, area closure for grazing or rotational grazing) or diversifying and selecting the most appropriate species for specific areas considering its resilience to forecasted climate change (adaptive management) could be more suitable.

SLM practices aiming to maintain or increase forest cover through afforestation, reforestation, and sustainable and adaptive management, while reducing deforestation, in particular in tropical forests. These practices have a significant potential for climate change mitigation and biodiversity preservation, while preventing land degradation and increasing the resilience of forest-dependent communities. Enhancing forest carbon stocks and forest cover with the most appropriated mix of species, and prioritising the use of indigenous species, in combination with watershed management and assisted regeneration practices, will enable managed and unmanaged forest ecosystems to adapt to extreme events such as heatwaves, droughts, floods, landslides, and sand and dust storms, as well as pest and disease control.

Promoting agroforestry practices such as plantations of crop combinations under multipurpose tree systems, intercropping with green covers in perennial woody crops, and inclusion of livestock contribute to achieving multiple benefits. The adoption of mixed systems contributes to increased soil quality and carbon sequestration, maintains soil fertility and nutrient cycling and controls soil erosion, while providing food and income to local communities and enhancing resilience to climate change.

Combining SLM technologies and approaches (e.g., through forest landscape restoration, integrated land-use approaches, ecosystem adaptation approaches, conservation agriculture approaches, etc.) can easily include, and maximise if well-designed, both contributions to land-based climate change adaption and mitigation, and addressing land degradation**.** Often, it will also result in other co-benefits, such protecting or enhancing biodiversity.

Increasing Soil Organic Carbon (SOC) stocks is key to most SLM practices and provides synergies for addressing DLDD, climate change adaptation and mitigation. Besides contributing to climate change mitigation by removing CO_2 from the atmosphere, enhancing organic carbon in soils improves soil health and fertility, water and nutrient retention capacity, food production potential and resilience to drought. The potential and magnitude of each of these benefits will depend on the baseline conditions, and local environmental, socio-economic and cultural conditions.

SLM practices have a high potential to enhance SOC sequestration, although estimates of this potential should consider the full Greenhouse Gas (GHG) balance, including possible interactions between the carbon and nitrogen cycles that could affect the net climate change mitigation potential of applied practices. Even when the mitigation potential of SLM is not fully achieved, its impact on SOC should be considered, since increasing SOC has crucial positive benefits for achieving LDN, climate change adaptation, food security, and protecting biodiversity.

Large scale adoption of SLM practices in all managed ecosystems (irrigated and rainfed croplands, grazing lands, forests and woodlands) could theoretically sequester about 1–2Gt Carbon per year globally within 30–50 years, although estimates vary in magnitude, depending on which land-use categories, management practices, and GHG fluxes are included. At any site, the rate of SOC sequestration depends on current SOC stocks and declines over time as the saturation level is approached; main carbon sequestration potential is in degraded soils. In soils with high SOC content, preventing SOC losses is priority. Overall, SLM provides an opportunity to recover between 21 to 51 Gt of the lost carbon in the world's agricultural and degraded soils. The achievable local or regional SOC sequestration may be higher or lower than the theoretical SOC sequestration potential, based on local environmental, socio-economic, cultural and institutional contexts.

Databases such as the World Overview of Conservation Approaches and Technologies (WOCAT), TERRAFRICA, the World Bank sourcebook, and the Voluntary Guidelines for Sustainable Soil Management (VGSSM) provide comprehensive recommendations and examples of SLM practices. The combined implementation of practices that address both soil and water conservation, the diversification of cropping systems, the integration of crop and livestock systems, and agroforestry, are the most effective and should be prioritised.

5.1 Barriers for SLM adoption and implementation

Despite scientific advances in understanding the causes and outcomes of land degradation, the adoption of SLM practices is still limited to a minority of innovative land users and practitioners in sustainable traditional systems. Although principles and practices of SLM are well-known and increasingly promoted at the policy and development cooperation level, land degradation is still increasing and becoming a major global threat. This evidences the wide gap existing between the acknowledgement of the need for SLM and the implementation of successful SLM practices.

IDENTIFIED BARRIERS TO THE IMPLEMENTATION OF SLM ARE RELATED TO TECHNOLOGICAL, ECOLOGICAL, INSTITUTIONAL, ECONOMIC AND SOCIO-CULTURAL ASPECTS.

Lack of access to appropriate technologies, practices, or equipment is a major barrier in many countries. This can either be due to a lack of access to knowledge and information on SLM options and their proper implementation, or because of insufficient resources in land, labour, inputs, biomass, energy, water or plants.

Empirical site specific research is a central component of SLM science, but provides limited opportunities for generalisation because results are inherently context-dependent. SLM practices that are technically effective or suitable for one specific location are not necessarily the best option for other site locations with different biophysical constraints and socio-economic contexts. Additionally, there are often knowledge gaps on the ecological implications of different spatial configurations and time scales for application of potentially suitable SLM options available. It is therefore important to have area- and case-specific technological packages, accompanied by the necessary capacity-building measures and resources for appropriate implementation. Often, knowledge gaps on the ecological implications at different spatial and time scales make it difficult to select the most suitable SLM options.

Environmental conditions can form a constraint for implementation of certain SLM practices. As local environmental characteristics (climate, topography, soil quality) often determine success or failure of SLM practices, initial characterisation of baseline conditions will help to select the most suitable land-use and/or management option, depending on local conditions and considering both on-site and off-site benefits.

Institutional and governance issues are often major barriers that hinder the adoption of SLM practices. For example, governance structures that aggravate or inhibit decision-making at different scales neither encourage cross-sectoral planning, nor address land tenure issues; rather, they cause instability over time. There is an urgent need for well-trained and effective extension services to facilitate and guide implementation, monitoring and evaluation of the impact of local SLM practices.

Limited finance and access to capital for implementation and maintenance of SLM. Economic considerations and incentives schemes are two of the land-users' primary motivations for selecting SLM technologies and practices, including the strong dependence on external subsidies for implementation and maintenance.

5.2 Opportunities and enabling conditions for upscaling SLM

- For successful upscaling of SLM, more attention must be paid to the social system from the first involvement stage, up to the long-term maintenance. Ensuring stakeholder participation throughout decision-making processes, from the design of SLM projects all the way to implementation and monitoring, will increase the likelihood for acceptance and implementation of SLM. From start to finish, the process should be highly solution-oriented, emphasising SLM and combining a local, participatory approach with global knowledge sharing.
- Integrating and mainstreaming SLM as land-based solutions towards addressing land degradation and climate change adaptation and mitigation across sectors, levels and stakeholder groups, making it a consideration in policy in all related areas (e.g., water, land planning, energy, poverty) can facilitate adoption, and also open new and previously inaccessible funding sources.

- The lack of a framework to assess the co-benefits and trade-offs and of information to support the promotion of enabling conditions for optimal SLM technologies and practices limits the ability of regulators, policy-makers and land managers to move towards more coherent SLM choices at different scales (in time and space) of implementation.

SLM WILL NOT ONLY PREVENT, REDUCE OR REVERT CHALLENGES POSED BY DLDD (SUPPORTING THE LDN TARGET), BUT CAN ALSO HELP TO MAINTAIN BIODIVERSITY, ALLEVIATE POVERTY, AND FOSTER ECONOMIC PROSPERITY, CONTRIBUTING TO THE SEVERAL SDGS IN A NUMBER OF WAYS.

Adoption of SLM that meets the need of addressing land degradation and adapting to, and mitigating, climate change, requires more transdisciplinary approaches, including new tools that can lead to better informed decision-making and effective knowledge-exchange mechanisms that facilitate new learning and behaviour change.

Some general supporting steps identified begin with assessment of the status of land under survey as well as the site-specific climate vulnerability and mitigation potentials (thereby considering technical and socio-economically feasible aspects). In the next step, the best site-specific SLM technologies should be selected, taking into account the socio-economic viability (of technologies on their own or in combination). Finally, measures should be identified that would strengthen the enabling conditions for their implementation. While designing the process, engaging most relevant stakeholders, through well designed stakeholder participation processes, should be considered at the different stages. This will likely lead to successful adoption and implementation of SLM towards achieving the DLDD goal and LDN target, as well as progress towards land-based climate change adaptation and mitigation goals. Nonetheless, it is important to bear in mind that this process should be tailored to specific circumstances to ensure that the best SLM practices are selected and successfully implemented in each case.

5.3 Recommendations for future research or assessments of existing knowledge

Learning from experience while promoting future research on how to foster synergies, focusing increasingly on comparative and more integrated studies, while single case studies will be essential to understand how to implement and scale SLM technologies out and up, while tailoring them to specific ecological and socio-economic realities.

Developing strategies and participatory processes to involve stakeholders at all levels, from farmers to local organisations, linking land management assessment and knowledge exchange, and integrating science-based data and stakeholder perspectives on both biophysical and socio-economic attributes to select the best SLM practices (and with an integrated evaluation tool).

Successfully addressing DLDD, climate change adaptation and mitigation requires sustaining and scaling up the implementation of SLM practices by appropriate policy instruments that enhance land user's livelihoods.

References

Adeel, Z., Safriel, U., Niemeiier, D., and White, R. (2005). *Ecosystems and Human Well-Being: Desertification Synthesis.* Washington D.C.: World Resources Institute.

Admiraal, A., den Elzen, M., Forsell, N., Turkovska, O., Roelfsema, M., and van Soest, H. (2015). *Assessing Intended Nationally Determined Contributions to the Paris climate agreement – what are the projected global and national emission levels for 2025–2030.* The Hague: PBL Netherlands Environmental Assessment Agency.

Aguilera, E., Lassaletta, L., Sanz-Cobeña, A., Garnier, J., and Vallejo, A. (2013). The potential of organic fertilizers and water management to reduce N_2O emissions in Mediterranean climate cropping systems. A review. *Agriculture, Ecosystems & Environment*, 164, 32–52.

Aguilera, E., Guzmán, G, and Alonso, A. (2015). Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards. *Agronomy for Sustainable Development*, 35 (2), 725–737. http://dx.doi:0.1007/s13593-014-0265-y.

Akhtar-Schuster, M., Bigas, H. and Thomas, R. (2010). *White Paper of the Dryland Science for Development Consortium (DSD), Working Group 3. Monitoring and assessment of desertification, land degradation and drought*: Knowledge management, institutions and economics.

Akhtar-Schuster, M., Hassan, F., Ahmed, M., Hayat, R., and Stöckle, C.O. (2016). Is rainwater harvesting an option for designing sustainable cropping patterns for rainfed agriculture? *Land Degradation & Development*, 27, 630–640. http://dx.doi: 10.1002/ldr.2464.

Akhtar-Schuster, M., Stringer, L.C., Erlewein, A., Metternicht, G., Minelli, S., Safriel, U., and Sommer, S. (2016). Unpacking the concept of land degradation neutrality and addressing its operation through the Rio Conventions. *Journal of Environmental Management*, 1-12.

Akhtar-Schuster, M., Thomas, R., Stringer, L., Chasek, P., and Seely, M. (2011). Improving the enabling environment to combat land degradation: institutional, financial, legal and science-policy challenges and solutions. *Land Degradation & Development*, 22, 299-312.

Alexander, A.B. (2012). Soil compaction on skid trails after selective logging in moist evergreen forest of Ghana. *Agriculture and Biology Journal of North America*. http://dx.doi:10.5251/abjna.2012.3.6.262.264.

Alexander, M.E., and Cruz, M.G. (2012). Graphical aids for visualizing Byram's fireline intensity in relation to flame length and crown scorch height. *Forestry Chronicle*, 88, 185–190.

Almagro, M., de Vente, J., Boix-Fayos, C., García-Franco, N., Melgares de Aguilar, J., González, D., Solé-Benet, A., and Martínez-Mena, M. (2016). Sustainable land management practices as providers of several ecosystem services under rainfed Mediterranean agroecosystems. *Mitigation and Adaptation Strategies for Global Change*, 21 (7), 1029–1043. http://dx.doi:10.1007/s11027-013-9535-2.

Almagro, M., Garcia-Franco, N., and Martínez-Mena. (2017). The potential of reducing tillage frequency and incorporating plant residues as a strategy for climate change mitigation in semiarid Mediterranean agroecosystems. *Agriculture, Ecosystems & Environment* (*in press*, http://dx.doi:10.1016/j.agee.2017.05.016).

Almagro, M., and Martínez-Mena, M. (2014). Litter decomposition rates of green manure as affected by soil erosion, transport and deposition processes, and the implications for the soil carbon balance of a rainfed olive grove under a dry Mediterranean climate. *Agriculture, Ecosystems & Environment*, 196, 167–177.

Amole, T.A., and Ayantunde, A.A. (2016). *Climate-smart livestock interventions in West Africa: A review.* CCAFS Working Paper no. 178. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark. Available online at: www.ccafs.cgiar.org.

Ananda, J., and Herath, G. (2009). A critical review of multi-criteria decision making methods with special reference to forest management and planning. *Ecological Economics*, 68 (10), 2535-2548. http://dx.doi: 10.1016/j.ecolecon.2009.05.010.

Armitage, D., Marschke, M., and Plummer, R. (2008). Adaptive co-management and the paradox of learning. *Global Environmental Change*, 18, 86-98.

Arroita, M., Causapé, J., Comín, F.A., Díez, J., Jiménez, J.J., Lacarta, J., Lorente, C., Merchán, D., Muñiz, S., Navarro, E., Val, J., and Elosegi, A. (2013). Irrigation agriculture affects organic matter decomposition in semi-arid terrestrial and aquatic ecosystems. *Journal of Hazardous Materials*. 263, 139–145.

Ayers, J., and Forsyth, T. (2009). Community-based adaptation to climate change: strengthening resilience through development. *Environment* 51(4), 22–31.

Badini, O., Stockle, C.O., Jones, J.W., Nelson, R., Kodio, A., and Keita, M. (2007). A simulation based analysis of productivity and soil carbon in response to time-controlled rotational grazing in the West African Sahel region. *Agricultural Systems*, 94, 87-96.

Bai, Z.G., Dent, D.L., Olsson, L., and Schaepman, M.E. (2008). Proxy global assessment of land degradation. *Soil Use and Management*, 24, 223 – 234.

Baker, J.M., Ochsner, T.E., Venterea, R.T., and Griffis, T.J. (2007). Tillage and soil carbon sequestration - what do we really know? *Agriculture, Ecosystems & Environment*, 118, 1-5.

Balian, E., Eggermont, H., and Le Roux, X. (2014). *Outputs of the Strategic Foresight workshop "Nature-Based Solutions in a BiodivERsA context"*. Brussels, June 11-12 2014. Biodiversity report, p.45.

Batjes, N.H. (2014). Projected changes in soil organic carbon stocks upon adoption of recommended soil and water conservation practices in the Upper Tana River catchment, Kenya. *Land Degradation & Development*, 25, 278–287. http://dx.doi:10.1002/ldr.2141.

Bautista, S., and Alloza, J. A.(2009). Evaluation of Forest Restoration Projects. In: Bautista, S., Aronson, J., and Vallejo, V. R., (eds.) *Land restoration to combat desertification. Innovative approaches, quality control and project evaluation*. 47-72. Fundación Centro de Estudios Ambientales del Mediterráneo - CEAM, Valencia, España.

Bekessy, S.A., and Wintle, B.A. (2008). Using carbon investment to grow the biodiversity bank. *Conservation Biology*, 22, 510–513.

Berenguer, E., Ferreira, J., Gardner, T.A, Aragão, L.E.O.C., Camargo, P.B., Cerri, C.E., Durigan, M., Oliveira Jr., R.C., Vieira, I.C.G., and Barlow, J. (2014). A large-scale field assessment of carbon stocks in human-modified tropical forests. *Global Change Biology.* http://dx.doi: 10.1111/gcb.12627.

Bestelmeyer, B.T., Okin, G.S., Duniway, M.C., Archer, S.R., Sayre, N.F., Williamson, J.C., and Herrick, J.E. (2015). Desertification, land-use, and the transformation of global drylands. *Frontiers of Ecology and the Environment* 13(1), 28-36. http://dx.doi:10.1890/140162.

Bernabé, A., Blasco, A., Llorca, M., and Lledó M.J. (2004). La restauración dunar con vegetación psamófita. In: *Cuad. Soc. Esp. Cien. For.*, 17, 131-137.

Bolte, A., Ammer, C., Löf, M., Madsen, P., Nabuurs, G.-J., Schall, P., Spathelf, P., and Rock, J. (2009). Adaptive forest management in central Europe: Climate change impacts, strategies and integrative concepts. *Scandinavian Journal of Forest Research*, 24, 473-482.

Bouwen, R., and Taillieu, T. (2004). Multi-party collaboration as social learning for interdependence: developing relational knowing for sustainable natural resource management. Journal of Community and Applied Social Psychology, 14, 137-153.

Bracmort, K.S., Engel, B., and Frankenberger, J. (2004). Evaluation of structural best management practices 20 years after installation: Black Creek Watershed, Indiana. *Journal of Soil and Water Conservation*, 59, 191–196.

Brain, S. (2010). The Great Stalin Plan for the Transformation of Nature. *Enviro Hist Durh Ncarbon, 2010*; 15 (4): 670-700. http://dx.doi: 10.1093/envhis/emq091.

Branca, G., McCarthy, N., Lipper, L., and Jolejole, M.C. (2011). *Climate-smart agriculture: a synthesis of empirical evidence of food security and mitigation benefits from improved cropland management*. Mitigation of Climate Change in Agriculture Series 3. Rome, Italy: FAO.

Bryan, B.A., Meyer, W.S., Campbell, C.A., Harris, G.P., Lefroy, T., Lyle, G., Martin, P., McLean, J., Montagu, K., Rickards, L.A., Summers, D.M., Thackway, R., Wells, S., and Young, M. (2013). The second industrial transformation of Australian landscapes*. Current Opinion in Environmental Sustainability*, 5, 278–287.

Burney, J.A., Davis, S.J., and Lobell, D.B. (2010). Greenhouse gas mitigation by agricultural intensification. *Proceedings of the National Academy of Sciences*, 107, 12052-12057.

Busari, M.A., Kukal, S.S., Kaur, A., Bhatt, R., and Dulazi, A.A. (2015). Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research*, 3, 119–129.

Butenschoen, O., Scheu, S., and Eisenhauer, N. (2011). Interactive effects of warming, soil humidity and plant diversity on litter decomposition and microbial activity. *Soil Biology and Biochemistry*, 43, 1902–1907.

Carter, S., Herold, M., Rufino, M.C., Neumann, K., Kooistra, L., and Verchot, L. (2015). Mitigation of agriculture emissions in the tropics: comparing forest land-sparing options at the national level. *Biogeosciences Discussions*, 12, 5435–5475.

Celano, G., Palese, A.M., Ciucci, A., Martorella, E., Vignozzi, N., and Xiloyannis, C. (2011). Evaluation of soil water content in tilled and cover-cropped olive orchards by the geoelectrical technique. *Geoderma*, 163, 163–170.

Certini, G. 2005. Effects of fire on properties of forest soils: a review. *Oecologia*, 143: 1–10. http://dx. doi:10.1007/s00442-004-1788-8

Chatterjee, A., and Lal R. (2009). On farm assessment of tillage impact on soil carbon and associated soil quality parameters. *Soil and Tillage Research*, 104, 270–277.

Cohen-Shacham, E., Walters, G., Janzen, C., and Maginnis, S. (2016). *Nature-based Solutions to address global societal challenges*. Gland, Switzerland: IUCN.

Cole C.V., Duxbury, J., Freney, J., Heinemeyer, O., Minami, K., Mosier, A., Paustian, K., Rosenberg, N., Sampson, N., Sauerbeck, D., and Zhao, Q. (1997). Global estimates of potential mitigation of greenhouse gas emissions by agriculture. *Nutrient Cycling in Agroecosystems*, 49, 221–228.

Colls, A., Ash, A., and Ikkala, N. (2009). *Ecosystem-based Adaptation: a natural response to climate change. Gland*, Switzerland: IUCN: IUCN, Gland, Switzerland.

Conacher, A. (2009). Land degradation: a global perspective. *New Zealand Geographer* 65, 91-94. http://dx. doi.org/10.1111/j.1745-7939.2009.01151.x.

Conant, R.T., Paustian, K., and Elliott, E.T. (2001). Grassland management and conversion into grassland: effects on soil carbon. *Ecological Applications*, 11, 343–355.

Conant, R.T., Paustian, K., del Grosso, S.J., and Parton, W.J. (2005). Nitrogen pools and fluxes in grassland soils sequestering carbon. *Nutrient Cycling in Agroecosystems*, 71, 239–248. http://dx.doi:10.1007/s10705-004-5085-z.

Conant, R.T. (2012). Grassland soil organic carbon stocks: status, opportunities, vulnerability. In: Lal, R., Lorenz, K., Hüttl, R.F., Schneider, B.U., and von Braun, J. (Eds). *Recarbonization of the Biosphere*, pp. 275-302, Springer, Dordrecht, The Netherlands.

Correal, E., Robledo, A., Rios, S., and Rivera, D. (2006). Mediterranean dryland mixed sheep-cereal systems. *Grassland Science in Europe*, 11, 14–26.

Cowie, A.L., Penman, T.D., Gorissen, L., Winslow, M.D., Lehmann, J., Tyrrell, T.D., Twomlow, S., Wilkes, A., Lal, R., Jones, J.W., Paulsch, A., Kellner, K., and Akhtar-Schuster, M. (2011). Towards sustainable land management in the drylands: Scientific connections in monitoring and assessing dryland degradation, climate change and biodiversity. *Land Degradation & Development*, 22(2), 248-260.

Cowie, A., Schneider, U., and Montanarella, L. (2007). Potential synergies between existing multilateral environmental agreements in the implementation of land use, land-use change and forestry activities. *Environmental Science & Policy*. Vol 10.

Critchley, W. (2007). *Working with Farmer Innovators*. Wageningen, The Netherlands: CTA.

Dalal, R.C., Wang, W., Robertson, G.P., and Parton, W.J. (2003). Nitrous oxide emission from Australian agricultural lands and mitigation options: a review. *Australian Journal of Soil Research*, 41, 165–195. http://dx.doi:10.1071/SR02064.

De Vente, J., 2012. Vegetated earth-banked terraces. In: Schwilch, G., Hessel, R., and Verzandvoort, S. (Eds.), DESIRE for Greener Land. Options for Sustainable Land Management in Drylands CDE, Alterra, ISRIC, CTA, Bern (Switzerland), Wageningen, The Netherlands, pp. 149-152.

De Vente, J., Reed, M.S., Stringer, L.C., Valente, S., and Newig, J. (2016). How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands. *Ecology and Society*, 21(2).

De Vente, J., Bautista, S., and Orr, B. (2017). Preface: Optimizing science impact for effective implementation of Sustainable Land Management. *Journal of Environmental Management*, 195, 1-3.

Dermisis, D., Abaci, O., Papanicolaou, A.N., and Wilson, C.G. (2010). Evaluating grassed waterway efficiency in southeastern Iowa using WEPP. *Soil Use and Management*, 26, 183–192.

Dhyani, S.K., Ram, A., and Dev, I. (2016). Potential of agroforestry systems in carbon sequestration in India. *Indian Journal of Agricultural Sciences*, 86 (9), 1103–12.

Di Gregorio, M., Nurrochmat, D.R., Paavola, J., Sari, I.M., Fatorelli, L., Pramova, E., Locatelli, B., Brockhaus, M., and Kusumadewi, S.D. (2017). Climate policy integration in the land-use sector: Mitigation, adaptation and sustainable development linkages. *Environmental Science and Policy*, 67, 35-43.

Donjadee, S., and Tingsanchali, T. (2013). Reduction of runoff and soil loss over steep slopes by using vetiver hedgerow systems. *Paddy and Water Environment*, 11, 573–581.

Driscoll, D.A., Catford, J.A., Barney, J.N., Hulme, P.E., Inderjit Martin, T. G., and Visser, V. (2014). New pasture plants intensify invasive species risk. *Proceedings of the National Academy of Sciences of the United States of America*, 111(46), 16622–16627. http://dx.doi.org/10.1073/pnas.1409347111

Dumanski, J., and Smyth, A.J. (1993). The issues and challenges of sustainable land management. Pages ll-23 In: Wood, R.C., and J. Dumanski (Eds.). *Proceedings of the International Workshop on Sustainable Land Management for the 2lst Century*. Vol. 2. Plenary papers. The Organizing Committee, International Workshop on Sustainable Land Management. Ottawa/Canada: Agricultural Institute of Canada.

Dupraz, C., and Newman, S.M. (1997). Temperate agroforestry: the European way. In: Gordon, A.M., and Newman S.M. (Eds.), *Temperate Agroforestry Systems.* CAB International, Wallingford, UK, pp. 181–236.

Eagle, J.A., Bird, J.A., Horwath, W.R., Linquist, B.A., Brouder, S.M., Hill, J.E., and van KesseL, C. (2000). Rice Yield and Nitrogen Utilization Efficiency under Alternative Straw Management Practices. *Agronomy Journal*, 92, 1096–1103. http://dx.doi:10.2134/agronj2000.9261096x

ELD Initiative. (2013). *The rewards of investing in sustainable land management*. Available online at http://www.eld-initiative.org/.

ELD Initiative (2015). *The value of land: Prosperous lands and positive rewards through sustainable land management*. Available online at www.eld-initiative.org.

Eichhorn, M.P., Paris, P., Herzog, F., Incoll, L.D., Liagre, F., Mantzanas, K., Mayus, M., Moreno, G., Papanastasis, V.P., Pilbeam, D.J. Pisanelli, A., and Dupraz, C. (2006). Silvoarable systems in Europe – past, present and future prospects. *Agroforestry Systems*, 67, 29–50. http://dx.doi: 10.1007/s10457-005-1111-7.

Ellert, B.H., and Bettany, J.R. (1995). Calculation of organic matter and nutrients stored in soils under contrasting management regimes. *Can. J. Soil Sci.*, 75, 529–538.

Elliot, W.J., Page-Dumroese, D., and Robichaud, P.R. (1996). *The Effects of Forest Management on Erosion and Soil Productivity.* In: Symposium on Soil Quality and Erosion Interaction. Keystone, Colorado, July 7th, 1996.

Enne, G., Zucca, C., Montoldi, A., and Noe, L. (2004). The Role of Grazing in Agropastoral Systems in the Mediterranean Region and their Environmental Sustainability. *Advances in GeoEcology,* 37.

Energy Transport and Water Department (ETWWA) (2010). *Improving Water Management in Rainfed Agriculture: Issues and Options in Water-Constrained Production Systems*.

Evans, J., ed. (2009). *Planted forests: uses, impacts and sustainability*. Wallingford, UK, CABI & FAO.

FAO. 1993. FESLM: *An international framework for evaluating sustainable land management.* World Soil Resources Report. A Discussion Paper (A.J. Smyth, and Dumanski, J.).

FAO. 2012. *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries, Forests in the Context of National Food Security.* Rome.

FAO. (2015). *Global Forest Resources Assessment 2015 How are the world's forests changing?* http://www.fao.org/3/a-i4793e.pdf

FAO. (2016). *The agriculture sectors in the Intended Nationally Determined Contributions*: Analysis by Strohmaier, R., Rioux, J., Seggel, A., Meybeck, A., Bernoux, M., Salvatore, M., Miranda, J., and Agostini, A. Environment and Natural Resources Management Working Paper No. 62. Rome. Available online at http://www.fao.org/3/a-i5687e.pdf

FAO and Intergovernmental Technical Panel on Soils (ITPS). (2015). *Status of the World's Soil Resources* (SWSR) – Main Report. Rome, Italy.

Farina, R., Seddaiu, G., Orsini, R., Steglich, E., Roggero, P.P., and Francaviglia, R. (2011). Soil carbon dynamics and crop productivity as influenced by climate change in a rainfed cereal system under contrasting tillage using EPIC. *Soil & Tillage Research*, 112 (1), 36-46.

Federici, S., Tubiello, F.N., Salvatore, M. Jacobs, H., and Schmidhuber, J. (2015). New Estimates of CO_2 Forest Emissions and Removals: 1990–2015. *Forest Ecology and Management*, 352, 89–98.

Ferwerda, W.H. (2015). *4 returns, 3 zones, 20 years: A Holistic Framework for Ecological Restoration by People and Business for Next Generations*. RSM/IUCN CEM.

Fiener, P., and Auerswald, K. (2006). Seasonal variation of grassed waterway effectiveness in reducing runoff and sediment delivery from agricultural watersheds in temperate Europe. *Soil & Tillage Research*, 87, 48–58.

Fisher, M.J., Rao, I.M., Ayarza, M.A., Lascano, C.E., Sanz, J.I., Thomas, R.J., and Vera, R.R. (1994). Carbon storage by introduced deep-rooted grasses in the South American Savannas. *Nature,* 371, 236–238.

Freeman, O.E., Duguma, L.A., and Minang, P.A. (2015). Operationalizing the integrated landscape approach in practice. *Ecology and Society*, 20(1), 24.

Follett, R.F., Kimble, J.M., and Lal, R., Eds. (2001). *The potential of US grazing lands to sequester carbon and mitigate the greenhouse effect.* Boca Raton, USA, CRC Press LLC.

Forsell, N., Turkovska, O., Gusti, M., Obersteiner, M., den Elzen, M., and Havlik, P. (2016). Assessing the INDCs' land-use, land-use change, and forest emission projections. *Carbon Balance and Management*, 11:26. http://dx. doi: 10.1186/s13021-016-0068-3.

Gaafar, A.M., Salih, A.A., Luukkanen, O., El Fadl, M.A., and Kaarakka, V. (2006). Improving the Traditional Acacia Senegal-Crop System in Sudan: The Effect of Tree Density on Water Use, Gum Production and Crop Yields. *Agroforestry Systems*, 66 (1), 1-11.

Gabathuler, E., Bachmann, F. and Kläy, A. 2011. *Reshaping Rural Extension. Learning for Sustainability (LforS) – An Integrative and Learning Based Advisory Approach for Rural Extension with Small-Scale Farmers*. Margraf, Weikersheim, Germany and Technical Centre for Agricultural and Rural Cooperation ACP–EU (CTA), Wageningen, The Netherlands

Garcia-Franco, N., Albaladejo, J., Almagro, M., and Martínez-Mena, M. (2015). Beneficial effects of reduced tillage and green manure on soil aggregation and stabilization of organic carbon in a Mediterranean agroecosystem. *Soil and Tillage Research*, 153(0), 66-75.

Garmendia, E., and Stagl, S. (2010). Public participation for sustainability and social learning: concepts and lessons from three case studies in Europe. *Ecological Economics*, 69, 1712-1722.

Gattinger, A., Jawtusch, J., Muller, A., and Mäder P. (2011*). No-till agriculture – a climate smart solution?* Climate Change and Agriculture Report No 2. Bischöfliches Hilfswerk Misereor e.V. Aachen.

Gibbons, S.M., Lekberg, Y., Mummey, D.L., Sangwan, N., Ramsey, P.W., and Gilbert, J.A. (2017). Invasive plants rapidly reshape soil properties in a grassland ecosystem. *mSystems*, 2:e00178-16. Available online at: http://dx.doi.org/10.1128/mSystems.00178-16.

Giger, M., Liniger, H., Sauter, C., and Schwilch, G. (2015). Economic benefits and costs of sustainable land management technologies: an analysis of WOCAT's global data. *Land Degradation & Development*. http://dx.doi: 10.1002/ldr.2429.

GEF. (2009). *GEF Annual Report 2009*. Available online at https://www.thegef.org/publications/gef-annual-report-2009.

Gonsalves, J., Becker, T., Braun, A., Campilan, D., De Chavez, H., Fajber, E., Kapiriri, M., Rivaca-Caminade, J., and Vernooy, R. (2005). *Participatory Research and Development for Sustainable Agriculture and Natural Resource Management: A Sourcebook. Understanding Participatory Research and Development.* International Potato Center-Users' Perspectives With Agricultural Research and Development, V*ol. 1*. Laguna, Philippines and International Development Research Centre, Ottawa, Canada.

Grassi, G., House, J., Dentener, F., Federici, S., den Elzen, M., and Penman, J. (2017). The key role of forests in meeting climate targets requires science for credible mitigation. *Nature*. http://dx.doi: 10.1038/NCLIMATE3227.

Guardia, G., Tellez-Rio, A., García-Marco, S., Martin-Lammerding, D., Tenorio, J.L., Ibáñeza M.Á., and Vallejo, A. (2016). Effect of tillage and crop (cereal versus legume) on greenhouse gas emissions and Global Warming Potential in a non-irrigated Mediterranean field. *Agriculture, Ecosystems and Environment*, 221, 187–197.

Hall, D.O. (1997). Biomass energy in industrialised countries – a view of the future. *Forest Ecology and Management*, 91, 17–45.

Hatfield, P.G., Goosey, H.B., Spezzano, T.M. Blodgett, S.L. Lenssen, A.W., Kott, R.W., and Marlowa, C.B. (2007). Incorporating sheep into dryland grain production systems III. Impact on changes in soil bulk density and soil nutrient profiles. *Small Ruminant Research,* 67, 222–231.

Hemmati, M. (2002). *Multi-stakeholder Processes for Governance and Sustainability*: Beyond Deadlock and Conflict. Earthscan, London.

Henderson, B.B., Gerber, P.J., Hilinski, T.E., Falcucci, A., Ojima, D.S., Salvatore, M., and Conant, R.T. (2015). Greenhouse gas mitigation potential of the world's grazing lands: Modeling soil carbon and nitrogen fluxes of mitigation practices. *Agriculture, Ecosystems & Environment*, 207, 91–100.

Herzog, F. (1994). Agroforestry and Land-use Change in Industrialised Nations. *Schweizerische Zeitschrift für Forstwesen,* 145, 761–763.

Holling, C.S. (2001). Understanding the Complexity of Economic, Ecological and Social Systems. *Ecosystems,* 4, 390-405.

Huang, M., Yang, L., Qin, H., Jiang, L., and Zou, Y. (2013). Quantifying the effect of bio-char amendment on soil quality and crop productivity in Chinese rice paddies. *Field Crops Research*, 11, 172–177.

Hurni, H. (2000). Assessing Sustainable Land Management (SLM). *Agriculture, Ecosystems & Environment,* 81, 83-92.

Hurni, H., Giger, M., and Meyer, K. (2006). *Soils on the global agenda. Developing International Mechanisms for Sustainable Land Management.* International Union of Soil Sciences, Bern, Switzerland.

Hussey, M., MacLachlan, M., and Mji, G. (2017). Barriers to the Implementation of the Health and Rehabilitation Articles of the United Nations Convention on the Rights of Persons with Disabilities in South Africa. *International Journal of Health Policy and Management*, 6 (4), 207-218. http://dx.doi:10.15171/ijhpm.2016.117.

International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). 2009. *Global report*. Edited by Beverly D. McIntyre et al.

IPCC. (2001). *The third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge/ UK: Cambridge University Press.

IPCC. (2006). *Guidelines for National Greenhouse Gas Inventories.* Hayana, Japan: Institute for Global Environmental Strategies (IGES).

IPCC. (2007). *Climate Change 2007: Mitigation of Climate Change*. Available online at http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter8.pdf.

IPCC. (2014). *Climate Change 2014: Mitigation of Climate Change*. Cambridge Univ. Press, 2014.

ISRIC. (1994). *World Soil Information,* ISRIC Report 1991/04. Wageningen, The Netherlands.

IPBES, (2016). *Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production*. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 36 pages.

Jackson, T. (2009). *Prosperity without growth? – The transition to a sustainable economy*. Sustainable Development Commission, London.

Jagathjothi, N., Ramamoorthy, K. and Kuttimani, R. (2011). Integrated nutrient management on growth and yield of rain fed direct sown finger millet. *Research on Crops*, 12, 79–81.

Jordan, N., Aldrich-Wolfe, L., Huerd, S., Larson, D., and Muehlbauer, G. (2012). Soil–Occupancy Effects of Invasive and Native Grassland Plant Species on Composition and Diversity of Mycorrhizal Associations. *Invasive Plant Science and Management*, 5(4), 494-505. http://dx.doi:10.1614/IPSM-D-12-00014.1.

Kaharabata, S.K., Drury, C.F., Priesack, E., Desjardins, R.L, McKenney, D.J., Tan, C.S., and Reynolds, D. (2003). Comparing measured and Expert-N predicted N_2O emissions from conventional till and no till corn treatments. *Nutrient Cycling in Agroecosystems*, 66(2), 107-118.

Kanter, D.R., Musumba, M., Wood, S.L.R., Palm, C., Antle, J., Balvanera, P., Dale, V.H., Havlik, P., Kline, K.L., Scholes, R.J., Thornton, P., Tittonell, P., and Andelman, S. (2016). Evaluating agricultural trade-offs in the age of sustainable development. *Agricultural Systems*. http://dx.doi: 10.1016/j.agsy.2016.09.010.

Kaye, J.P., and Quemada, M. (2017). Using cover crops to mitigate and adapt to climate change. A review. *Agronomy for Sustainable Development*, 37 (4). http://dx.doi: 10.1007/s13593-016-0410-x.

Kell, D. (2012) Large-scale sequestration of atmospheric carbon via plant roots in natural and agricultural ecosystems: why and how. *Philosophical Transactions of the Royal Society*, B. 367, 1589-1597.

Kellon, D., and Arvai, J. (2011). Five propositions for improving decision making about the environment in developing communities: Insights from the decision sciences. *Journal of Environmental Management*, 92, 363–371.

Key, G., Whitfield, M.G., Cooper, J., de Vries, F.T., Collison, M., Dedousis, T., Heathcote, R., Roth, B., Mohammed, D., Molyneux, A., van der Putten, W.H., Dicks, L.V., Sutherland, W.J., and Bardgett, R.D. (2016). Knowledge needs, available practices, and future challenges in agricultural soils. *Soil*, 2, 511–521.

Kuwait Institute for Scientific Research (KISR). (2017). *Controlling shifting sand in Kabd Research and Innovation Station* (Project EC026S).

Kissinger, G., Herold, M., and de Sy, V. (2012*). Drivers of Deforestation and Forest Degradation: A Synthesis Report for REDD+ Policymakers*. Lexeme Consulting, Vancouver, Canada.

Klemarczyk R.J., and Hahn, T.C. (1994). *Reassessment of biomass harvesting on small woodlots in New Hampshire.* New Hampshire Timberland Owners Association. United States Department of Agriculture.

Kravchenko, A.N., and Robertson, G.P. (2010). Whole-profile soil carbon stocks: The danger of assuming too much from analyses of too little. *Soil Science Society of America Journal*, 75, 235-240.

Kurz, W.A., Dymond, C.C., Stinson G., Rampley, G.J., Neilson, E.T., Carroll, A.L., Ebata, E., and Safranyik, L. (2008). Mountain pine beetle and forest carbon feedback to climate change. *Nature* ,452, 987-990.

Kust, G., Andreeva, O., and Cowie, A. (2016). Land Degradation Neutrality: Concept development, practical applications and assessment. *Journal of Environmental Management*, 1-9. http://dx.doi.org/10.1016/j.jenvman.2016.10.043.

Lal, R. (2001). Soil degradation by erosion. *Land Degradation and Development*, 12, 519-539.

Lal, R. (2015). Sequestering carbon and increasing productivity by conservation agriculture. *Journal of Soil and Water Conservation*, 70 (3), 55-62.

Lal, R., Safriel, U., and Boer, B. (2012). *Zero Net Land Degradation: A New Sustainable Development Goal for Rio+ 20.* A Report Prepared for the Secretariat of the UNCCD.

Lamb, D., and Gilmour, D. (2003). *Rehabilitation and Restoration of Degraded Forests*. IUCN, Gland, Switzerland and Cambridge, UK and WWF, Gland, Switzerland, pp.110.

Lamb, D., Erskine, P.D., and Parrotta, J.A. (2005). Restoration of degraded tropical forest landscapes. *Science*, 310, 1628–1632.

Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., and Thomas, C.J. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science*, 7 (1), 25-43. http://dx.doi:10.1007/s11625-011-0149-x.

Latawiec, A.E., Crouzeilles, R, Brancalion, P.H.S., Rodrigues, R.R., Sansevero, J.B.B., dos Santos, J.S., and Strassburg, B.B.N. (2016). Natural regeneration and biodiversity: A global meta-analysis and implications for spatial planning. *Biotropica*, 46, 844–855.

Le Quéré, C., Andres, R. J., Boden, T., Conway, T., Houghton, R. A., House, J. I., Marland, G., Peters, G. P., van der Werf, G. R., Ahlström, A., Andrew, R. M., Bopp, L., Canadell, J. G., Ciais, P., Doney, S. C., Enright, C., Friedlingstein, P., Huntingford, C., Jain, A. K., Jourdain, C., Kato, E., Keeling, R. F., Klein Goldewijk, K., Levis, S., Levy, P., Lomas, M., Poulter, B., Raupach, M. R., Schwinger, J., Sitch, S., Stocker, B. D., Viovy, N., Zaehle, S., and Zeng, N. (2013). The global carbon budget 1959–2011. *Earth System Science.* Data 5, 165–185. Available online at http://www.earth-syst-sci-data.net/5/165/2013/

Leeuwis, C., and Pyburn, R. (2002). Social Learning for Rural Resource Management. In Wheelbarrows Full Of Frogs: Social Learning in Rural Resource Management: International Research and Reflections: Assen. The Netherlands, 11–24.

Leguedois, S., Ellis, T.W., Hairsine, P.B., and Tongway, D.J. (2008). Sediment trapping by a tree belt: processes and consequences for sediment delivery. *Hydrological Processes*, 22, 3523–3534.

Lewis, S.L., and Maslin, M.A. (2015). Defining the Anthropocene. *Nature*, 519, 171-180.

Liebhold, A.M. (2012). Forest pest management in a changing world. *International Journal of Pest Management*, 58 (3), 289–295.

Lindroth, A., Lagergren, F., Grelle, A., Klemedtsson, L., Langvall, O.L.A., Weslien, P. E.R., and Tuulik, J. (2009). Storms can cause Europe-wide reduction in forest carbon sink. *Global Change Biology*, 15 (2), 346-355.

Liniger, H.P., William, C., Grunter, M., Schwilch, G., and Studer, R.M. (2007). *Where the land is greener: Case studies and analysis of soil and water conservation initiatives worldwide*. Wageningen, The Netherlands.

Liniger, H.P., Mekdaschi Studer, R., Hauert, C., and Gurtner, M. (2011). *Sustainable Land Management in Practice – Guidelines and best Practices for Sub-Saharan Africa.* TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and FAO.

Liu, X.Y., Qu, J.J., Li, L.Q., Zhang, A.F., Jufeng, Z., Zheng, J.W., and Pan, G.X. (2012). Can biochar amendment be an ecological engineering technology to depress N2O emission in rice paddies? – A cross site field experiment from South China. *Ecological Engineering*, 42, 168–173.

Locatelli, B., Pavageau, C., Pramova, E., and di Gregorio, M. (2015). Integrating climate change mitigation and adaptation in agriculture and forestry: opportunities and trade-offs. *WIREs Climate Change*, 6, 585–598.

Lorenz, K., and Lal, R. (2014). Soil organic carbon sequestration in agroforestry systems. A review. *Agronomy for Sustainable Development*. http://dx.doi:10.1007/s13593-014-0212-y.

Machmuller, M.B., Kramer, M.G., Cyle, T.K., Hill, N., Hancock, D., and Thompson, A. (2015). Emerging land-use practices rapidly increase soil organic matter. *Nature Communications*, 6 (6995).

McDonald, T., Gann, G. D., Jonson, J., and Dixon, K. W. (2016). *International Standards for the Practice of Ecological Restoration – Including Principles and Key Concepts.* First Edition. Society for Ecological Restoration (SER).

MacKenzie, A.F., Fan, M.X., and Cadrin, F. (1998). Tillage, Corn-Soybean-Alfalfa Rotations, and Nitrogen Fertilization. *Journal of Environmental Quality*, 27(3), 698-703.

Maestre, F.T., and Cortina, J. (2004). Pinus halepensis plantations useful as a restoration tool in semiarid Mediterranean areas? *Forest Ecology and Management*, 198(1-3), 303–317.

Mansourian, S., Vallauri, D., and Dudley, N. (in cooperation with WWF International). (2005). *Forest Restoration in Landscapes: Beyond Planting Trees*. Springer, New York.

Marland, G., McCarl, B.A., and Schneider, U.A. (2001). Soil carbon: policy and economics. *Climate Change*, 51, 101–117. http://dx.doi:10.1023/A:1017575018866.

Marques, M.J., Schwilch, G., Lauterburg, N., Crittenden, S., Tesfai, M., Stolte, J., Zdruli, P., Zucca, C., Petursdottir, T., Evelpidou, N., Karkani, A., AsliYilmazgil, Y., Panagopoulos, T., Yirdaw, E., Kanninen, M., Rubio, J.L., Schmiedel, U., and Doko, A.(2016). Multifaceted Impacts of Sustainable Land Management in Drylands: *A Review. Sustainability*, 8 (177). http://dx.doi:10.3390/su8020177.

Martínez-Mena, M., Garcia-Franco, N., Almagro, M., Ruiz-Navarro, A., Albaladejo, J., de Aguilar, J.M., Gonzalez, D., and Querejeta, J.I. (2013). Decreased foliar nitrogen and crop yield in organic rainfed almond trees during transition from reduced tillage to no-tillage in a dryland farming system. *Eur. J. Agron*. 49, 149–157.

Martínez-Mena M, López J, Almagro M, Boix-Fayos C, and Albaladejo J. (2008). Effect of water erosion and cultivation on the soil carbon stock in a semiarid area of South-East Spain. *Soil and Tillage Research*, 99,(1): 119-129.

Martínez- Palacios, A., Prat, C., and Ríos-Patrón E. (2015). Land reclamation by agave forestry with native species in the mountains of Michoacan state. In: Romeo, R., Vita, A., Manuelli, S., Zanini, E., Freppaz, M. & Stanchi, S. (Eds.). *Understanding Mountain Soils: A contribution from mountain areas to the International Year of Soils 2015,* pp 97-99. FAO.

Mayor, A.G., Valdecantos, A., Vallejo, V.R., Keizer, J.J., Bloem, J., Baeza, J., González-Pelayo, O., Machado, A.I., and de Ruiter, P.C. (2016). Fire-induced pine woodland to shrub land transitions in Southern Europe may promote shifts in soil fertility. *Science of the Total Environment*, 573, 1232-1241.

Mbow, C., Smith, P., Skole, D., Duguma, L., and Bustamante, M. (2014). Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. *Current Opinion in Environmental Sustainability*, 6, 8–14.

Medawatte, M.B.A., Amarasinghe, J., Iqbal, M.C.M., and Ranwala, S.M.W. (2014). Restoration of a degraded dry forest using nurse trees at Dambulla, Sri Lanka. *Conservation Evidence*, 11, 16-19.

Mekonnen, M., Keesstra, S.D., Stroosnijder, L., Baartman, J.E.M., and Maroulis, J. (2015). Soil conservation through sediment trapping: a review. *Land Degradation Development*, 26, 544–556. http://dx.doi:10.1002/ldr.2308.

Millennium Ecosystem Assessment (MA). (2005). *Ecosystems and Human Well-being: Desertification Synthesis.* Washington, DC: World Resources Institute.

Minkkinen, K., Korhonen, R., Savolainen, I., and Laine, J. (2002). Carbon balance and radiative forcing of Finnish peat lands 1900–2100 —the impact of forestry drainage. *Global Change Biology*, 8, 785–799. http://dx.doi: 10.1046/j.1365-2486.2002.00504.x

Monteny, G.-J., Bannink, A., and Chadwick, D. (2006). Greenhouse gas abatement strategies for animal husbandry. *Agriculture, Ecosystems & Environment*, 112, 163–170. http://dx. doi:10.1016/j.agee.2005.08.015.

Moore, P., Hardesty, J., Kelleher, S., Maginnis S., and Myers, R. (2003). *Forests and wildfires: fixing the future by avoiding the past.* In: XII World Forestry Congress, 2003. Québec, Canada.

Moraru, P.I., and Rusu, T. (2013). Effect of different tillage systems on soil properties and production on wheat, maize, and soybean crop. *International Scholarly and Scientific Research & Innovation*, 7, 679-692.

Morin, J. (1993). Soil crusting and sealing. In: FAO. Soil tillage in Africa: needs and challenges. *FAO Soils Bulletin* 69. Available online at: http://www.fao.org/docrep/t1696e/t1696e06.htm.

Mosquera-Losada, M.R, Moreno, G., Pardini, A., McAdam, J.H., Papanastasis, V., Burgess, P.J., Lamersdorf, N., Castro, M., Liagre, F., and Rigueiro-Rodríguez, A. (2012). Past, Present and Future of Agroforestry Systems in Europe. In: P.K.R. Nair and D. Garrity (Eds.). *Agroforestry - The Future of Global Land-use*. Advances in Agroforestry 9, *Springer*, Dordrecht. http://dx.doi:10.1007/978-94-007-4676-3_16.

Mukul, S.A., Herbohn, J., and Firn, J. (2016). *Tropical secondary forests regenerating after shifting cultivation in the Philippines uplands are important carbon sinks*. Scientific Reports 6. http://dx.doi:10.1038/srep22483

Mutegi, J.K., Mugendi, D.N., Verchot, L.V., and Kung'u, J.B. (2008). Combining napier grass with leguminous shrubs in contour hedgerows controls soil erosion without competing with crops. *Agroforestry Systems*, 74, 1–13.

Nabuurs, G.J., Thürig, E., Heidema, N., Armolaitis, K., Biber, P., Cienciala, E., Kaufmann, K., Mäkipää, R., Nilsen, P., Petritsch, R., Pristova, T., Rock, J., Schelhaas, M.J., Sievanen, R., Somogyi, Z., and Vallet, P. (2008). Hotspots of the European forests carbon cycle. *Forest Ecology and Management*, 256, 194–200.

Nair, P. K. R. and Garrity, D. P. (Eds.).(2012) Agroforestry - The Future of Global Land-use, Advances in Agroforestry 9, *Springer*, Dordrecht. http://dx. doi:10.1007/978-94-007-4676-3_16.

Nair, P.K.R. (1984). *Soil productivity aspects of agroforestry*. ICRAF, Nairobi.

Nair, P.K.R. (1985). Classification of agroforestry systems. *Agroforestry Systems*, 3, 97-128.

Nair, P.K.R. (1993). An introduction to agroforestry. *Kluwer Academic Publishers*, Dordrecht, The Netherlands, p. 489.

Ndah, H.T., Schuler, J., Uthes, S., Zander, P., Triomphe, B., Mkomwa, S., and Corbeels, M. (2015). Adoption potential for conservation agriculture in Africa: a newly developed assessment approach (QAToCA) applied in Kenya and Tanzania. *Land Degradation & Development* 26, 133–141. http://dx.doi:10.1002/ldr.2191.

Nave, L.E., Vance, E.D., Swanston, C.W., and Curtis, P.S. (2011). Fire effects on temperate forest soil C and N storage. *Ecological Applications*, 21, 1189-1201.

Neely, C., Bunning, S., and Wilkes, A. (2009). *Review of evidence on drylands pastoral systems and climate change: Implications and opportunities for mitigation and adaptation*. FAO. Land and Water Discussion Paper 8.

Neff, J.C., Townsend, A.R., Gleixner, G., Lehman, S.J., Turnbull, J., and Bowman, W.D. (2002). Variable effects of nitrogen additions on the stability and turnover of soil carbon. *Nature*, 419 (6910), 915–917.

Nieto, O.M., Castro, J., and Fernández-Ondoño, E. (2013). Conventional tillage versus cover crops in relation to carbon fixation in Mediterranean olive cultivation. *Plant Soil*, 365, 321–335.

Nkonya, E., Winslow, M., Reed, M., Mortimore, M., and Mirzabaev, A. (2011). Monitoring and assessing the influence of social, economic and policy factors on Sustainable Land Management in drylands. *Land Degradation & Development*, 22, 240-247.

Noble, I.R., Hu, S., Anokhin, Y.A., Carmin, J., Goudou, D., Lansigan, F.P., Osman-Elasha, B., and Villamizar, A. (2014). Adaptation needs and options. Pages 833–868. In: C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White (Eds.). *Climate change (2014): Impacts, adaptation, and vulnerability. Part A: global and sectoral aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA.

Novara, A., Gristina, L., Guaitoli, F., Santoro, A., and Cerdà, A. (2013). Managing soil nitrate with cover crops and buffer strips in Sicilian vineyards. *Solid Earth*, 4, 255–262. http://dx.doi:10.5194/se-4-255-2013.

Obia, A., Mulder, J., Martinsen, V., Cornelissen, G., and Børresen, T. (2016). In situ effects of biochar on aggregation, water retention and porosity in light-textured tropical soils. *Soil and Tillage Research*, 155, 35-44. http://dx.doi.org/10.1016/j.still.2015.08.002.

Olander, L.O., Bustamante, M.C.C., Asner, G.P., Telles, E., and do Prado, Z.A. (2005). Surface soil changes following selective logging in an Eastern Amazon forest. *Earth Interactions*, 9, 1-19.

Orr, B.J., Cowie, A.L., Castillo Sanchez, V.M., Chasek, P., Crossman, N.D., Erlewein, A., Louwagie, G., Maron, K., Metternicht, G.I., Minelli, S., Tengberg, A.E., Walter, S., and Welton, S. (2017*). Scientific Conceptual Framework for Land Degradation Neutrality.* A Report of the Science-Policy Interface of the UNCCD.

Page, S.E., Siegert, F., Rieley, J.O. Boehm,J.-D.V., Jaya A., and Limin, S. (2002). The amount of carbon released from peat and forest fires in Indonesia during 1997. *Nature*, 420, 61-65.

Palese, A.M., Vignozzi, N., Celano, G., Agnelli, A.E., Pagliai, M., and Xiloyannis, C. (2014). Influence of soil management on soil physical characteristics and water storage in a mature rainfed olive orchard. *Soil & Tillage Research*, 144, 96–109.

Papanastasis, V.P., Bautista, S., Chouvardas, D., Mantzanas, K., Papadimitriou, M., Mayor, A.G., Koukioumi, P., Papaioannou, A., and Vallejo, R.V. (2015). Comparative assessment of goods and services provided by grazing regulation and reforestation in degraded Mediterranean rangelands. *Land Degradation & Development*. http://dx.doi:10.1002/ldr.2368.

Pardo, G., del Prado, A., Martínez-Mena, M., Bustamante, M.A., Martín, J.A.R., Álvaro-Fuentes, J., and Moral, R. (2017). Orchard and horticulture systems in Spanish Mediterranean coastal areas: Is there a real possibility to contribute to C sequestration? *Agriculture, Environment & Ecosystems*. http://dx.

Paustian, K. et al., (2004). *Agricultural mitigation of greenhouse gases: science and policy options.* Council on Agricultural Science and Technology (CAST) report, R141 2004.

Paustain, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G.P., and Smith, P. (2016). Climate-smart soils. *Nature*, 532, 49–57.

Perez, C.A., Carmona, M.R., Fariña, J.M., and Armesto, J.J. (2009). Selective logging of lowland evergreen rainforests in Chiloe Island, Chile: Effects of changing tree species composition on soil nitrogen transformations. *Forest Ecology and Management*, 258, 1660–1668.

Peters, G.P., Andrew, R.M., Boden, T., Candell, J.G., Ciais, P., Le Quéré, C., Marland, G., Raupach, M.R., and Wilson, C. (2013). The challenge to keep global warming below 2°C. *Nature Climate Change*, 3, 4–6.

Peters, M., Herrero, M., Fisher, M., Erb, K.-H., Rao, I., Subbarao, G.V., Castro, A., Arango, J., Chará, J., Murgueitio, E., van der Hoek, R., Läderach, P., Hyman1, G., Tapasco, J., Strassburg, B., Paul, B., Rincón, A., Schultze-Kraft, R., Fonte, S., and Searchinger, T. (2013). Challenges and opportunities for improving eco-efficiency of tropical forage-based systems to mitigate greenhouse gas emissions. *Forrajes Tropicales*, 1, 156-167.

Peters, M., Rao, I., Fisher, M., Subbarao, G., Martens, S., Herrero, M., van der Hoek, R., Schultze-Kraft, R., Miles, J., Castro, A., Graefe, S., Tiemann, T., Ayarza, M., and Hyman, G. (2013). Tropical forage-based systems to mitigate greenhouse gas emissions. In: Hershey CH, and Neate, P (Eds.) *Eco-Efficiency: From vision to reality*. CIAT (Centro Internacional de Agricultura Tropical), Cali, Colombia. p. 171–190.

Plaza-Bonilla, D., Arrúe, J.L., Cantero-Martínez, C., Fanlo, R., Iglesias, A., and Álvaro-Fuentes, J. (2015). Carbon management in dryland agricultural systems. A review. *Agronomy for Sustainable Development*, 35, 1319–1334.

Poeplau, C., and Don, A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis. *Agriculture, Ecosystems and Environment*, 200, 33–41.

Poesen, J., Wesenael, B., Govers, G., Martinez-Fernandez, J., Desmet, B., Vandaele, K., Quine, T., and Degraer, G. (1997). Patterns of rock fragment cover generated by tillage erosion. *Geomorphology*, 18, 193-197.

Pohl, C., Rist, S., Zimmermann, A., Fry, P., Gurung, G., Schneider, F., Speranza, C., Kiteme, B., Boillat, S., Serrano, E., Hadorn, G., and Wiesmann, U. (2010). Researchers' roles in knowledge co-production: experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal. *Science and Public Policy*, 37, 267-281.

Poulton, P.R., Pye, E., Hargreaves, P.R., and Jenkinson, D.S. (2013). Accumulation of carbon and nitrogen by old arable land reverting to woodland. *Global Change Biology*, 9, 942–955.

Prasad, P., Satyanarayana, V., Murthy, V., and Boote, K.J. (2002). Maximizing yields in rice–groundnut cropping sequence through integrated nutrient management. *Field Crops Research*, 75, 9–21.

Pretty, J., and Bharucha, Z.P. (2015). Integrated pest management for sustainable intensification of agriculture in Asia and Africa. *Insects*, 6, 152–182. http://dx.doi:10.3390/*insects* 6010152.

Ramirez, K.S., Craine, J.M., and Fierer, N. (2012). Consistent effects of nitrogen amendments on soil microbial communities and processes across biomes. *Global Change Biology*, 18 (6), 1918–1927.

Ravi, S., Breshears, D.D., Huxman, T.E., and D'Odorico, P. (2010). Land degradation in drylands: interactions among hydrologic–aeolian erosion and vegetation dynamics. *Geomorphology*, 116, 236–245.

Reed, M.S. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation*, 141, 2417-2431.

Reed, M. S., Evely, A.C., Cundill, G., Fazey, I., Glass, J., Laing, A., Newig, J., Parrish, B., Prell, C., Raymond, C., and Stringer, L.C. 2010. What is social learning? *Ecology and Society,* 15 (4).

Reed, M. S., Buenemann, M., Atlhopheng, J., Akhtar-Schuster, M., Bachmann, F., Bastin, G., Bigas, H., Chanda, R., Dougill, A. J., Essahli, W., Evely, A. C., Fleskens, L., Geeson, N., Glass, J. H., Hessel, R., Holden, J., Ioris, A. A. R., Kruger, B., Liniger, H. P., Mphinyane, W., Nainggolan, D., Perkins, J., Raymond, C. M., Ritsema, C. J., Schwilch, G., Sebego, R., Seely, M., Stringer, L. C., Thomas, R., Twomlow, S., and Verzandvoort, S. (2011). Cross-scale monitoring and assessment of land degradation and sustainable land management: A methodological framework for knowledge management. *Land Degradation & Development*, 2, 261–271. doi:10.1002/ldr.1087.

Reed, M.S., and Stringer, L.C. and the international panel of experts. (2015). *United Nations Convention to Combat Desertification (UNCCD) 3rd scientific conference impulse report. Climate change and desertification: Anticipating, assessing & adapting to future change in drylands*. Available online at https://sustainabledevelopment.un.org/content/documents/19303sc.unccd.impulse-report.pdf

Reed, M.S., and Stringer, L.C. (2016). *Land Degradation, Desertification and Climate Change*: *Anticipating, Assessing and Adapting to Future Change*. Routledge, UK, p. 224.

Reed J, Van Vianen J, Barlow J, Sunderland T (2017) Have integrated landscape approaches reconciled societal and environmental issues in the tropics? *Land Use Policy* 63:481–49

Hannah Reid (2016) Ecosystem- and community-based adaptation: learning from community-based natural resource management, Climate and Development, 8:1, 4-9, http://dx.doi: 10.1080/17565529.2015.1034233.

Rist, L., Felton, A., Samuelsson, L., Sandström, C., and Rosvall, O. (2013). A new paradigm for adaptive management. *Ecology and Society*, 18 (4), 63.

Robertson, G.P. (2004). Abatement of nitrous oxide, methane and other non-CO2 greenhouse gases: the need for a systems approach. In: Field C.B, and Raupach, M.R. (Eds.). *The global carbon cycle. Integrating humans, climate, and the natural world* . pp. 493–506. Washington, DC*:* Island Press.

Rota, A., and Sperrandini, S. (2009). *Livestock and pastoralists. Livestock Thematic Papers. Tools for project design*. IFAD. Available online at www.ifad.org/lrkm/index.htm.

Roux, D., Stirzaker, R., Breen, C., Lefroy, E., and Cresswell, H. (2010). Framework for participative reflection on the accomplishment of transdisciplinary research programs. *Environmental Science & Policy*, 13, 733-741.

Rowell, A., and Moore, P.F. (2000). Global review of forest fires. IUCN/WWF, pp.64.

Runsten, L. and Tapio-Bistrom, M.L. (2011). *Land tenure, climate change mitigation and agriculture. Mitigation of Climate Change in Agriculture (MICCA) project*.

Santurf, J.A. (2005). What is forest restoration? Restoration of boreal and temperate forests. *CRC Press*, 3-11.

Sanz-Cobena, A., Lassaletta, L., Aguilera, E., del Prado, A., Garnier, J., Billen, G., Iglesias, A., Sánchez, B., Guardia, G., Abalos, D., Plaza-Bonilla, D., Puigdueta-Bartolomé, I., and Moral, R. (2016). Strategies for greenhouse gas emissions mitigation in Mediterranean agriculture: A review. *Agriculture, Ecosystems and Environment*. http://dx.doi.org/10.1016/j.agee.2016.09.038

Sathaye, J., Najam, A., Cocklin, C., Heller, T., Lecocq, F., Llanes-Regueiro, J., Pan, J., Petschel-Held, G., Rayner, S., Robinson, J., Schaeffer, R., Sokona, Y., Swart, R., Winkler, H., Burch, S., Corfee Morlot, C., Dave, R., Pinter, L., and Wyatt, A. 2007. Sustainable development and mitigation. In: Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer (Eds.). *Climate Change (2007): Mitigation.* Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press*, pp. 691-743.

Sayer, J., Sunderland, T., Ghazoul, J.-L., Pfund, J.-L., Sheil, D., Meijaard, E., Venter, M., Boedhihartono, A.K., Day, M., Garcia, C., van Oostenj, C., and Buck, L.E. (2013). Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land-uses. *Proceedings of the National Academy of Sciences of the United States of America, 110(21)*, 8349-8356. Available online at: http://dx.doi.org/10.1073/pnas.1210595110.

Schneider, F., Fry, P., Ledermann, T., and Rist, S. (2009). Social Learning Processes in Swiss Soil Protection—The 'From Farmer - To Farmer' Project. *Human Ecology*, 7 (4), 475-489.Scherr, S.J., Shames, S., and Friedman, R. (2012). From climate-smart agriculture to climate-smart landscapes. *Agriculture & Food Security*, 1, 12. http://dx.doi:10.1186/2048-7010-1-12.

Schnabel, R.R., Franzluebbers, A.J., Stout,W. L., Sanderson, M.A., and Stuedemann, J.A. (2001). The effects of pasture management practices. In: Follett, R.F., J. M. Kimble, and Lal, R. (Eds.). The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect), pp. 291–322. Boca Raton, FL: Lewis.

Scholes, R.J. and van der Merwe, M.R. (1996). Sequestration of carbon in savannas and woodlands. *Environmental Professional*, 18, 96-103.

Schwilch, G., Bachmann, F., and Liniger, H.P. (2009). Appraising and selecting conservation measures to mitigate desertification and land degradation based on stakeholder participation and global best practices. *Land Degradation & Development*, 20 (3), 308-326.

Schwilch, G., Bachmann, F., Valente, S., Coelho, C., Moreira, J., Laouina, A., Chaker, M., Aderghal, M., Santos, P., and Reed, M.S. (2012). A structured multi-stakeholder learning process for Sustainable Land Management. *Journal of Environmental Management*, 107, 52-63.

Schwilch, G., Bestelmeyer, B., Bunning, S., Critchley, W., Herrick, J., Kellner, K., Liniger, H.P., Nachtergaele, F., Ritsema, C.J., Schuster, B., Tabo, R., van Lynden, G., and Winslow, M. (2011). Experiences in monitoring and assessment of Sustainable Land Management. *Land Degradation & Development*, 22 (2), 214-225. http://dx.doi:10.1002/ldr.1040.

Schwilch, G., Hessel, R., and Verzandvoort, S. (2012b). *Desire for Greener Land. Options for Sustainable Land Management in Drylands*. Bern, Switzerland, and Wageningen, The Netherlands. University of Bern - CDE, Alterra - Wageningen UR, ISRIC - World Soil Information and CTA - Technical Centre for Agricultural and Rural Cooperation.

Schwilch, G., Liniger, H.P., and Hurni, H. (2014). Sustainable Land Management (SLM) Practices in Drylands: How Do They Address Desertification Threats? *Environmental Management*, 54 (5), 983-1004.

Scott, J. 1998. *Seeing it like a State: How certain schemes to improve the human condition have failed.* New Haven and London: Yale University Press.

Scott, A. (2011). Focusing in on focus groups: effective participative tools or cheap fixes for land use policy? *Land Use Policy*, 28, 684-694.

Setia, R., Marschner, P., Baldock, J., Chittleborough, D., Smith, P., and Smith, J. (2011). Salinity effects on carbon mineralization in soils of varying texture. *Soil Biology and Biochemistry*, 43, 1908–1916.

Shames, S., Buck, L.E., and Scherr, S.J. (2011). Reducing costs and improving benefits in smallholder agriculture carbon projects: implications for going to scale. In: Wollenberg E, Nihart A, Tapio-Bistrom M, and Grieg-Gran, M. (Eds.). *Agriculture and Climate Change Mitigation*. London, UK: Earthscan.

Shaxson, F., and Barber, R. (2003). *Optimizing soil moisture for plant production. The significance of soil porosity*. FAO Soils Bulletin 79. Rome, Italy.

Shvidenko, A., Barber, D.V., Persson, R., et al., (2005). Forest and wood- land systems. In: Hassan R, Scholes R, and Ash N (Eds.). *Millennium Ecosystem Assessment: ecosystems and human well-being – current state and trends*. Cambridge, UK: Cambridge University Press.

Sietz, D., Fleskens, L., and Stringer, L.C. (2017). Learning from non-linear ecosystem dynamics is vital for achieving land degradation neutrality. http://dx.doi: 10.1002/ldr.2732.

Singh, R. (2002). Effect of integrated nutrient management in cluster bean (Cyamopsis tetragonoloba)–wheat (Triticum aestivum) cropping system under western Rajasthan condition. *Indian Journal of Agronomy*, 47, 41–45.

Smith, K.A., Mc Taggart, I.P., and Tsuruta, H. (1997). Emissions of N_2O and NO associated with nitrogen fertilization in intensive agriculture, and the potential for mitigation. *Soil Use and Management*, 13, 296–304. http://dx.doi:10.1111/j.1475-2743.1997.tb00601.x.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., and Smith, J. (2008). Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society* B, 363, 789–813.

Smith, P., Bustamante, M., and Ahammad, H. et al. (2014). Agriculture, forestry and other land-use (AFOLU). In: *Climate Change 2014: Mitigation of Climate Change.* Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 811–922. Cambridge University Press, Cambridge.

Smith, P. et al., (2016). Biophysical and economic limits to negative CO_2 emissions. *Nature Climate Change*, 6, 42–50. http://dx.doi:10.1038/nclimate2870.

Soler, C.M.T., Bado, V.B., Traore, K., Bostick, W.M., Jones, J.W., and Hoogenboom, G. (2011). Soil organic carbon dynamics and crop yield for different crop rotations in a degraded ferruginous tropical soil in a semi-arid region: a simulation approach. *Journal of Agricultural Science*, 149, 579-593.

Soussana, J.F., Loiseau, P., Vuichard, N., Ceschia, E., Balesdent, J., Chevallier, T., and Arrouays, D. (2004). Carbon cycling and sequestration opportunities in temperate grasslands. *Soil Use and Management*, 20, 219–230.

Stavi, I. (2013). Biochar use in forestry and tree-based agroecosystems for increasing climate change mitigation and adaptation. *The International Journal of Sustainable Development and World Ecology*. http://dx.doi:10.1080/13504509.2013.773466.

Stavi, I., Bel, G., and Zaady, E. (2016). Soil functions and ecosystem services in conventional, conservation, and integrated agricultural systems. A review. *Agronomy for Sustainable Development*, 36 (32).

Sthapit, B., Lamers, H., and Rao, R. (2013). *Custodian farmers of agricultural biodiversity: selected profiles from South East Asia.* Proceedings of the Workshop on Custodian Farmers of Agricultural Biodiversity. Biodiversity International. New Delhi, India.

Stockmann, U., Adams, M.A., Crawford, J.W., Field, D.J., Henakaarchchi, N., Jenkins, M., Minasny, B., McBratney, A.B, de Courcelles, V. de R., Singh, K., Wheeler, I., Abbott, L., Angers, D.A., Baldock, J., Bird, J., Brookes, P.C., Chenu, C., Jastrow, J.D., Lal, R., Lehmann, J., O'Donnell, A.G., Parton, W.J., Whitehead, D., and Zimmermann, M. (2013). The knowns, known unknowns and unknowns of sequestration of soil organic Carbon. *Agriculture, Ecosystems and Environment,* 164 (1), 80–99.

Stringer, L., Reed, M., Dougill, A., Seely, M., and Rokitzki, M. (2007). Implementing the UNCCD: participatory challenges. *Natural Resources Forum*, 31, 198-211.

Tàbara, J. D., and Pahl-Wostl, C. (2007). Sustainability learning in natural resource use and management. *Ecology and Society,* 12 (2), 3.

Tejada, M., and Benítez, C. (2014). Effects of crushed maize straw residues on soil biological properties and soil restoration. *Land Degradation and Development*, 25, 501–509. http://dx. doi:10.1002/ldr.2316.

Thomas, R.J., Akhtar-Schuster, M., Stringer, L.C., Marques, M.J., Escadafal, R., Abraham, E., and Enne, G. (2012). Fertile ground? Options for a science-policy platform for land. *Environmental Science Policy*, 16, 122-135.

Tian, H.Q., Lu, C.Q., Melillo, J., Ren, W., Huang, Y., Xu, X.F., Liu, M., Zhang, C., Chen, G., Pan, S., Liu, J., and Relly, J. (2012). Food benefit and climate warming potential of nitrogen fertilizer uses in China. *Environmental Research Letters*, 7. http://dx. doi:10.1088/1748-9326/7/4/044020.

Tibke, G. (1988). Basic principles of wind erosion control. *Agriculture, Ecosystems and Environment*, 22(23), 203-122.

Tubiello, F.N. Salvatore, M., Ferrara, A. F., House, J., Federici, S., Rossi, S., Biancalani, R., Condor Golec, R. D., Jacobs, H., Flammini, A., Prosperi, P., Cardenas-Galindo, P., Schmidhuber, J., Sanz Sanchez, M. J., Srivastava, N., and Smith, P. (2015). The Contribution of Agriculture, Forestry and other Land-use activities to Global Warming, 1990–2012. *Global Change Biology* 21 (7), 2655-2660. http://dx.doi: 10.1111/gcb.12865.

UNCCD. (2013). *A Stronger UNCCD for a Land-Degradation Neutral World*, Issue Brief. Bonn, Germany.

UNCCD. (2015a). *Climate change and land degradation: Bridging knowledge and stakeholders.* Outcomes from the UNCCD 3rd Scientific Conference, Cancun, Mexico.

UNCCD. (2015b). *Science-Policy Interface: progress report and work programme 2016-2017* (ICCD/COP(12)/CST/6.

UNFCCC. (2015). *Conference of the Parties in its twenty-first session*. FCCC/CP/2015/10/ Add.1.

UNGA. (2011). *Addressing desertification, land degradation and drought in the context of sustainable development and poverty eradication*.

UNGA. (2015a). *Sustainable Development Summit: 17 goals to transform our World*.

UNGA. (2015b). *Transforming our world: the 2030 Agenda for Sustainable Development. Resolution adopted by the UNGA on 25 September 2015 (A/RES/70/1).* Available online at: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

United Nations. (1993). *Agenda 21. Programme of Action for Sustainable Development of the United Nations (UNCED)*. United Nations, New York. 294 pages.

United Nations Conference on Sustainable Development (RIO+20). (2012). *The Future We Want. Outcome document.* Rio de Janeiro, Brazil, 20–22 June.

Uriarte, M., and Chazdon, R.L. (2016). Incorporating natural regeneration in forest landscape restoration in tropical regions: Synthesis and key research gaps. *Biotropica*, 48, 915–924. http://dx.doi: 10.1111/btp.12411

Ussiri, D.A.N., Lal, R., and Jareck, M.K. (2009). Nitrous oxide and methane emissions from long-term tillage under a continuous corn cropping system in Ohio. *Soil and Tillage Research*, 104(2), 247-255.

Valdecantos, A., Vallejo, V.R., Baeza, J., Bautista, S., Boeschoten, M., Christoforou, M., Daliakopoulos, I.N., González-Pelayo, O., Guixot, L., Keizer, J.J., Panagea, I., Quaranta, G., Salvia, R., Santana, V., Tsaltas, D., and Tsanis, I.K. (2016). *Report on the restoration potential for preventing and reversing regime shifts*. CASCADE project Scientific Reports, report number 13, pp.104.

Van Alphen, B.J. (2000). *Precision Nitrogen fertilization: a case study for Dutch arable farming*. http://edepot.wur.nl/314598.

Van Leeuwen, J.P., Lehtinen, T., Lair, G.J., Bloem, J., Hemerik, L., Ragnarsdóttir, K.V., Gísladóttir, G., Newton, J.S., and de Ruiter, P.C. (2015). An ecosystem approach to assess soil quality in organically and conventionally managed farms in Iceland and Austria. *Soil*, 1, 83–101. http://dx.doi:10.5194/soil-1-83-2015.

Ventier, M., Ladier, J., and Rey, F. (2014). *Erosion control on forest soils with vegetation, under global change.* École nationale des eaux et forêts. Special Issue p.12.

Verhulst, N., Nelissen, V., Jespers, N., Haven, H., Sayre, K.D. Raes, D., Deckers, J., and Govaerts, B. (2011). Soil water content, maize yield and its stability as affected by tillage and crop residue management in rainfed semi-arid highlands. *Plant and Soil*, 344 (1-2), 73-85.

Vicente-Vicente, J.L., García-Ruiz, R., Francaviglia, R., Aguilera, E., and Smith, P. (2016). Soil carbon sequestration rates under Mediterranean woody crops using recommended management practices: a meta-analysis. *Agriculture, Ecosystems & Environment*, 235, 204–214.

Vilagrosa, A., Llorca, M., Llovet, J., Puértolas, J., Chirino, E., Bautista, S., Mayor, A. G., Urgeghe, A. M., Luis, V. C., Alloza, J. A., and Vallejo, V. R., 2009. Restoration actions to combat desertification and the effects over ecosystem functionality and plant diversity: A demonstration project in Albatera (Alicante, Spain). In: *Ecological Engineering: from concepts to applications.* Paris, Francia.

Villela, D.M., Nascimento, M.T., Aragão, L.E.O.C., and Gama, D.M. (2006). Effect of selective logging on forest structure and nutrient cycling in a seasonally dry Brazilian Atlantic forest. *Journal of Biogeography*, 33, 506–516.

Vitousek, PM, Naylor, R., Crews, T., David, M.B., Drinkwater, L.E., Holland, E., Johnes, P.J., Katzenberger, J., Martinelli, L.A., Matson, P.A., Nziguheba, G., Ojima, D., Palm, C.A., Robertson, G.P., Sanchez, P.A., Townsend, A.R., and Zhang, F.S. (2009), Agriculture: Nutrient imbalances in agricultural development. *Science*, 324, 1519–1520.

Wang, Z., Hoffmann, T., Six, J., Kaplan, J.O., Govers, G., Doetterl, S., and Van Oost, K. (2017). Human-induced erosion has offset one-third of carbon emissions from land cover change. *Nature Climate Change*, 7 (5), 345-349.

Wei, W., Chen, D., Wang, L., Daryanto, S., Chen, L., Yu, Y., Lu, Y., Sun, G., and Feng, T. (2016). Global synthesis of the classifications, distributions, benefits and issues of terracing. *Earth-Science Reviews,* 159, 388–403. http://dx.doi:10.1016/j.earscirev.2016.06.010.

Wilhelm, W.W., Johnson, J.M.F., Hatfield, J.L., Voorhees, W.B., and Linden, D.R. (2004). Crop and soil productivity response to corn residue removal: A literature review. *Agronomy Journal*, 96, 1-17.

Williamson, P. (2016). Scrutinizing CO_2 removal methods. *Nature*, 530, 153–155.

Wolfgramm, B., Liniger, H.P., and Nazarmavloev, F. (2014). *Integrated watershed management in Tajikistan.* IWSM policy brief. University of Bern, Centre for Development and Environment (CDE), Switzerland.

Wolf, D., Amonette, J.E., Street-Perrott, F.A., Lehmann, J., and Joseph, S. (2010). Sustainable biochar to mitigate global climate change. *Nature Communications*, 1 (56). doi: 10.1038/ncomms1053.

World Bank. (2008a). *Global Monitoring Report, 2008. MDGs and the Environment: Agenda for Inclusive and Sustainable Development*. The International Bank for Reconstruction and Development & World Bank: Washington, DC.

World Bank, (2008b). *Sustainable Land Management Sourcebook*. The World Bank, Washington D.C. 178pp. Available online at http://siteresources.worldbank.org/EXTARD/Resources/336681-1215724937571/eBook.pdf.

WOCAT. (2002). *Questionnaire on SWC Technologies. A Framework for the Evaluation of Soil and Water Conservation (revised).* Centre for Development and Environment. Institute of Geography, University of Berne, Berne, 63 pages.

WOCAT. Available online at https://www.wocat.net/en/knowledge-base/documentation-analysis/global-regional-books.html

Wolosin, M., Breitfeller, J., and Schaap, B. (2016). The Geography of REDD+ Finance Deforestation, Emissions, and the Targeting of Forest Conservation Finance. Washington, DC: Forest Trends. Available online at: http://www.forest-trends.org/documents/files/doc_5334.pdf.

Wu, W., and Ma, B. (2015). Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. *Science of the Total Environment*, 512, 415– 427.

Young, A. (1989). *Agroforestry for Soil Conservation*. CAB International, Wallingford, UK.

Zdruli, P., Pagliai, M., Kapur, S., and Cano, A. (2010). What we know about the saga of land degradation and how to deal with it? In: Zdruli, P., Pagliai, M.,Kapur, S., Cano, A.F. (Eds.). *Land Degradation and Desertification: Assessment, Mitigation and Remediation* 2010, Part 1, pp. 3e14. http://dx.doi:10.1007/978-90-481-8657-0_1.

Zhang, X, Li, H., He, J., Wang, Q., and Golabi, M.H. (2009). Influence of conservation tillage practices on soil properties and crop yields for maize and wheat cultivation in Beijing, China. *Australian Journal of Soil Research,* 47(4).

Zhang, X., Liu, X., Zhang, M., Dahlgren, R.A., and Eitzel, M. (2010). A review of vegetated buffers and meta-analysis of their mitigation efficacy in reducing nonpoint source pollution. *Journal of Environmental Quality*, 29, 76-84.

Zornoza, R., Rosales, R. M., Acosta, J. A., de la Rosa, J. M., Arcenegui, V., Faz, Á., and Pérez-Pastor, A. (2016). Efficient irrigation management can contribute to reduce soil CO 2 emissions in agriculture. *Geoderma*, 263, 70-77.

Annex 1. Case examples to illustrate technologies from Chapter 2

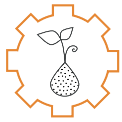
SLM technology groups:
(1)Integrated soil fertility management,
(2) Minimum soil disturbance,
(3) Pest and diseases control,
(4) Soil erosion control,
(5) Vegetation management,
(6) Water management,
(7) Reducing deforestation,
(8) Afforestation and reforestation,
(9) Sustainable forest management,
(10) Forest restoration,
(11) Grazing pressure management,
(12) Animal waste management,
(13) Agroforestry (trees combined with crops, grasses and/or animals),
(14) Agropastoralism (animals grazing in croplands).

LAND USE: CROPLAND

TECHNOLOGY GROUP: Integrated soil fertility management

SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
Application of organic fertilizers	Organic fertilizer (compost; straw pen manure with litter or household waste) to enhance productivity by improving the structure and fertility of the soil, as well as its capacity for infiltration and water retention. It stimulates biological activity in the soil and increases yields and production.	WOCAT database reference: T_MLI009en
Biochar soil amendment to increase biomass productivity, and sequester C	Application of fine-grained charcoal as an amendment to improve the soil quality and mitigate GHG emissions from croplands.	WOCAT database reference: T_ITA017en
Production and application of bio-humus	Use soil red worms for processing fresh manure filled into a trench.	WOCAT database reference: T_KYR006en
Planting pits for soil fertilization and moisture improvement	The planting pits are filled with organic vegetative material mixed with decomposing manure to form a reservoir of nutrients. The main objective is to improve soil fertility, reducing soil erosion, improving moisture infiltration and retention, and enabling the plantation to withstand the dry months.	WOCAT database reference: T_UGA026en
Changing fertilizer application rate, fertilizer type, timing, precision application, inhibitors	Look for the optimum synthetic fertilizer type, application rate and timing. This is a common practice in intensive agriculture of crops and orchards, in particular where N leakage to the water table is a problem to water pollution.	van Alphen, B.J. 2000. Precision Nitrogen fertilization: a case study for Dutch arable farming. http://edepot.wur.nl/314598.

LAND USE	TECHNOLOGY GROUP	SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
LAND USE: CROPLAND	TECHNOLOGY GROUP: Integrated soil fertility management	**Straw retention in rice paddies**	Rice yield and nitrogen utilization efficiency under alternative straw management Practices.	Eagle, J.A., Bird, J.A., Horwath, W.R., Linquist, B.A., Brouder, S.M., Hill, J.E. and van KesseL, C. 2000. Rice Yield and Nitrogen Utilization Efficiency under Alternative Straw Management Practices. Agronomy Journal, 92, 1096–1103.
LAND USE: CROPLAND	TECHNOLOGY GROUP: Integrated soil fertility management	**Composting using Indigenous Microorganism and application**	By taking advantage of natural process of decomposition of organic matter by microorganism's compost is produced from weeds and bio waste available in the farm. Compost is a rich source of organic matter which improves soil tilth. Its decomposition slowly releases available nutrients for plant uptake. The compost is used later on side or in nearby cropland farms.	WOCAT database reference: T_PHI063en
LAND USE: CROPLAND	TECHNOLOGY GROUP: Integrated soil fertility management	**Micro-fertilization and seed priming**	Micro-fertilization is the application of small amounts of mineral fertilizer to the planting hole.	WOCAT database reference: T_MLI001en
LAND USE: CROPLAND	Minimum soil disturbance	**Strip Tillage**	Cropping system for maize which reduces the reworking of the soil to the stripes, in which the seeds are planted.	WOCAT database reference: T_SWI007en
LAND USE: CROPLAND	Minimum soil disturbance	**Permanent soil cover**	Maintenance of continuous soil cover alternating crops and cover crops as a practice to improve soil quality and reduce diffuse agricultural water pollution.	WOCAT database reference: T_ITA010en
LAND USE: CROPLAND	Minimum soil disturbance	**No-till technology**	Growing crops (or pastures) without disturbing the soil through tillage, direct seeding/planting.	WOCAT database reference: T_MOR010en



LAND USE	TECHNOLOGY GROUP	SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
CROPLAND	Minimum soil disturbance	**Direct planting**	Leaving crop residues on the soil surface and subsequent planting through the mulch.	WOCAT database reference:T_GHA001en
CROPLAND	Minimum soil disturbance	**Mulching in croplands**	Mulching involves spreading waste crop after harvesting. Covering the soil with mulch protects it against wind and water erosion and provides nutrients which has a positive effect on yields and food security.	WOCAT database reference: T_NIG079en
CROPLAND	Pest and diseases control	**Integrated production and pest management**	All available techniques for combatting pests, while eliminating or keeping pesticide use at economically justified levels. It reduces risks to human and animal health and to the environment.	WOCAT database reference: T_MLI021en
CROPLAND	Pest and diseases control	**Application of biological agents to increase crop resistance**	Use of biological agents as facilitators and soil amendments.	WOCAT database reference: T_GRE013en
CROPLAND	Pest and diseases control	**Use of phyto-pesticides**	Using environmentally friendly phyto-pesticides, made from natural plant extracts (potatoes, onions or tomato stalks as well as from garlic, pepper, dandelion, common wormwood and thorn apple extracts) to help combat pests and diseases.	WOCAT database reference: T_TAJ380en
CROPLAND	Pest and diseases control	**Biological pest control**	Ecological engineering aiming primarily at the regulation of pest species, through the provision of habitats for their natural enemies. Other ecosystem services, such as pollination may simultaneously be enhanced.	WOCAT database reference: T_PHI065en
CROPLAND	Pest and diseases control	**Trees as buffer zones**	Tree rows established to prevent pest from crossing in between blocks. Further, the technology provides haven for flora and fauna which are endemic in the area.	WOCAT database reference: T_PHI054en

LAND USE: CROPLAND

TECHNOLOGY GROUP: Soil erosion control *Structural measures*

SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
Soil Bund with Contour Cultivation	It is a structural measure with an embankment of soil or stones or soil and stones, constructed along the contour and stabilized with vegetative measures (grass and fodder trees).	WOCAT database reference: T_ETH043en
Vegetated earth-banked terraces	Earth-banked terraces are 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.	WOCAT_QT_Summary-T_SPA002en
Soil /stone bunds	Stone bund is an embankment of stone constructed across the slope following the contour.	WOCAT database reference: T_ETH028en
Stone lines / Stone walls	Stone constructions along contours that are and do not pond runoff water but instead, they slow down the speed, filter it and spread the water over the field, thus enhancing water infiltration and reducing soil erosion. Usually are built in series running along the slope.	WOCAT database reference: T_KEN660en
Rockwall Terracing	Rockwall terracing refers to the piling of stones or rocks along contour lines to reduce soil erosion in hilly areas.	WOCAT database reference: T_PHI049en
Traditional cut-off drain	Graded ditch out of soil and stones to protect the fields below from water runoff. It can be done across several land uses types.	WOCAT database reference: T_ETH031en

LAND USE: CROPLAND

TECHNOLOGY GROUP: Soil erosion control *Structural measures*

SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
Terracing in watershed	Reshaping unproductive land into a series of levelled, gently-sloping platforms creates conditions suitable for cultivation and prevents accelerated erosion.	WOCAT database reference: T_AS632en
Semi-circular bunds (for crops and forest/rangeland)	Semi-circular bunds are used to rehabilitate degraded, denuded and hardened land for crop growing, grazing or forestry. This technique involves building low embankments with compacted earth or stones in the form of a semi-circle with the opening perpendicular to the flow of water and arranged in staggered rows. They are constructed on gently to moderately sloping pediments and plateau areas in order to rehabilitate areas that are degraded, denuded and/or affected by soil crusting.	WOCAT database reference: T_NIG071en
Progressive bench terrace	Bench terraces are progressively expanded to form a fully developed terrace system in order to reduce runoff and soil erosion on medium- to high- angled loess slopes.	WOCAT database reference: T_CHN053en
Haraghie stone bund	A structure built from stone and soil, constructed along the contour of the crop area to minimize soil erosion and prevent runoff damage from downstream fields.	WOCAT database reference: T_ETH046en

LAND USE: CROPLAND

TECHNOLOGY GROUP: Soil erosion control *Vegetative measures*

SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
Shelterbelts and windbreaks, live hedges	Belts of trees, planted in a rectangular grid pattern or in strips within, and on	WOCAT database reference: T_CHN048en
Vegetative strips	Within individual cropland plots, strips of land are marked out on the contour and left un-ploughed in order to form permanent, cross-slope barriers of naturally established grasses and herbs.	WOCAT database reference: T_PHI003en
Tree row and grass strip to sustain filtering	Tree planting and establishment of grass strips along the river. Grass is planted to stabilize steep slopes and to supply material for the construction of tea baskets. The vegetation prevents surface water and eroded soil flowing from the agricultural fields directly into the river. Therefore, sediments and chemicals used on the field are retained in the riparian soils and do not pollute the river.	WOCAT database reference: T_KEN654en
Paved and grassed waterways	Artificial drainage channel constructed along the steepest slope to receive runoff from cutoff drains and graded structures and drain to the natural waterway safely. Vegetative waterway is constructed in areas where stone is not available and in gentle slopes. Paved waterways are suitable in steeper terrains and areas with large amount of stones. The waterway carries excess water to the river, reservoirs or gullies safely without creating erosion.	WOCAT database reference: T_ETH051en
Living fences / windbreaks	Planting of herbaceous plants or trees along property boundaries to serve as windbreaks and as sources of fodder and fuel.	WOCAT database reference: T_PHI013en

LAND USE	TECHNOLOGY GROUP	SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
LAND USE: CROPLAND	TECHNOLOGY GROUP: Soil erosion control *Combined measures*	**River bank stabilization**	Plantation of long root trees in lower catchment areas and tree plantation to stabilize riverbank are most common practices. They can be considered also as revegetation measures and can be done across several land uses types.	WOCAT database reference: T_KEN664en WOCAT database reference: T_AS23en
LAND USE: CROPLAND	TECHNOLOGY GROUP: Soil erosion control *Combined measures*	**Water-spreading weirs**	Structures that span the entire width of a valley to spread floodwater over the adjacent land area.	WOCAT database reference: T_CHA001en
LAND USE: CROPLAND	TECHNOLOGY GROUP: Soil erosion control *Combined measures*	**Gully control and catchment protection**	Integrated gully treatment consisting of several simple practices including stone and wooden check dams, cut-off drains and reforestation in sediment traps.	WOCAT database reference: T_BOL004en
LAND USE: CROPLAND	TECHNOLOGY GROUP: Soil erosion control *Combined measures*	**Integrated runoff water management**	Integrated runoff water management is a system of integrated runoff water and drainage management that allows cul-tivation in a swampy valley bottom. The System divides the land into raised beds which are separated by furrows, acting as drainage channels.	WOCAT database reference: T_UGA005en
LAND USE: CROPLAND	TECHNOLOGY GROUP: Vegetation management	**Seed priming**	Seed priming consists of soaking seeds for 8 hours prior to sowing and micro fertilization is the application of small amounts of mineral fertilizer to the plant-ing hole.	WOCAT database reference: T_MLI001en
LAND USE: CROPLAND	TECHNOLOGY GROUP: Vegetation management	**Choice plant species/varieties**	Introducing vegetable species and varieties using succession planting. For example, maintaining a large number of mango and garcinia genetic resources in Western Ghats (India).	Sthapit, B., Lamers, H. and Rao, R. 2013. Custodian farmers of agricultural biodiversity: selected profiles from South East Asia. Proceedings of the Workshop on Custodian Farmers of Agricultural Biodiversity. 11-12 February. Biodiversity International. New Dehli, India.

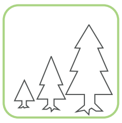
LAND USE: CROPLAND

TECHNOLOGY GROUP: Vegetation management

SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
Traditional shifting cultivation	It is a rain-fed cultivation practice for subsistence, where natural vegetation is cleared off by slash-and-burn, to grow mixed annual crop for one year and then the land is left fallow for 3-5 years for natural regeneration. In certain type of tropical soils this practice could trigger soil organic carbon depletion.	WOCAT database reference: T_BAN003en
Long term fallow or set-aside	Arable land that is set aside or not cultivated for an extended period. In the first two to three years the arable land becomes overgrown with annual and biennial plants (weedy fallow). In the next five to seven years rhizomatous plants dominate and, as the soil becomes more compact, are supplanted by loosely bunched and, later, densely bunched grasses. Then the vegetation typical for natural meadow or steppe conditions develops.	Scatena, F.N., et al. 1996. Cropping and fallowing sequences of small farms in the "terra firme" landscape of the Brazilian Amazon: a case study from Santarem, Para. Ecological Economics, 29-40.
Multiple Cropping, intercropping	It is an agronomic practice that consist in growing two or more crops on the same land simultaneously in a given growing season.	WOCAT database reference: T_TAN001en WOCAT database reference: T_ETH011en WOCAT database reference: T_TAJ007en
Green cover in perennial woody crops	Perennial grasses in orchards and vine-yards between rows to provide perma-nent soil cover.	McGourty, G. 1994. Cover crops for North Coast vineyards. Practical Winery & Vineyard 15 (2), 8–15.

Land use	Management	SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
LAND USE: CROPLAND	Vegetation management	**Perennial cropping systems**	Woody crops such olive groves, fruit trees or vineyards. Organic and conventional perennial cropping systems, including citrus, subtropical trees, other fruit trees, tree nuts, vineyards, and olives.	Aguilera, E., Guzmán, G. and Alonso, A. 2015. Greenhouse gas emissions from conventional and organic cropping systems in Spain. II. Fruit tree orchards. Agronomy for Sustainable Development, 35 (2), 725–737
LAND USE: CROPLAND	Vegetation management	**Crop rotation**	It is an agronomic practice that consists in the successive cultivation of different crops in a specified order on the same fields, in contrast to a one-crop system or to haphazard crop successions. Throughout human history, wherever food crops have been produced, some kind of rotation cropping appears to have been practiced.	WOCAT database: T_CHL002en
LAND USE: CROPLAND	Water management *Usage of sustainable irrigation systems*	**Cascading Rock Irrigation Channel**	Irrigation channel constructed of stones and on rocky slopes to channel water runoff from the high mountains at the valley floor.	WOCAT database reference: T_TAJ371en
LAND USE: CROPLAND	Water management *Usage of sustainable irrigation systems*	**Spate irrigation**	It is a traditional water diversion and spreading technique under which seasonal floods of short duration are diverted from ephemeral rivers (wadis) to irrigate cascades of leveled and bunded fields in the coastal plains.	WOCAT database reference: T_ERI001en
LAND USE: CROPLAND	Water management *Usage of sustainable irrigation systems*	**Spiral water pumps**	Method of pumping water by using an undershot water wheel which has a scoop connected to a spiral tube. Spiral water pumps can carry water from the river to fields that are up to 30 meters higher than the river without the input of electricity or fuel.	WOCAT database reference: T_TAJ394en
LAND USE: CROPLAND	Water management *Usage of sustainable irrigation systems*	**Micro-irrigation systems**	Drip irrigation - delivering small amounts of water directly to the plants through pipes.	WOCAT database: T_MLI013en

		SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
LAND USE: CROPLAND	Water management *Water harvest*	**Water harvesting from concentrated runoff for irrigation purposes**	Water harvesting systems, collecting the runoff from hillslopes, can be found at regular distances to supply water points.	Frot, E., van Wesemael, B., Benet, A.S. and House, M.A., 2008. Water harvesting potential in function of hillslope characteristics: A case study from the Sierra de Gador (Almeria province, south-east Spain). Journal of Arid Environments, 72(7), 1213-1231.
LAND USE: CROPLAND	Water management *Water harvest*	**Water harvest**	Rainwater catchment system, such as roof rainwater catchment system feeding underground water tank.	WOCAT database reference: T_BOT004en
LAND USE: CROPLAND	Water management *Water harvest*	**Recharge of groundwater; water collection to enable off-season irrigation**	Storage efficiency in off-seasons a water management practice in which water is applied in advance of the growing season.	Stone, L.R., Schlegel, A.J., Lamm, F.R. and Spurgeon, W.E. 1994. Storage efficiency of preplant irrigation. Journal of Soil and Water Conservation, 49 (1), 72-76.
LAND USE: CROPLAND	Water management *Drainage*	**Sub-surface drainage**	Sub-surface drainage on irrigated lands in saturated and salinized soils by means of sub-soil drainage pipes. It can be considered a land base agriculture mitigation option, where through water drainage management N runoff leaching results id reduce N2O emissions.	WOCAT database reference: T_RSA010af
LAND USE: CROPLAND	Water management *Drainage*	**Mid-season rice paddy drainage**	Mid-season drainage involves the removal of surface flood water from the rice crop for about seven days towards the end of tillering.	http://www.climatetechwiki.org/technology/rice-mid-season-drainage



LAND USE: FOREST / WOODLAND

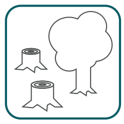
TECHNOLOGY GROUP: Afforestation/Reforestation

SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
Afforestation with species mix at different scales	Establishment of a forest or stand of trees in an area where there was no previous tree cover (in the last 50 years according to UNFCCC, 2002).	WOCAT database reference: T_ERI002en
Land reclamation by introducing native forest species	Native trees, shrubs and grasses planted through participatory action.	Martínez- Palacios, A., Prat, C. and Ríos-Patrón, E. 2015. Land reclamation by agave forestry with native species in the mountains of Michoacan state. In: Understanding Mountain Soils: A contribution from mountain areas to the International Year of Soils 2015, by Romeo, R., Vita, A., Manuelli, S., Zanini, E., Freppaz, M. & Stanchi, S. (ed). pp 97-99. FAO. 2015.
Reforestation in former forest lands	Establishment of new forest areas in formerly (less than 50 years according to UNFCCC, 2002) deforested lands.	Murthy, I.K., Alipuria, A.K. and Ravindranath, N.H. 2012. Potential for increasing carbon sink in Himachal Pradesh, India. Tropical Ecology 53(3), 357-369. Agrawal, A.. 1996. Reforestation in Ecuador's Dry Forest. Desert Plants, pp 12-14.
Reintroduction of forest cover after wildfires	Plantations after fire in the Mediterranean region.	WOCAT database reference: T_SP012en

LAND USE	CATEGORY	SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
LAND USE: FOREST / WOODLAND	Afforestation/Reforestation	**Forest establishment in semi-arid land**	Project implemented to put into practice the best available restoration techniques for the restoration of semi-arid ecosystems, to disseminate and transfer this technology to forest managers, to help in disseminating Forest Administration initiatives for	Vilagrosa, A., Llorca, M., Llovet, J., Puértolas, J., Chirino, E., Bautista, S., Mayor, A. G., Urgeghe, A. M., Luis, V. C., Alloza, J. A., and Vallejo, V. R., 2009. Restoration actions to combat desertification and the effects over ecosystem functionality.
LAND USE: FOREST / WOODLAND	Water management; Drainage	**Trees for bio-drainage**	Bio drainage systems make use of the evapotranspirative power of plants, especially of trees, to lower groundwater tables and it could be an alternative providing several advantages as the negative side effects of conventional drainage systems are reduced and, as they require less investment, may find quicker application. Biological systems provide for such an alternative, although the availability of land is a decisive factor in the eventual establishment of bio drainage systems. However, in most cases, in developing countries water scarcity is the predominant feature and not land scarcity.	Heuperman, A.F., Kapoor, A.S. and Denecke, H.W.. 2002. Biodrainage - Principles, Experiences and Applications. International Programme for Technology and Research in irrigation and Drainage Food and Agriculture Organization of the United Nations.
LAND USE: FOREST / WOODLAND	Fire control, pest and diseases control	**Management for forest fire prevention**	Promotion of fire resistant species. Such as combination of clearing of fire-prone seeder species and planting of more fire-resistant re-sprouting species directs the vegetation to later successional stages.	Jucker, M., Liniger, H., Valdecantos, A., and Schwilch, G., 2016. Impacts of Land Management on the Resilience of Mediterranean Dry Forests to Fire. Sustainability, 8, 981: http://dx.doi.org/10.3390/su8100981.

LAND USE	TECHNOLOGY GROUP	SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
FOREST / WOODLAND	Fire control, pest and diseases control	**Controlling anthropogenic disturbances such as fire and pest outbreaks**	Cleared strip network for fire prevention: firebreak. The basic principle of a firebreak network is to split continuous forest areas (where a lot of fuel is built up) into smaller patches separated by vegetation-free strips in order to prevent large fores.	Xanthopoulos, G., Caballero, D., Galante, M., Alexandrian, D., Rigolot, E. and Marzano, R. 2006. Forest fuels management in Europe. In 'Fuels Management – How to Measure Success', 28–30 March 2006, Portland, OR. (Eds PL Andrews, BW Butler) USDA Forest Service, Rocky Mountain Research Station, Proceedings RMRS-P-41, 29–46.
		Control of wildfires in peatlands	Forest fire control comprises three activity components: prevent forest fire from occurring; extinguish forest fires rapidly while they are still small; use fire only for certain purposes and on a limited scale.	Adinugroho, W.C., Nyoman, I., Suryadiputra, N., Saharjo, B.J. and Siboro, L. 2005. Manual for the Control of Fire in Peatlands and Peatland Forest. Climate Change, Forests and Peatlands in Indonesia Project. Wetlands International - Indonesia Program.

LAND USE	TECHNOLOGY GROUP	SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
LAND USE: FOREST / WOODLAND	TECHNOLOGY GROUP: Forest restoration	**Assisted regeneration**	Assisted natural regeneration (ANR) is a simple, low-cost forest restoration method that can effectively convert deforested lands of degraded vegetation to more productive forests. The method aims to accelerate, rather than replace, natural successional processes by removing or reducing barriers to natural forest regeneration such as soil degradation, competition with weedy species, and recurring disturbances (e.g., fire, grazing, and wood harvesting). Compared to conventional reforestation methods involving planting of tree seedlings, ANR offers significant cost advantages because it reduces or eliminates the	WOCAT database reference: T_MO013en Shono, K., Cadaweng, E. and Durst, P.. 2007. Application of Assisted Natural Regeneration to Restore Degraded Tropical Forestlands. Restoration Ecology, 5 (4), 620–626.
LAND USE: FOREST / WOODLAND	TECHNOLOGY GROUP: Reducing deforestation	**Establishment of protected forest areas**	Establishment of protected forest areas, such as natural and national parks. Protecting forest in reserves, and controlling other anthropogenic disturbances.	Wendland, K.J., Baumann, M., Lewis, D.J., Sieber, A. and Radeloff, V.C. 2015. Protected Area Effectiveness in European Russia: A Postmatching Panel Data Analysis. Land Economics, 91 (1), 149–168. ISSN 0023-7639; E-ISSN 1
LAND USE: FOREST / WOODLAND	TECHNOLOGY GROUP: Reducing deforestation	**Reducing slash and burn agriculture**	Traditional slash-and-burn agricultural cycles are characterized by the alternation of cropping and fallow phases, when secondary vegetation grows. At the end of fallow phases, trees are cut and burnt, and the ashes enrich the soil, thereby allowing a new.	Palm C., Vosti S.A., Sanchez P. and Ericksen J. (ed). 2005. Slash-and-Burn Agriculture. The search for alternatives Columbia University Press, 464 pp.ISBN 0–231–13450–9 (cloth : alk. paper) — ISBN 0–231–13451–7 (pbk. : alk. paper). Http://www.asb.cgiar.



LAND USE: FOREST / WOODLAND

TECHNOLOGY GROUP: Soil erosion control

SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
Trees for watershed management	Watershed management is the integrated use of land, vegetation and water in a geographically discrete catchment or drainage area for the benefit of its residents, with the objective of maintaining the hydrological services that the watershed provides and of reducing or avoiding negative dowsream or groundwater.	Wolfgramm, B., Liniger, H.P. and Nazarmavloev, F. 2014. Integrated Watershed Management in Tajikistan. IWSM policy brief. University of Bern, Centre for Development and Environment (CDE), Berne, Switzerland.
Afforestation and Hillside Terracing	Tree plantations in combination with hillside terracing to protect upper catchment areas. The technology requires appreciable expense, labor and expertise, but if maintained well, it results in multiple ecological and economic benefits: Soil cover has improved, water is conserved, the severe problems of soil erosion have been reduced, and dams further downstream are protected from siltation. Trees have become an important source of income for the rural communities, wood is a valuable resource mainly needed for construction, and also as fuel.	WOCAT database reference: T_ERI002en
Hydro-mulching	The hydromulch is a complex mixture which basically contains water and wood or paper fibers. Additionally it can contain seeds, surfactants, seed-growing biostimulants, nutrients and a green colorant. Hydromulch is spread immediately after a wildfire in order to reduce overland flow and prevent soil erosion.	WOCAT database reference: T_POR005en
Landslide prevention using drainage trenches lined with fast growing trees	The construction of linear gravel bed ditches lined with local tree species, at angles across a hill slope to channel the surface water.	Root, A.W. (1958). Prevention of landslides. Landslides and engineering practice./Ed. EB Eckel, 113-149.

LAND USE	TECHNOLOGY GROUP	SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
LAND USE: FOREST / WOODLAND	Soil erosion control	**Mulching after forest fires**	Forest slash mulch is spread immediately after a wildfire in order to prevent soil erosion and reduce overland flow.	Prats, S.A., MacDonald, L.H., Monteiro, M., Ferreira, A.J.D., Coelho, C.O.A., and Keizer, J.J. 2012. Effectiveness of forest residue mulching in reducing post-fire runoff and erosion in a pine and a eucalypt
	Soil erosion control	**Trees on mountain slopes together with moisture accumulating trenches**	Collecting rainwater in artificial trenches on hill and mountain slopes for the accumulation of water in the soil around the roots of trees planted in the trenches.	WOCAT database reference: T_TUM003en
	TECHNOLOGY GROUP: Sustainable forest management	**Forest irrigation and fertilization**	This could include the water can be collected from fogs under favorable climatic conditions; and applying animal manure to forestland.	UNEP, 1997.Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean. IETC Technical Publication Series by UNEP International Environmental Technology Centre, Osaka/Shiga, Japan, 1997. Unit of Sustainable Development. Estrela, M.J., Valiente, J.A., Corell, D., Fuentes, D., and Valdecantos, A. 2009. Prospective use of collected fog water in the restoration of degraded burned areas under dry Mediterranean conditions. Agricultural and forest meteorology, 149 (11), 1896-1906.

LAND USE: FOREST / WOODLAND

TECHNOLOGY GROUP: Sustainable forest management

SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
Selective logging	Cutting out of trees that are mature or defective, or of inferior kinds to encourage the growth of the remaining trees in a forest or wood. Selective forest clearing aims in reducing the connectivity and the amount of (dead standing) fuel, as well as redu	WOCAT database reference: T_SP010en WOCAT database reference: T_SP011en
Adjust forest plantations rotation periods	Short-rotation forestry is defined as the silvicultural practice under which high-density, sustainable plantations of fast-growing tree species produce woody biomass on agricultural land or on fertile but degraded forest land. Trees are grown either as single stems or as coppice systems, with a rotation period of less than 30 years and with an annual woody production of at least 10 tones of dry matter or 25 m^3 per hectare.	Christersson, L. and Verma, K. 2006. Short-rotation forestry – a complement to “conventional” forestry. Unasylva - No. 223. An international journal of forestry and forest industries,57, 2006/1. McKay, H. 2011. Short Rotation Forestry: review of growth and environmental impacts. Forest Research Monograph, 2, Forest Research, Surrey, p. 212.
Selective logging	Cutting out of trees that are mature or defective, or of inferior kinds to encourage the growth of the remaining trees in a forest or wood.Selective forest clearing aims in reducing the connectivity and the amount of (dead standing) fuel, as well as redu	Valdecantos, A., Baeza, M. J. and Vallejo, V. R., 2009. Vegetation Management for Promoting Ecosystem resilience in Fire-Prone Mediterranean Shrublands. Restoration Ecology, 17(3), 414-421. http://dx.doi.org/10.1111/j.1526-100X.2008.00401.x
Woodlots for biomass production	A woodlot is a parcel of a woodland or forest capable of small-scale production of forest products (such as wood fuel, sap for maple syrup, sawlogs, and pulpwood) as well as recreational uses like bird watching, bushwalking, and wildflower appreciation.	Klemarczyk, R.J. and Hahn, T.C. 1994. Reassessment of biomass harvesting on small woodlots in New Hampshire. New Hampshire Timberland Owners Association.

LAND USE: FOREST / WOODLAND

TECHNOLOGY GROUP: Sustainable forest management

SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
Reducing logging waste	RIL (Reduced Impact Logging) can be defined as 'the intensively planned and carefully controlled implementation of timber harvesting operations to minimize the environmental impact on forest stands and soils'. It involves a number of practical measures, s	Elias. 2006. Financial analysis of RIL implementation in the forest concession area of PT. Suka Jaya Makmur, West Kalimantan and its future implementation options. In: The proceeding of ITTO-MoF
Fuelwood production	Fuelwood refers to various forms of wood that are used as fuel for cooking, heating or to drive steam-powered engines or turbines for electricity generation. Fuelwood remains the primary source of fuel for much of the world's population. Unfortunately, overconsumption of fuelwood has led to deforestation and habitat loss, and unless wood is burned in efficient furnaces, its combustion contributes to emissions. Fuelwood can include firewood, charcoal, pelletized sawdust and wood chips	Pandey, J. C. et al. 2014. Pine Briquetting- An Endeavour for Green Fuel. Indian Forester, S.l., 478-482. ISSN 2321-094X.
Forest irrigation and fertilization	This could include the water can be collected from fogs under favorable climatic conditions; and applying animal manure to forestland.	Estrela, M. J., Valiente, J. A., Corell, D., Fuentes, D., and Valdecantos, A. 2009. Prospective use of collected fog water in the restoration of degraded burned areas under dry Mediterranean conditions. Agricultural and forest meteorology, 149 (11), 1896-1

LAND USE	TECHNOLOGY GROUP	SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
FOREST / WOODLAND	Sustainable forest management	**Short rotation biomass production from forest**	Willow biomass production under conditions of low-input agriculture on marginal soils Willow was planted using a pole cutting system, on sites that were unsuitable for food crops.	Stolarski, M.J., Szczukowski, S., Tworkowski, J. and Klasa,A. 2011.Willow biomass production under conditions of low-input agriculture on marginal soils, Forest Ecology and Management, 262(8), 1558-1566, ISSN 0378-112.
LAND USE: GRAZING LANDS	Animal waste management	**Improved cattle shed for urine collection**	Collection of cattle urine in improved cattle sheds for use as liquid manure and organic pesticide	WOCAT database reference: T_NEP001en
LAND USE: GRAZING LANDS	TECHNOLOGY GROUP: Grazing pressure management	**Stocking density**	Ultra-high stock density grazing system: this grazing management practice is generally characterised by high stock density (i.e. number of animals/unit area) in a small camp of mature forage and short grazing periods and most importantly long forage recovery (regrowth) periods	Truter, W., Toit, L.D., Smith, H., Trytsman, G. and Lund, A. 2016. Conservation agriculture: Ultra-high stock density grazing systems. In: SA Graan/Grain. October 2016.
LAND USE: GRAZING LANDS	TECHNOLOGY GROUP: Grazing pressure management	**Rotational grazing**	Management system based on the subdivision of the grazing area into a number of enclosures and the successive grazing of these paddocks by animals in a rotation	Axel, R. 2001. An evaluation of open rotational grazing. Agricola,12, 94-98.
LAND USE: GRAZING LANDS	TECHNOLOGY GROUP: Grazing pressure management	**Eco-graze**	An ecologically sound and practical grazing management system, based on rotation, wet season resting and getting the right balance between stock numbers and the forage resource.	Ash, A. Corfield, J. and Ksiksi, T . 1992. The Ecograze Project - developing guidelines to better manage grazing country. CSIRO. ISBN 0-9579842-0-0

Land use	Technology group	SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
LAND USE: GRAZING LANDS	TECHNOLOGY GROUP: Grazing pressure management	**Rangeland resting**	Stopping grazing for pre-established periods of time	Sghaier, M., Ouessar, M., Catacutan, D.C. andBriki, M. Context of oum zessar watershed Tunisia. Afromaison project. In: Observatoire du Sahara et du Sahel.
		Area closure to grazing	Area closure is a land management practice aiming to address severe soil degradation, loss of vegetation cover and low water holding capacity of degraded lands by rehabilitating and restoring the natural resource bases (soil, vegeta-tion and soil water) and enhancing the productive and environmental functions through community consultation and collective actions	WLRC, 2015. Area Closure. Rehabilitation of Degraded Lands and Grasslands. Brief No. 2. Water & Land Resource Centre
		Communal grazing management	Improve grazing capacity by applying rotation	Tinoziva, H., Prisca, M., Charles, M. and Edson, G., 2013. Influence of Communal Area Grazing Management System on the Nutritive Value of Forages Selected by Cattle in a Semi-Arid area of Zimbabwe. Greener Journal of Agricultural Sciences, 3 (9), 663-668.
	Integrated soil fertility management	**Manure separation to better distribute organic matter**	Separation of cow manure is a com-mon practice on dairy farms in The Netherlands to improve the nutrient use efficiency	Gebrezgabher, S.A., Meuwissen, M.P., Kruseman, G., Lakner, D. and Oude Lansink, A.G.J.M. 2015. Factors influencing adoption of manure separation technology in the Netherlands, Journal of Environmental Management,150 (1).

LAND USE	TECHNOLOGY GROUP	SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
LAND USE: GRAZING LANDS	Integrated soil fertility management	**Nutrient management**	Nutrient Management on Pastures and Haylands: The primary goal of nutrient management is to promote biomass productivity that provides profit for producers while minimizing negative environmental impacts. Additional goals include improvement of soil quality, increased soil carbon (C) sequestration, and providing important ecosystem services	Wood, C.W., Moore, P.A., Joern, B.C., Jackson, R.D. and Cabrera, M.L. 2012. Nutrient Management on Pastures and Haylands. Conservation outcomes from pastureland and hayland practices : assessment, recommendations, and knowledge gaps, 25.
LAND USE: GRAZING LANDS	TECHNOLOGY GROUP: Vegetation management	**Range pitting and reseeding**	Technique used to restore degraded rangelands (steppe areas). Small shallow 'pits' are scooped out by the action of inclined metal disks (similar to the disks of a disk plough). A seed hopper mounted on the top of the implement releases small quantities of range-plant seeds into the pits and an attached light harrow covers the seeds with a thin layer of loose topsoil.	WOCAT database reference: T_SYR002en
LAND USE: GRAZING LANDS	TECHNOLOGY GROUP: Vegetation management	**Off-season irrigation of fields and pastures**	Early irrigation of fields and pastures to retain soil moisture during the dry season as a mechanism for pasture improvement	Chamma, D.D. 2014. Fostering the use of on-farm ponds and roof catchments for off-season small-scale irrigation in ethiopia. Fourth newsletter of the Afrhinet project.
LAND USE: GRAZING LANDS	TECHNOLOGY GROUP: Vegetation management	**Improved fodder production on degraded pastureland**	Transformation of degraded pastureland to high quality fodder plot. Grass and legumes are planted on degraded pasture land in fenced fodder plots	WOCAT database reference: T_UGA029en
LAND USE: GRAZING LANDS	TECHNOLOGY GROUP: Vegetation management	**Grazing land rehabilitation with shrubs plantation**	Rehabilitation measures, including eyebrow pits and live fencing to reestablish a protective vegetative cover	WOCAT database reference: T_NEP013en

LAND USE: GRAZING LANDS

TECHNOLOGY GROUP: Vegetation management

SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
Cut-and-carry fodder production	Highly productive and sustainable cut-and-carry system	Tanner, J.C., Owen, E., Winugroho, M. and Gill M. 1995. Cut and carry feeding of indigenous grass in Indonesian sheep production: effect of forage wilting and quantity of forage offered on intake and on yield of compost made from refusals and excreta.
Creation of a perennial grass seed area	Improvement of pastures through planting perennial legumes, cereals and grasses and creating seed banks	Nadezhda, F. 2016. Creating varieties of the perennial cereal grasses by the polycross method in northern kazakhstan. Ekin Journal of Crop Breeding and Genetics 2(1):30-35.
Improved use of fire for sustainable grassland management	Prescribed burning is the process of planning and applying fire to a predetermined area, under specific environmental conditions, to achieve a desired outcome.	Stubbendieck, J., Volesky, J. and Ortmann, J. 2007. Grassland Management with prescribed fire. In: The board of Regents of the University of Nebraska. Nailsma's Carbon program. (https://www.nailsma.org.au/developing-new-educational-resources-savanna- burninghtml.html)

		SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
LAND USE: MIXED	TECHNOLOGY GROUP: Agri-pastoral systems	**Incorporating sheep into dryland grain production systems**	Pastoral system dominated by fallow. At least two criteria may allow to differentiate the current agropastoral systems from traditional nomadic pastoralism: (i) most small ruminant producers now have a permanent settled base, and i¡) livestock eeding is much more dependent on cultivated crops or heir eed. Crop and ivestock production have become more closely integrate. Under sedentary mixed farming, sheep and goats are kept in small flocks as a supplement o crop production. The main arable crops grown are cereals, mainly barley and legumes. Alternate cropping, with a allow every other year, is often practised but he area cultivated varies rom year o year depending on the rainfall	Nefzaoui, A. and Ben Salem, H. 1999. Pastoral systems dominated by cereal-fallow combination in North Africa and West Asia. In: Etienne M. (ed.). Dynamics and sustainability of Mediterranean pastoral systems. Zaragoza : CIHEAM, 1999. p. 199-212. Cahiers Option.
LAND USE: MIXED	TECHNOLOGY GROUP: Agrisilvicultural systems	**Animal Draft Zero-Tillage**	The three elements, namely trees, animals and crops, can be integrated in what are called agri-sylvo-pastoral systems and are illustrated by home gardens involving animals as well as scattered trees on croplands used for grazing after harvests.	Kaoma-Sprenkels, C., Stevens, P.A. and Wanders, A.A. 1999. IMAG-DLO and conservation tillage: Activities and experiences. In: Kaumbutho P G and Simalenga T E (eds), 1999. Conservation tillage with animal traction. A resource book of the Animal Traction Netw.
		Home gardens	Home gardens, containing tree, shrub, herbs, vine, tuber layers as well as poultry, produce food for household consumption as well as an additional income	Keller, H. 2003. International/ Cambodia.Handbook for Home Gardening in Cambodia: The Complete Manual for Vegetable and Fruit Production. Phnom Penh: Helen Keller Worldwide.

LAND USE: MIXED — TECHNOLOGY GROUP: Agrisilvicultural systems

SLM TECHNOLOGY CASE	DESCRIPTION	REFERENCE
Orchard with integrated grazing and fodder production (Silvo-pastoralism)	Increased productivity of the land by planting fruit trees and conserving the land by restricting the access of livestock	Stephens, M.., Donaghy, P. and Griffiths, J. 2010. Silvopastoralism — an opportunity waiting, Farming Ahead January 2010 No. 216. Montagnini, F., Muhammad, I. and Murgueitio, E.2013 Silvopastoral systems and climate change mitigation in Latin America. Bois et forêts des Tropiques, 316 (2).
Plantation crop combinations, multipurpose trees on crop lands	Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arragament or temporal sequence	WOCAT database reference: T_ITA012en

Scientific evidence shows that SLM practices, if widely adopted, help to prevent, reduce or revert land degradation and achieve land degradation neutrality (LDN), contribute to climate change adaptation and mitigation, protect biodiversity, achieve multiple sustainable development goals, and increase human well-being globally.

This report assesses the synergistic potential of SLM practices while also critically evaluating the possible trade-offs between addressing desertification, land degradation and drought (DLDD), climate change mitigation and adaptation. The assessment provides a scientifically sound basis to understand SLM's potential to contribute to multiple objectives, and provides practical guidance for creating an enabling environment for selection and large-scale implementation of effective, locally-adapted SLM practices.

In accordance with the rules and procedures established by the UNCCD Conference of the Parties (COP), the report was prepared by an author team of 5 lead authors and 7 contributing authors. In December 2016, following a competitive public tender, the Basque Centre for Climate Change (BC3) was commissioned to prepare this report in association with the Mediterranean Center for Environmental Studies and the SPI. A scoping meeting was held on 19-20 December 2016 in Bonn, Germany; SPI members as well as representatives of BC3, external experts in SLM, climate change and sustainable development participated in the meeting.

Following an intensive assessment of technical documents and peer-reviewed scientific literature, a draft produced by the authors underwent a three step review process, including an internal review (7 reviewers), and external scientific peer-review (6 reviewers) as well as a review by the Bureau of the COP. The lead authors have ensured that all government and expert review comments received appropriate consideration.

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