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Land degradation and the Sustainable Development Goals: Threats and potential remedies

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Land degradation and the Sustainable Development Goals: Threats and potential remedies

Paul L. G. Vlek, Asia Khamzina, and Lulseged Tamene
Editors

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Photo: Georgina Smith/CIAT

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Abbreviations

AHP	analytical hierarchy process
CSA	climate-smart agriculture
FAO	Food and Agricultural Organization of the United Nations
GDP	gross domestic product
GHG	greenhouse gas
GIS	geographical information systems
GLASOD	Global Assessment of Human-induced Soil Degradation
ILM	integrated landscape management
INDC	Intended Nationally Determined Contribution
ILWRM	integrated land and water resources management
IWRM	integrated water resources management
LAC	Latin America and the Caribbean
LADA	Land Degradation Assessment in Drylands project
LD	land degradation
LDN	land degradation neutrality
LULUCF	land use, land-use change and forestry
LUP	land-use planning
MEA	Millennium Ecosystem Assessment
MSW	municipal solid waste
NDVI	normalized difference vegetation index
NPP	net primary production
NR	natural resource
RRR	resource recovery and reuse
SDGs	Sustainable Development Goals
SFA	sustainable food and agriculture
SLM	sustainable land management
SOM	soil organic matter
SWC	soil and water conservation
TEV	total economic value
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization
WOCAT	World Overview of Conservation Approaches and Technologies

1. Introduction

P.L.G. Vlek and L. Tamene

Land comprises a range of biophysical components such as soil, water, flora, and fauna, embedded in a landscape shaped by its geomorphology and subjected to a climate that is often under different forms of human manipulation. Land provides natural habitats and serves many purposes – for agriculture, forestry, pastoralism, infrastructure development, mining, and tourism. Apart from these so-called economic uses, land provides a range of ecosystem services such as nutrient cycling, carbon sequestration, and water and air purification; it also fulfills social and spiritual needs.

The natural attributes of land are generated over long-time spans. Soil formation takes place over decades to centuries (Mason et al., 2016). The flora and microfauna suited to the soil in the prevailing climate conditions will evolve with the soil conditions while playing a soil-forming function. Flora will go through evolutionary stages from pioneer to climax vegetation, which can vary depending on the climate, from sparse grassland and tundra to dense forests. Pioneer vegetation often involves plants that depend on synergistic microorganisms such as phosphate-solubilizing fungi and bacteria or nitrogen-fixing bacteria (Wubs et al., 2016). Land in its natural condition undergoes regular rejuvenation, as often fires occur that destroy vegetation, returning large quantities of carbon, nitrogen and sulfur to the atmosphere, after which pioneer species appear to recapture them (Gehring et al., 2005; Kugbe et al., 2012).

The hysteretic nature of the degradation–rejuvenation cycle varies with the form and degree of degradation and climatic conditions, but reclamation times are multiples of what it takes to degrade land (FAO, 1990). Soil organic matter (SOM) plays a key role in the rejuvenation process, serving as microbial substrate and regulating nutrient dynamics (FAO, 2005). The rate of SOM decomposition in humid tropical conditions can exceed those in temperate climates by a factor of four (Jenkinson and Ayanaba, 1977). SOM accumulation – the net result of vegetative productivity and consumption – in the humid tropics and temperate climes far exceeds that in the dry areas (FAO, 2005).

The role of land in supporting humankind is multilayered. Land provides a host of ecosystem services, of which provisional services are often considered paramount (MEA, 2005). Food, forage, fiber, fuel and forest products derived from land have sustained an increasing population, but at a cost. As the demand for these products multiply, other ecosystem services are being degraded or used unsustainably. According to the MEA (2005), this is true for about 15 out of 24 of the ecosystem services evaluated in this assessment (including 70% of regulating and cultural services). The impact and cost of such loss in ecosystem services, essential to human survival, is difficult to fathom, as many of them have never been seriously studied (TEEB, 2010). However, it is likely that a farmer working marginal lands trajectory B in Figure 1.1) is eking out a living at great ecological and economic cost and with diminishing returns. In fact, the MEA (2005) claims that the total economic value associated with managing natural ecosystems sustainably is at times higher than the value associated with the conversion of the ecosystem through farming, clear-cut logging, or other intensive uses. The challenge in the future will be to sustainably derive ecosystem services from land, following an environmental Kuznets curve as shown in trajectory A of Figure 1.1 (Zhang et al., 2015).

Taking land into cultivation is predicated on the removal of native vegetation, which is normally accompanied by a loss in SOM (Post and Kwon, 2000). This transformation may lead to a new equilibrium in SOM, which might be sustainable over millennia, e.g. the rice paddies of Southeast Asia or the rice and wheat producing areas of the Nile Delta. However, there are numerous examples of cultivated land degrading to the point where it must be abandoned due to mismanagement or excessive pressure on the land (Hillel, 1991). Early abandonment by shifting agriculture to other land may allow repeated use of the land over time if there are reasonable recovery times (Sanchez, 1976), but such shifting cultivation systems are not suitable for intensive agriculture. Once land degradation takes hold, land loses certain intrinsic qualities or the capability to perform vital functions, both economic and ecological (Katyal and Vlek, 2000). Blaikie and Brookfield (1987) described land degradation as a weakening in the capability of land to produce benefits when it is put to a land use under a specific set of management options. Soil and vegetation are the two basic components that determine an ecosystem's functions and services. Among a wide range of land ecosystem services, primary production has a pivotal role as it generates products on which many of the other ecosystem services depend (Figure 1.2) (MEA, 2005; Safriel, 2007).

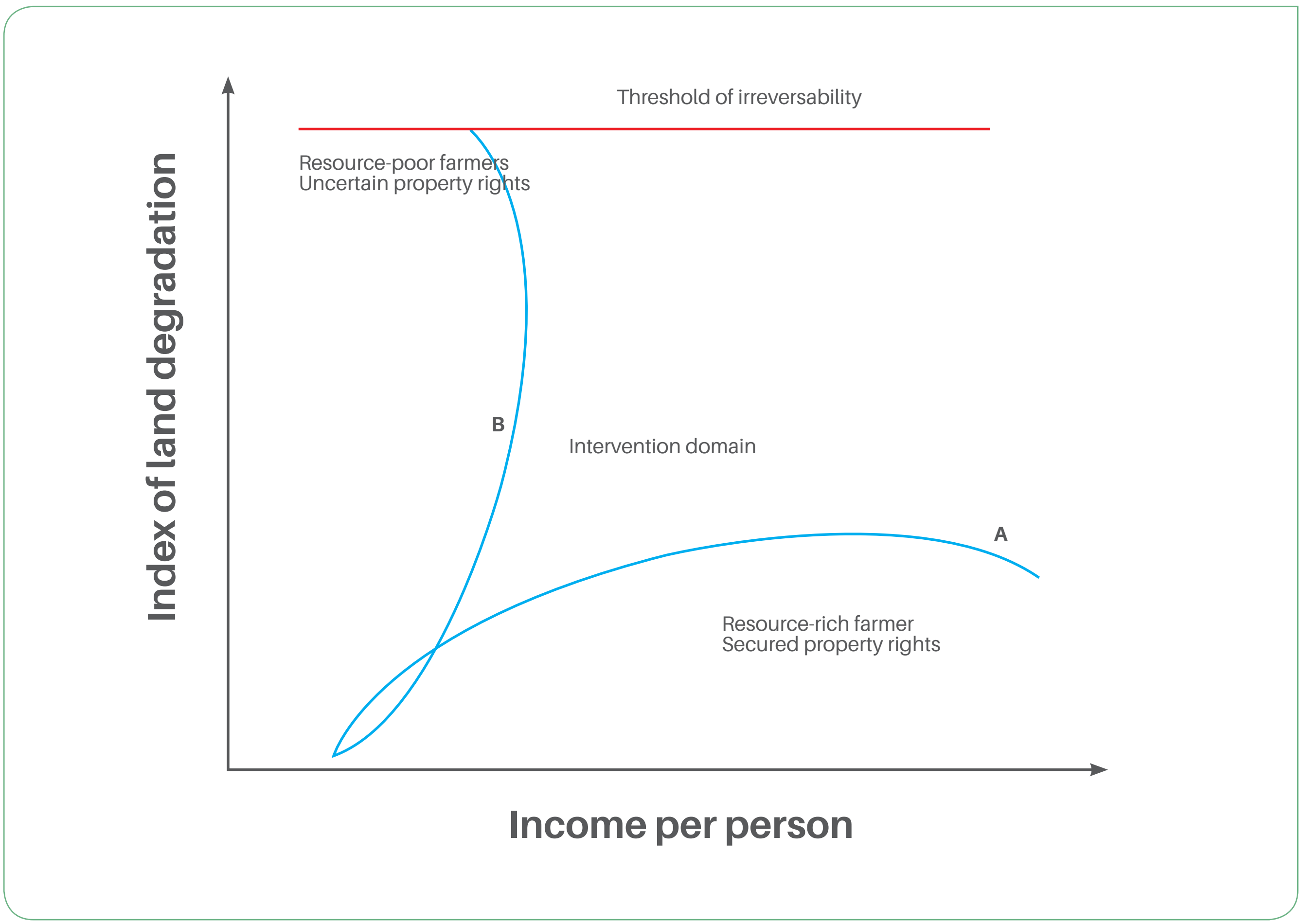

Figure 1.1 Land degradation as a function of income for resource-rich farmers (trajectory A) and resource-poor farmers (trajectory B).

Land might be unsuitable for one purpose but not for another (Johnson and Lewis, 1995). Thus, land degradation is use-specific, management sensitive, and not always permanent. The key to sustainable land use, according to FAO (2007), is the "matching" of land-use requirements with land attributes. Stakeholder participation in the selection of a "suitable" land-use type with specific management practices based on land potential is a key principle of land-use planning. It contributes to the reduction of land degradation and facilitates the trade-offs in multipurpose land use. These concepts are explored in Chapter 2.

The causes of land degradation are varied and are related to deterioration in climatic conditions and interventions by people or animals. Changes due to climate change have occurred repeatedly, even during the relatively short time span of the existence of Homo sapiens, but rarely with the speed that we are witnessing now during the Anthropocene (IPCC, 2007) following the Industrial Revolution (Abram et al., 2016). Flora, and consequently fauna are unable to adjust as rapidly to the new climatic conditions, turning some arid and semiarid areas into virtual deserts once a tipping point is reached. In contrast, most ecosystems have sufficient resilience to recover from longer periods of drought or floods. Degradation due to direct human intervention is due mostly to excessive demands on the land. Hardin (1999) postulated a fundamental ecological principle: "Thou shalt not transgress the carrying capacity", a principle that nature imposes rigorously by adjusting the animal population and restoring equilibrium between production and consumption. Since the onset of agriculture, farming communities have struggled to adhere to this principle and its violation has been the cause for some great civilizations to disappear (Hillel, 1991). Strategies to cope with climate change and land degradation should take advantage of the lessons learned over time by farmers' and land users' experience in dealing with these calamities, much of which is retained as indigenous knowledge.

According to the Global Footprint Network, humans consumed the total available resource pool for the year 2016 by 8 August, thus borrowing the necessary additional resources for the remainder of the year from future generations (GFN, 2016). In 1970, this so-called Earth Overshoot Day was still in mid-December. It is in this context that the United Nations defined a new set of Sustainable Development Goals (SDGs) that aim to gradually reduce the pressure on the natural resource (NR) base while allowing the poorer segments of society room to grow out of poverty. The implementation of the ambitious SDGs depends on individual nations and their plans. Land degradation is explicitly targeted in SDG 15 and its Target 15.3. However, land is referred to in other goals. It is mentioned in Target 2.4 (end hunger, achieve food security, improved nutrition and sustainable agriculture); Target 3.9 (ensure healthy lives and promote well-being and reduce deaths/illnesses from polluted soil); Goal 7 (ensure access to affordable sustainable and modern energy; Goal 11 (make cities & settlements safe, resilient and sustainable); Goal 12 (ensure sustainable consumption and production patterns). In addition, Goal 1 (end poverty) 6 (ensure availability of water & sanitation) and Goal 13 (take urgent action to combat climate change) all have a relationship to land. The impacts of land degradation on the SDGs are reviewed in Chapter 3. The role of soils in reaching the SDGs has been reviewed by Brevik et al. (2015) and Keesstra et al. (2016).

Land degradation is a creeping phenomenon (Vlek et al., 2008) and is often recognized only when corrective action, i.e. a shift from trajectory B to trajectory A (Figure 1.1) has become prohibitive. The question of the degree of degradation depends on where the threshold of irreversibility is positioned (Figure 1.1). The resolve and economic strength of a community may increase the chances that a degraded piece of land will receive the investments needed to restore its functions. The funding made available by Western governments for such restoration (e.g. by the EPA Superfund) are not readily available to developing or emerging economies. Moreover, the overall wealth of a community will determine to what extent farmers can follow curve A or are bound to follow curve B in using their land. The assessment of the extent of land degradation is hampered by this lack of clear definitions and by the lack of long-term, land-based observation points, while alternative assessments from space are only at an early stage of development (Vlek et al., 2010). Details are discussed in Chapter 4.

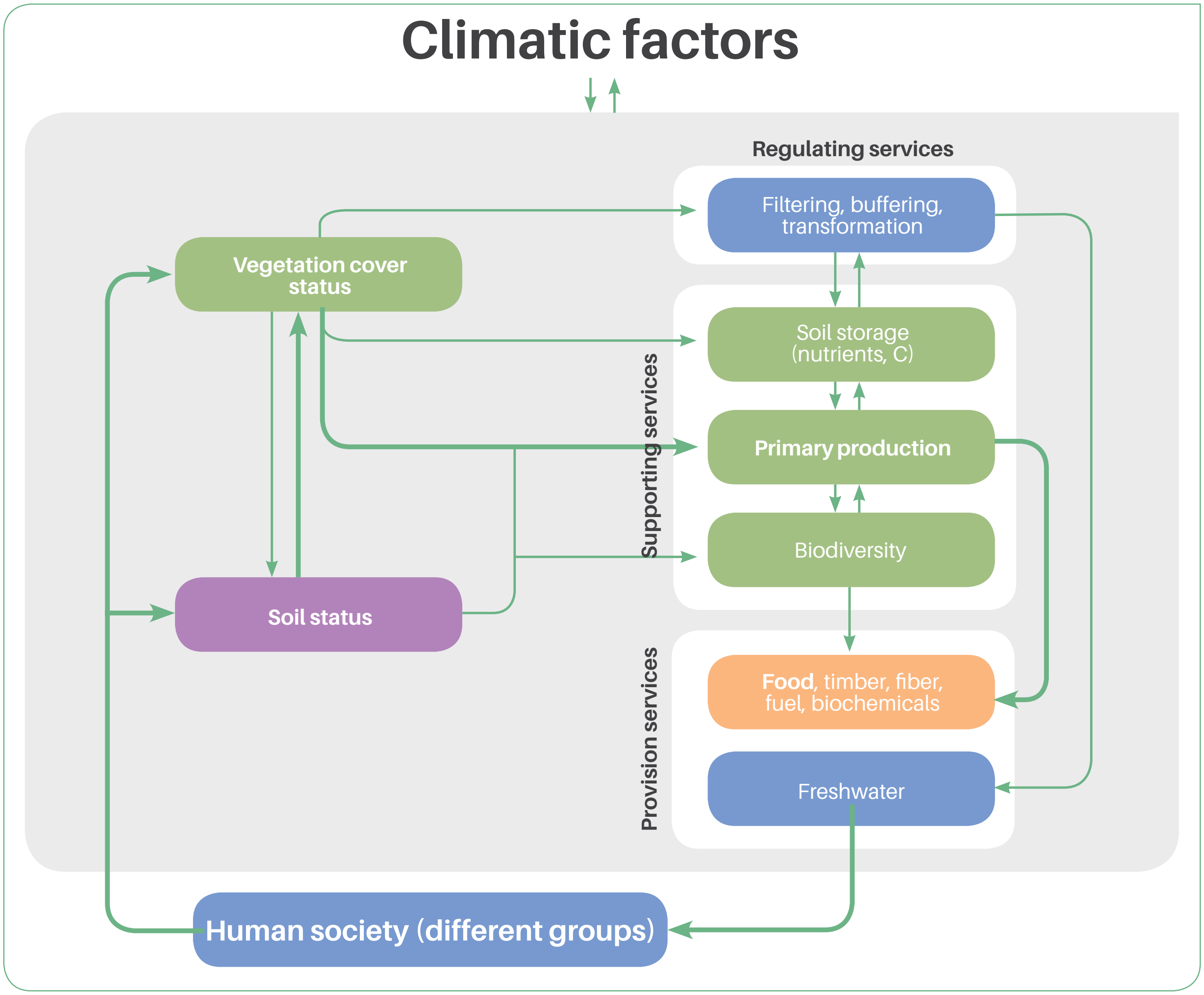

Figure 1.2 Soil and vegetation components as the basis of land ecosystem functions and services.
Source: Modified from Safriel (2007).

Land degradation is one of the symptoms of resource mismanagement and misuse, threatening sustainable development, and international agencies are calling for a halt to this scourge. In the outcome document of Rio+20, the international community identified the need to take actions by striving to achieve a land degradation neutral (LDN) world within the context of sustainable development. Land degradation neutrality implies that land degradation should be minimized and that unavoidable land degradation should be offset by restorative efforts. Provided mechanisms are in place to promote equity and manage conflicts, the concept of a LDN world can serve to promote sustainable land management and restoration under the various themes of the SDGs. The role of integrated landscape management (ILM) in attaining LDN and experiences so far with this approach as well as strategies, laws and incentives for such policies to be implemented at scale are discussed in Chapter 5.

As healthy land resources are essential in realizing many of the SDGs, this paper aims to assess the impact of continued land degradation on key SDGs. This CGIAR paper also addresses the SDGs from the perspective of achieving food security as an imperative.


Photo: Georgina Smith/CIAT

2. The trade-offs in multi-purpose land use

P.L.G. Vlek, with

H. Azadi, A. Bhaduri, L. Bharati, A.K. Braimoh, Chr. Martius, T. Sunderland, and F. Taheri

2.1 Introduction

Ecosystem health is directly addressed in several SDGs, while it is an implicit requirement in others. With an expanding population and developing economies, the pressure on land for food production has been relentless and has often led to the loss of other essential ecosystem services (ESSs). Unsustainable pressure on natural resources threatens the very ecosystem services on which the global food system depends (Howe et al., 2014). Thus, conserving natural resources is fundamental to sustainable production in the long term, especially given the vulnerability of agriculture and fisheries to climate change (Berry et al., 2006).

Finding a just and sustainable trade-off between food production and one or more of the other ESS is about equitably optimizing a dynamic and complex socio-ecological system. Figure 2.1 shows on the vertical y-axis food production as a societal imperative and on the horizontal x-axis, other ESSs that are derived from land with variable value to on- and off-site stakeholders. For simplicity, we depict a linear trade-off relationship but in fact, the shape of the trade-off curve will vary for the different ESSs and contexts. Finding satisfactory solutions for a simple trade-off with multiple stakeholder interests in mind is complex and this complexity increases exponentially as more ESSs are added to the mix (Schindler and Hilborn, 2015). To illustrate the trade-off dilemma, four representative ES services – climate change mitigation, water storage, biodiversity, and space for infrastructure – are considered here.

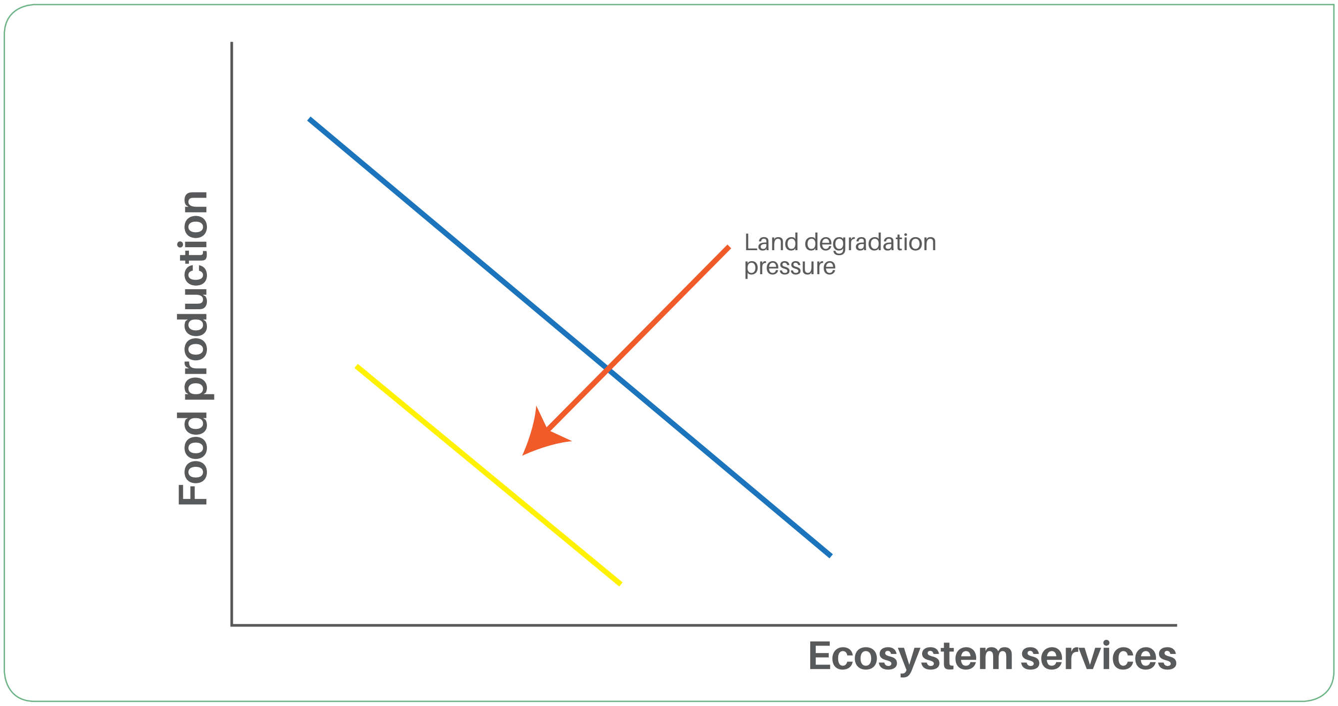

Figure 2.1 Simplified visualization of key guiding principle in trade-offs in ecosystem services.

2.2 Land for food and climate change mitigation

Agriculture is the major consumer of the world's land and water resources and is an important contributor to greenhouse gas (GHG) emissions (Alig et al., 2010). Land conversion to agriculture is the principal driver behind deforestation worldwide. Some 24% of global GHG emissions are attributable to agriculture (13%) which increased until 2010 (Smith et al., 2014), as well as land-use change (11%), which has been increasing since 2008 (Le Quéré et al., 2016). The scale of global emissions from agriculture and land-use change is increasing because of population growth, growing consumption of meat and dairy products, and the rising use of nitrogen fertilizers. Conversion to agricultural land presents a trade-off to society because the same land used for providing essential food, feed, fiber, and biofuels, could store large amounts of carbon in soils and biomass in its natural state and thereby mitigate climate change. Expanding croplands to meet the needs of a growing population, changing diets, and biofuel production comes at the cost of reduced carbon stocks in natural vegetation and soils (West et al., 2010). Leveraging the mitigation potential of the land sector is therefore important in meeting emission reduction targets, in addition to adapting to a changing climate (IPCC, 2014).

Different ecosystems store different amounts of carbon, depending on their species composition, soil types, climate, relief, and other biophysical features. The amount of carbon stored in plant biomass ranges from 3 Gt in croplands to 212 Gt in tropical forests while soil carbon stocks range from 100 Gt for temperate forests to 471 Gt for boreal forests (Table 2.1). The boreal forests and wetland biomes have the highest density of carbon storage. Soils generally hold more carbon than vegetation across biomes and account for 81% of terrestrial carbon stock at the global level (Table 2.1).

Table 2.1 Carbon stocks in vegetation and top 1 meter of soils of world biomes.

Biomes	Area (million km²)	Carbon stocks (Gt C) and proportion in the ecosystem (%)				
		Vegetation	Proportion (%)	Soils	Proportion (%)	Total
Tropical forests	17.6	212	49.5	216	50.5	428
Temperate forests	10.4	59	37.1	100	62.9	159
Boreal forests	13.7	88	15.7	471	84.3	559
Tropical savannas	22.5	66	20.0	264	80.0	330
Temperate grasslands	12.5	9	3.0	295	97.0	304
Deserts	45.5	8	4.0	191	96.0	199
Tundra	9.5	6	4.7	121	95.3	127
Wetlands	3.5	15	6.3	225	93.8	240
Croplands	16	3	2.3	128	97.7	131
Total	**151.2**	**466**		**2011**		**2477**
Proportion (%)		**19**		**81**		**100**

Source: Watson et al. (2000).

The average carbon loss resulting from converting natural ecosystems to croplands is highest in the tropics (120 t C ha^{-1}) as tropical forests store much more above-ground biomass carbon than any other biome. Carbon–crop trade-off analysis shows that nearly three times as much carbon has been lost per tonne of crop yield in the tropics compared to temperate regions (Figure 2.2). The high carbon loss per unit crop yield in the tropics results from two factors: the combined highest average carbon loss from conversion and the lowest average crop yield values.

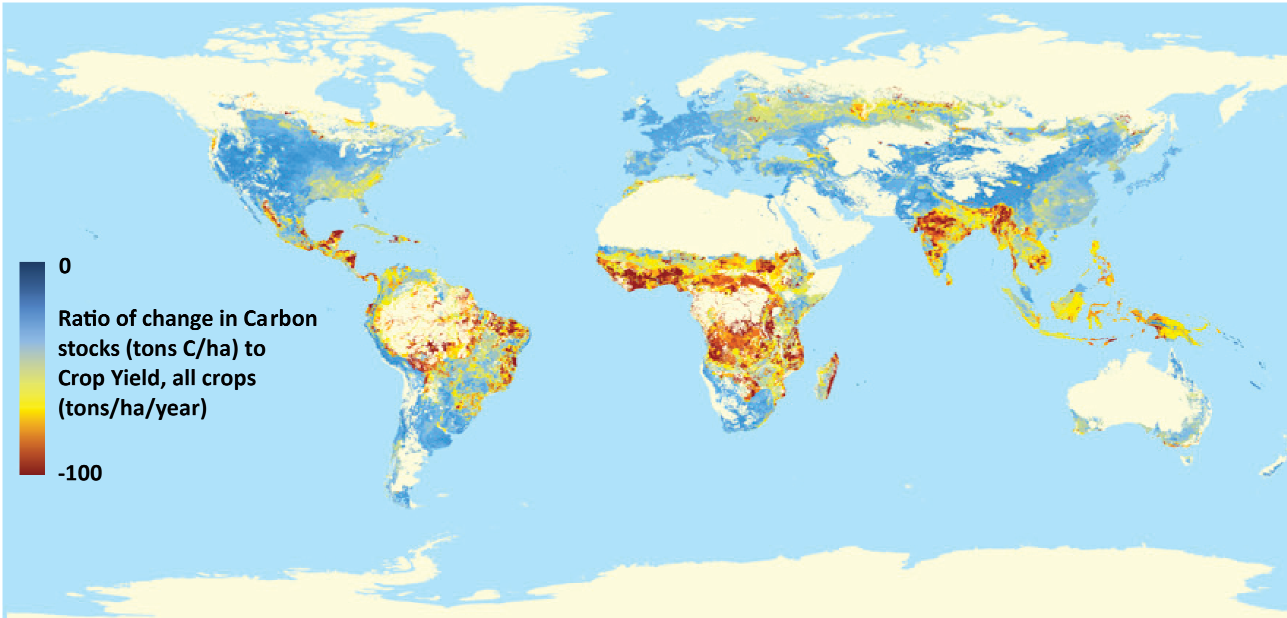

Figure 2.2 Trade-off index showing change in carbon stock per unit of annual crop production.
Source: West et al. (2010).

In meeting the demand for food, we rely on both the expansion and intensification of agricultural production. Intensification of agriculture is based on concentrated livestock production and increasing use of fertilizer and other inputs. Compared to land conversion, the relative contribution of agricultural operations to CO_2 emissions in agricultural-based economies is very small – about 4% – out of which 70% is due to energy use in fertilizer production (Vlek et al., 2004). Thus, in developing countries, conversion of natural vegetation to farmland is the primary source of non-fossil fuel emissions. While intensification adds to the agricultural sector's GHG emissions, a central question is whether the cost of further intensification in terms of fertilizer-related CO_2 emissions can be justified by the carbon sequestration on agricultural land that is spared for reforestation.

A recent study indicates that increasing fertilizer consumption in developing countries (excluding China) by 20% could lead to cereal yields increase of 5–20% depending on crop and region (Table 2.2).

The amount of land that communities could set aside for reforestation because of the increase in productivity ranges from 2 million ha for sub-Saharan Africa to 7 million ha for South Asia, while emissions from a 20% increase in fertilizer production range from 0.4 million t to 6.5 million t. Intensification would result in carbon sequestration that far outweighs the emissions associated with the production of extra fertilizer required to increase yields. A 1% GHG emission rate from the additional fertilizer (IPCC, 2006) would not materially change this balance. The CO_2 balance ranges from an average of 13 million t CO_2 for sub-Saharan Africa to 41 million t CO_2 for South Asia. There is, however, a wide variation in the amount of land spared per unit of CO_2 emissions from increased fertilizer production. Due to the low usage of fertilizer, a 20% increase in sub-Saharan Africa would spare a mere 2 million ha whereas in South Asia with more than 10 times the fertilization rate of sub-Saharan Africa, it would spare 7 million ha.

Table 2.2 Potential carbon sequestration from reforestation of agricultural land that can be spared because of increasing fertilizer use by 20% on prime land.

	Sub-Saharan Africa	Near East/ North Africa	East Asia	South Asia	Latin America and Caribbean	Total
Increase in cereal yield (%) from 20% increase in use of fertilizer						
Rice	5.1	8.7	9.8	10.0	10.7	8.9
Wheat	11.0	11.1	NA	7.4	12.2	10.4
Maize	9.9	11.3	20.0	8.3	13.2	12.5
Potential spared land area (millions of ha)	2.0	2.7	6.1	7.0	5.0	22.9
CO_2 emission from 20% increase in fertilizer production (millions of tonnes)	0.37	1.20	1.90	6.54	1.85	11.9
Potential CO_2 sequestration by forest regeneration (Mt) on spared land						
Low rate (4 $tCO_2\ ha^{-1}\ yr^{-1}$)	8.1	10.7	24.8	28.4	20.3	92.3
High rate (9.5 $tCO_2\ ha^{-1}\ yr^{-1}$)	19.2	25.3	58.5	67.2	47.9	218
CO_2 balance (millions of tonnes)	7.7	9.5	22.9	21.9	18.4	80.4
Low	7.7	9.5	22.9	21.9	18.4	80.4
High	18.8	24.1	56.6	60.8	46.1	206
Average	13.3	16.8	39.8	41.2	32.3	143

Source: Modified from Vlek et al. (2004); NA = data not available.

The designation of land to be targeted for sustainable intensification and that which should be spared or set aside for land restoration is an exercise in landscape management and requires community consensus building and concerted action. Failing to do so is a recipe for land degradation, a major concern in sub-Saharan Africa (Vlek et al., 2010). More than 40% of Africa's 220 million ha of farmland are losing at least 30 kg per ha of nutrients annually, leading to annual losses of more than US$4 billion (IFDC, 2013). Hence, restoring degraded lands in Africa by replenishing nutrients, reducing soil erosion, and increasing water retention capacity, will be critical in meeting escalating food demands.

In addition to the community effort in managing landscapes, the individual farmer can minimize the carbon footprint while producing food. Sustainable intensification by investing in soil through fertilizer and judicious use of crop residue and manure, combined with soil conservation measures, improved varieties with high genetic yield potential and nutrient use efficiency would improve food production and retain the natural resources essential to sustain this productivity (Braimoh et al., 2016). Adoption of sustainable intensification approaches are required to minimize trade-offs to society in our attempt to use land for food and climate mitigation. One such approach, conservation agriculture, has been widely adopted over the past decades (Vlek and Tamene, 2009; Powlsen et al., 2016) although it consists of a variety of approaches with varying effects (Giller et al., 2009; Govaerts et al., 2009). However, sustainable intensification is not just a technological adjustment but comprises three reinforcing pillars that must be appropriately combined and scaled up to address the challenges of food security and climate change in the years to come (Figure 2.3).

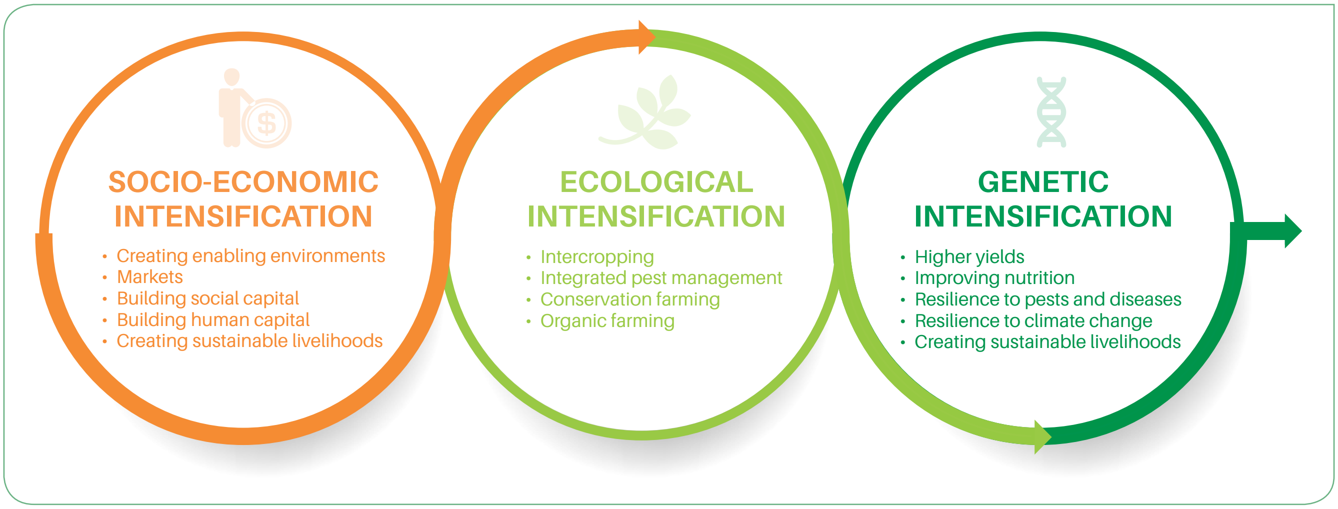

Figure 2.3 The three reinforcing components of sustainable intensification.
Source: Montpellier Panel (2013).

Socioeconomic factors often pose barriers to successful adoption of sustainable intensification practices, which must be removed or overcome with appropriate incentives. Such barriers include the significant up-front investments and expenditures that are often required for sustainable intensification technologies (Thomas et al., 2017). Necessary inputs, such as improved seeds and fertilizers, should be made available in local markets. Farmers require information and the evidence base about the potential gains of adopting a new technology and its compatibility with traditional practices.
Many farmers have little experience of the kinds of collective action that are needed for proper landscape management or the adoption of certain sustainable intensification technologies. This approach, known as "climate-smart agriculture (CSA)", is seen as a viable way of managing land sustainably and increasing agricultural productivity under the new realities of a changing climate (CCAFS and FAO, 2014). CSA aims to sustainably increase agricultural productivity and incomes while adapting and building resilience to climate change, and reducing GHG emissions from agriculture. It is context specific, evidence-based, and assesses synergies and trade-offs across multiple objectives as a basis for informing and reorienting policy in response to climate change. Action-oriented solutions for scaling up include promoting nationwide CSA and sustainable intensification policies to increase adoption of CSA technologies, increasing national investment to boost CSA, and building sustainable private sector-led input markets, ensuring equitable land access, and fostering inclusive and innovative knowledge management systems.

2.3 Land for food and the provision of water

While the connection between water and food security has made it to the top of the scientific and public agenda, the obvious connections between water and land resources in the production of food, feed, fiber and fuel, and the functioning of ecosystems are just starting to gain attention. Land cover and land use are paramount in linking the terrestrial and atmospheric compartments of the hydrological cycle. In fact, land plays an important role in water supply including reservoirs and underground water storage. Land-use changes will affect these cycles and thus cause changes in water availability, quality and management. This is critical to food security as irrigated agriculture represents about 20% of the cultivated land and contributes up to 40% of global food production (FAO and Global Mechanism of the UNCCD, 2015). Globally, agriculture is the largest user of water, using 70% of total ground and surface water withdrawals (Vasily et al., 2015).

Without appropriate inputs, agricultural productivity has traditionally been low and, with increasing pressure on land, declining. Intensive farming to meet food demands involves the increased use of fertilization and irrigation to maintain the productivity of soils and increase yields. Today, the intensification of agriculture in emerging economies such as India and China is repeating the problems of excessive use of these inputs witnessed in Western agriculture (Zhang et al., 2015). This often leads to degradation of water resources with increased nutrients and toxins in groundwater and surface waters (Cassman, 1999; Tilman et al., 2002). The degradation of water and land thus often occurs simultaneously, leading to a lower level of ESSs, and reduced capacity for food production and income generation (Penning de Vries et al., 2002; Vörösmarty et al., 2010). In fact, efforts to secure water can be counterproductive if land degradation processes are not kept in check. The result is the siltation of reservoirs, resulting in a reduced reservoir storage capacity, damaged irrigation infrastructure (Montanarella, 2007), pollution of potable water (Ilan and Lal, 2015), or eutrophication and low-oxygen conditions, with serious consequences for food production and human health (Myers et al., 2013). Conversely, poor management of available water can cause serious damage to land and topsoil, as seen in the salinization of many irrigated agricultural lands (Hillel and Vlek, 2005).

Recent research has shown that vast areas across the globe have arrived at acute levels of imposed threat to the quantity or quality of their fresh water resources (Vörösmarty et al., 2010). Over 60% of the largest rivers, which collectively discharge half of global run-off to the oceans, show at least moderate threat levels at the river mouth, with eight rivers showing very high threat to human water security. The sources of degradation in many of the most threatened rivers within the developing world bear remarkable similarities to those in industrialized countries. Sampling of rivers across the United States showed wide spread degradation across 750,000 km (50%) of sampled river length where the impacts of chemical fertilizers have often spread to water systems (UNEP, 2016). These nutrients find their ways into lakes and deltas where they result in eutrophication (Seitzinger et al., 2010; Vörösmarty et al., 2010; Ringler et al., 2013). Integrated land and water management is crucial to achieve human water security while preserving other ESSs (Vörösmarty et al., 2010).

While integrated water resources management (IWRM) has been identified by the community of water professionals as a most promising framework to tackle the management of the resource sustainably, the necessary integration and joint management of land and water has not been given similar recognition. Several IWRM projects during the last decades have shown that the collaboration and integration of different sectors is a prerequisite to successfully manage water in a basin-wide context. However, although land management is a crucial component of IWRM, it is usually only considered for securing human water supplies without acknowledging its impact on other ecosystem services. Thus, the concept of IWRM must be extended to a broader integrated resource management accounting framework for the range of ecosystem services relevant to all socioeconomic and geographic conditions. Both can differ widely within and between regions.

Water and land resources are also linked by the increasing number of large dams that were built as multipurpose schemes, serving energy production, irrigation, domestic supply, and flood control needs. Large dams have been built for over 130 years and since 2000, the construction of dams of more than 60 m in height has increased. Such dams prevent the flow of nutrients and sediments, hamper fish spawning, and affect the water cycle by increasing water residence time, thereby affecting the conditions of various ecosystems and their services. However, dams can work effectively as part of healthy landscapes with ecosystems that are not degraded and eroded, reducing destructive flash flows and retaining sediments on land. An ecosystem-based management approach would bring the elements of energy, food and water into a single nexus, and can help mitigate the trade-offs while generating co-benefits (Hoff, 2011; Bhaduri et al., 2015). Combined with cost and benefit analysis, this approach is a useful support for land-use planners and decision makers (Bekchanov and Lamers, 2016).

Nexus planning does not always lead to win-win situations. Trade-offs are often unavoidable and must be calculated and assessed in designing optimal solutions. Taking a system's view can help increase efficiencies and optimize production value, but value can be a subjective measurement. For example, discussions between Nepal and India on the development of large dams in the Upper Ganges Basin have been deadlocked because India wants larger dams for energy and to store water for downstream irrigation requirements, whereas Nepal argues that large dams with large reservoirs consume too much prime agricultural land. Gaining efficiency in one sector can be detrimental to other sectors. For instance, when electricity becomes cheaper it is typically used more, which may encourage unsustainable extraction of groundwater for irrigation. Therefore, understanding the connections among water, land, food and energy within a broader socio-ecological systems perspective can promote efficiency and improve the management of trade-offs. The benefits are better food, water and energy security and more equitability in their distribution.

Integrated management of land and water resources (ILWRM) and nexus planning are predicated on the willingness of policy makers to provide the enabling conditions for such an approach. Although policy makers have been keenly aware of the challenges associated with managing water, land and energy resources, few have considered their interdependence. This is because in many countries, different institutions and agencies are responsible for managing agriculture, land, water and energy, and usually there is little reliance on the data for planning. To effectively manage this nexus using an integrated approach, greater collaboration, coordination and planning among the different sectors and their institutions should be facilitated through institutional reform and incentive mechanisms.

2.4 Land for food and biodiversity

The role of biodiversity in the food security discourse has gradually moved from being perceived as: a constraint to further agricultural expansion and intensification, to a necessary component of an environmentally sustainable integrated approach to achieving global food security. The Millennium Ecosystem Assessment (MEA, 2005) has influenced this changing perception of the role of biodiversity for food security and, latterly, the SDGs have demonstrated decisively that food security, health and nutrition are "inextricably linked" with the health of natural ecosystems and the biodiversity they contain (Whitmee et al., 2015). Although long considered mutually exclusive (Tscharntke et al., 2005; Brussaard et al., 2010), biodiversity conservation and food security are intrinsically linked.

However, the expansion of large-scale agricultural production systems often comes at the expense of more biodiverse, heterogeneous landscapes. The loss of forests and tree-based agricultural systems in tropical regions, primarily to monocultural agricultural expansion, threatens the integral contributions biodiversity can make to improved livelihoods, food security, equity, income security, dietary diversity and nutrition of communities near such systems (Deakin et al., 2016).

As food security is currently high on the agenda in many political and scientific arenas, it is crucial to understand the contribution of biodiversity to a food and nutrition secure future. Ecologists and conservation biologists focus primarily on biodiversity conservation on nonagricultural lands, but a narrow focus on conservation fails to recognize the role biodiversity plays in fulfilling production requirements (Schroth et al., 2004; Godfray et al., 2010; Chappell and Lavalle, 2011). Most of the world's biodiversity remains outside of protected areas, often in complex, multifunctional landscapes occupied by people and their associated farming systems, particularly in the tropics (Alcorn, 1993; Putz et al., 2001; Sayer and Maginnis, 2005; Padoch and Pinedo-Vasquez, 2010; Powell et al., 2015).

Approximately 7,000 plant species and several thousand animal species have been used historically for human nutrition and health requirements (Ehrlich and Wilson, 1991; Tuxill, 1999; Toledo and Burlingame, 2006). Today, 12 plant crops and 14 animal species provide 98% of world's food needs. Three crops – wheat, rice, and maize – account for more than 50% of global energy intake (Ehrlich and Wilson, 1991; Thrupp, 2000; Khoury et al., 2014). Uniformity of production and wider biodiversity destruction has led to the loss of many wild relatives of crop plants (Tuxill, 1999) and livestock (Pilling, 2010). FAO suggests that three-quarters of the varietal genetic diversity of agricultural crops has been lost in the past 100 years (FAO, 2008). The genetic erosion of our nutritional base has considerable implications for food security, nutrition and health (Vincenti et al., 2008). Relying on a narrow genetic base for nutrition makes society considerably vulnerable to the hazards of monocrop agriculture and genetic uniformity, leading to crop failures and ultimately famine (Thrupp, 2000). Most modern crop and livestock varieties are derived from their wild relatives, and it is estimated that products derived from genetic resources (including agriculture, pharmaceuticals, etc.) are worth an estimated US$500 billion per year (Ten Kate and Laird, 1999).

Biodiversity continues to provide an important safety net during times of food insecurity, particularly during times of low agricultural production (Angelsen and Wunder, 2003; Karjalainen et al., 2010) linked with seasonal or cyclical food gaps (Arnold, 2008; Vincenti et al., 2008) or during periods of climate induced hazards (Cotter and Tirado, 2008). Wild harvested meat provides 30–80% of protein intake for many rural communities (Pimentel et al., 1997; Fa et al., 2003), particularly when domesticated alternative sources of protein are absent. The World Health Organization (WHO) estimates that in many developing countries, up to 80% of the population relies on biodiversity for its primary health care (Herndon and Butler, 2010) and the loss of biodiversity has been linked to the increased emergence and transmission of infectious diseases, with deleterious impacts on human health (Keesing et al., 2010; Myers et al., 2013).

The inherent conflict between an increasing human population and finite natural resources on the planet is evident in the trade-off between food production and biodiversity. Humans have increased their agricultural productivity through gains at scale, which have often come at the expense of biodiversity (e.g. Ziv et al., 2012). Here we focus on biodiversity trade-offs in land-based agricultural production systems.

By raising production efficiency through intensification, biodiversity is being reduced, and this in turn reduces the number of ESSs that support production (Wilby et al., 2009). This can have dramatic consequences. Many crops depend on insects for pollination. Pollination is thus one ecosystem service provided by biodiversity which is consistently underestimated. Pollination services can be replaced by human activity only at very high cost. Globally, the economic value of the pollination service provided by insect pollinators such as bees was about US$199 billion in 2005 for the main food crops (Gallai et al., 2008), or about 9.5% of the value of the global agricultural food production in the same year (Christmann et al., 2009). A worldwide decline of pollinators has been observed (FAO, 2008) due to diseases, climate change, invasive species, habitat loss and modern, large-scale, agro-industrial production based on high input of chemicals. Many pollinators are crop specific; their disappearance could wipe out the crop in question within a cropping period. Reduced pollinator diversity could have direct effects on the diversity of our diet; it would certainly have dire consequences for the economics of crop production.

Loss of ESSs is not only a concern at the field scale but also at the landscape and continental scale. Pollinators often come from forest patches in the landscape, thus providing an important ecosystem service in cropland nearby. Losing the forest means losing these services if no measures are taken to accommodate these insects elsewhere in the landscape. The role of natural habitats in biocontrol can vary dramatically depending on type of crop, pest, predator, land management, and landscape structure (Tscharntke et al., 2016). Similarly, biodiversity losses upstream (e.g. tree cover loss or loss of soil function) lead to reduced ecosystem services downstream. Furthermore, such effects can be at work over thousands of kilometers. In Amazonia, air masses carry water from the Amazon Basin via "atmospheric rivers" to distant southeastern Brazil and northern Argentina; this is known as the "biotic pump" (Newell et al., 1992; Arraut et al., 2011). There are thus obvious trade-offs between preserving the Amazonian rain forest to ensure continued water delivery to the agricultural production areas in the south or pursuing agricultural production by pushing out the forest frontier (Verchot, 2015). A landscape approach adds options to the basket of opportunities, which are not available when working just at the field/plot scale.

Biodiversity loss both within and beyond agricultural ecosystems affects food availability and choices, and income and wealth creation because of diminished provisioning ecosystem services. Hence, biodiversity is not only a feature of food security (as provisioning ecosystem service); it also affects the ability of cropland to rely on supporting ESSs from adjacent land such as providing water, pest control, etc. A balance must be found in multifunctional landscapes (Cardinale et al., 2012). Crop diversification (Bobojonov et al., 2013) combined with conservation agriculture (Vlek and Tamene, 2009; Powlson et al., 2016), addressing diverse production technologies, CSA, and addressing the whole food production system including policies and incentives, offer a variety of options in which food production and biodiversity conservation can be optimized.

Increasing the productivity gains within such improved systems to feed the future billions remains a key objective which may benefit from the feedback effects by which biodiversity raises productivity – these effects have been identified and quantified across a variety of landscapes and ecosystems (e.g. Liang et al., 2016). Using the principles of CSA (FAO, 2010, 2011b; Milder et al., 2015) combines already used and tested practices (e.g. conservation agriculture, agroforestry, crop residue management, water harvesting, and diversity conservation) with improved policies, investments, and institutional frameworks. This is also expected to have positive effects on biodiversity.

Land degradation pressure reduces our options to meet both the food demands and conserve biodiversity (Figure 2.1), whereas applying principles of sustainable agriculture, conservation agriculture and CSA will counter land degradation and help attaining both. Degradation corresponds to moving the line in Figure 2.1 to lower, and restoration to higher levels. But changes in the slope of this relationship might be achieved if intensive agriculture were combined with efforts to improve biodiversity.

Some key elements of successful action to preserve biodiversity in food production systems are offered in the recent report from the FAO High Level Panel of Experts on Food Security and Nutrition (HLPE, 2016). It recommends the adoption of a systems approach to integrating NRM and agriculture, strengthening governance systems across scales, integrating forest and agricultural land use across the productive landscape, and supporting the contribution of biodiversity to income and regional and global food production.

2.5 Land for food and infrastructure

Urbanization and industrialization are development trends that can occur spontaneously but are often encouraged to alleviate pressure on land in rural areas. These developments are however usually poorly managed, leading to urban poverty and poorly planned urban expansion. Ironically in this process, valuable agricultural land is converted for housing, transport or other productive uses. Currently, as much as 54% of the population lives in cities with 3% of the global land surface covered by infrastructure (WBGU, 2016), equivalent to 26% of the earth surface under cultivation. Population growth and persistent urbanization and infrastructure development lead to urban encroachment into agricultural lands and is often considered an unavoidable global phenomenon (Buxton and Taylor, 2011; Valerial and Fiona, 2012). Both in China (Han and He, 1999; Ho and Lin, 2004) and in India (Fazal, 2001), the phenomenon is attracting increasing attention as these countries experienced huge loss of agricultural land due to rapid urbanization and the expansion of urban areas.

Urbanization results from rural push and urban pull factors. The urban pull results from the perception of rural people that urban and industrialized regions provide significant opportunities for employment and livelihood (Jaysawal and Saha, 2014). The rural push factors drive people away from the deteriorating quality of life in rural areas (Jedwab et al., 2014). Cities are growing internally and pushing their boundaries into agricultural lands, in many cases without regard for the suitability of the land for urban expansion or the loss in productive capacity. Often the best agricultural lands are appropriated, with farmers trying to compensate for their land loss by taking on new, often inferior land under cultivation (Malik and Ali, 2015).

The development of the industrial sector was the first engine of economic growth although the service and energy sectors are believed to have usurped this role in the last half century (Azadi et al., 2011). Governmental industrialization policies encourage the development of industrial zones at the expense of agricultural lands in urban fringe areas (Minghong et al., 2004; Xu, 2004; Nguyen et al., 2011; Zhong et al., 2011). The promotion of the energy sector in many developing countries has caused a further significant increased rate of agricultural land conversion (Azadi et al., 2013; Vandergeten et al., 2016).

While serving as an engine of economic growth (Tariq et al., 2006; Azadi et al., 2011), the conversion of productive land to urban areas has become a hindrance to world food security (Khan and Hanjra, 2008) as it reduces the land available for food and timber production (Wu and Irwin, 2008). For example, in Indonesia, within five years, about one million hectares (about 5%) of arable land have been converted to urban use to meet the increasing demands of industrial and infrastructural development (Halim et al., 2007). Such reports have fed an ongoing debate on whether agricultural lands should be converted to other uses. In the pro-ruralists view, land conversion has negative impacts such as the loss of prime agricultural land, reduced agricultural jobs and wasted investment in irrigation infrastructure. Consequently, it affects agricultural production and threatens food security and should be curtailed. In contrast, pro-urbanists argue that land conversion is a logical consequence of urban growth. According to them, the decline of agricultural production can be compensated by intensification and agro-biotechnological advances elsewhere. Hence, they don't consider land conversion to be a threat (Azadi et al., 2011). Irrespective of the viewpoint, the sealing of agricultural land surfaces leads to a shift in the trade-off curve in Figure 2.1 towards the origin when it comes to the delivery of ecosystem services and to urban flooding and heat islands. Urban centers tend to modify regional nutrient and water flows, causing environmental stress both in the regions of origin as well as in the areas of destination of these essential chemicals.

Finally, in many developing countries, poorly managed urban sprawl and lack of transparent regulation of land rights have caused serious social conflicts over land. The land market in these countries also faces governance challenges including corruption and bribery, illegal land transfer, weak service provision and inefficient land administration (Deininger and Feder, 2009; Koroso, 2011). In fact, major problems associated with agricultural land conversion are related to weak land governance, lack of recognition and protection of the rights of poor farmers to land and poor land-use planning (LUP) and the processes involved in the decisions about land use (Ramakrishna, 2003). A sustainable nexus on land for food and infrastructure can be promoted through good land governance and proper LUP. The challenge then is to find a means to implement these plans.

Researchers (Lavigne Delville, 2007; Rudi et al., 2012) increasingly emphasize the role of land governance in the food versus infrastructure nexus. Land governance is defined as: "the rules, processes and structures through which decisions are made about access to land and its use, the way the decisions are implemented and enforced, the way that competing interests in land are managed" (Palmer et al., 2009). Land governance is basically about determining and implementing sustainable land policies and establishing a strong relationship between people and land (Enemark et al., 2010).

Weak governance in land tenure tends to arise in many developing countries where the laws are complicated or conflicting, fickle or outdated, where people who work in land agencies are poorly trained and paid, or where decision-making processes are not transparent and civil society is poor (Le Meur, 2005). Consequently, governments cannot prevent or steer the displacement of poor farmers from their land to meet the need of the growing population for more housing, industrially based job opportunities and infrastructures reflected in high rates of agricultural land conversion.

In contrast, strong land governance realizes and ensures the rights to land and ensures enforceable claims on land, with the level of enforcement ranging from national laws to local, rural rules. It confers to people a recognized ability to control and manage land and dispose of its products as well as engaging in transactions such as transferring or leasing land (IFAD, 2008). Once strong governance is established on land, decision making becomes more transparent and inclusive, and common rights through which the rule of law can be applied equally to all groups are more respected (Le Meur, 2005). Accordingly, strong land governance is increasingly seen as a precondition for sustainable resolution in the nexus of ensuring food security and infrastructure progress. Improved governance can result in land administration, which governs transparent, accessible, informative, and effective rules on land that result in judicious land conversion and development (Lavigne Delville, 2007). Strong governance requires good monitoring. Current geographical information systems (GIS) can identify settlement densification, expansion processes, and quantify loss of agricultural land, even differentiated by land quality, during settlement growth (Conrad et al., 2015).

Determining optimal uses of land is a crucial step in preventing its degradation because of urban pressure and in making progress towards an integrated and sustainable nexus (Prato, 2007). To optimize the integrated use of land, different techniques have been used globally with some adjustments to account for diverse local circumstances (Makhdum, 2009). Land-use planning is a process of analyzing and determining the land suitability of a given region for a certain use (e.g. agriculture, forest, infrastructure or recreation, etc.) and the key to rational land allocation (Ramakrishna, 2003). An important part of this process is to determine the criteria that influence the suitability of the land (Al-Shalabi et al., 2006) through multicriteria analysis. One such tool is the analytical hierarchy process (AHP), (Saaty, 1990). Taking "sustainability" into account, the technique involves paired comparisons of socioeconomic objectives that are as important as eco-political aspects (Xu et al., 2006; Zeng et al., 2007).

The AHP is an important member of a general family of multicriteria decision-making tools, which combine the information on various criteria to form a single index of evaluation. It is aided by a GIS as a means for handling a wide range of data from different multi-spatial, multi-temporal and multi-scale sources for a time-efficient and cost-effective analysis. Accordingly, the combination of the two techniques (AHP/GIS) is a powerful approach to deal with a complexity of LUP and optimize the ecosystems services that carefully planned urban landscapes can provide. Many researchers (Davidson et al., 1994; Joerin et al., 2001; Sicat et al., 2005; Chen et al., 2007) believe that spatial multi-criteria assessment (MCA)-based decision making is one of the most effective techniques for land-use and environmental planning and to resolve the agricultural–ecological– infrastructural nexus problems that many nations are facing. It is widely recognized that infrastructural development is desirable and will not be stopped, but such infrastructure does not necessarily need to take the best agricultural land and that urban development can benefit greatly from urban landscape planning, thus retaining essential ESSs that benefit the urban dweller.

3. Land resources and the SDGS

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3.1 Introduction

Land degradation and measures to reduce LD are linked to multiple SDGs in a complex system with trade-offs and synergistic relationships. This chapter examines some of the most important elements of these relationships with a focus on the SDGs related to food security, health, agricultural production, climate and responsible consumption. Given the complex interactions between LD and the multiple ecosystem services that land provides (Chapter 2), it is unavoidable that in implementing strategies to meet the SDGs, policy makers are confronted with trade-offs. In fact, LD affects at least six SDGs directly (Figure 3.1).

Arrows in the upper part of Figure 3.1 illustrate the presence of systemic links between the SDGs in general. Upward arrows in the lower part of Figure 3.1 represent specific effects of types of LD on selected SDGs that can be mediated by measures such as restoration, prevention, and rehabilitation. Downward pointing arrows in the lower part of the figure indicate potential feedback effects of interventions to achieve the SDGs on LD. For example, agricultural productivity loss due to LD will increase the costs and prospects of achieving Goal 2 (end hunger). Likewise, some LD types promote GHG emissions from soils and thus compromise efforts towards pursuing Goal 13 (climate action). Policies and measures adopted to address specific SDGs (or merely one SDG) can have detrimental effects on land quality and in turn jeopardize policy action towards other SDGs. Pushing the system for food production to eliminate hunger (SDG 2) might threaten SDGs 3, 6 (and 15 if this is done at the expense of forest cover with concomitant loss of carbon to the atmosphere and with water and air pollution due to erosion). Also, agrochemical strategies to increase agricultural yields can produce health externalities while some forms of reforestation can reduce terrestrial biodiversity and downstream water availability. The design of SDG implementation strategies should be informed by the functional links between LD, and the respective SDGs, as seen in Figure 3.1. This chapter focuses on direct and bidirectional links between LD and (selected) SDGs, while underlining trade-offs between strategies to pursue individual goals (see Figure 3.1).

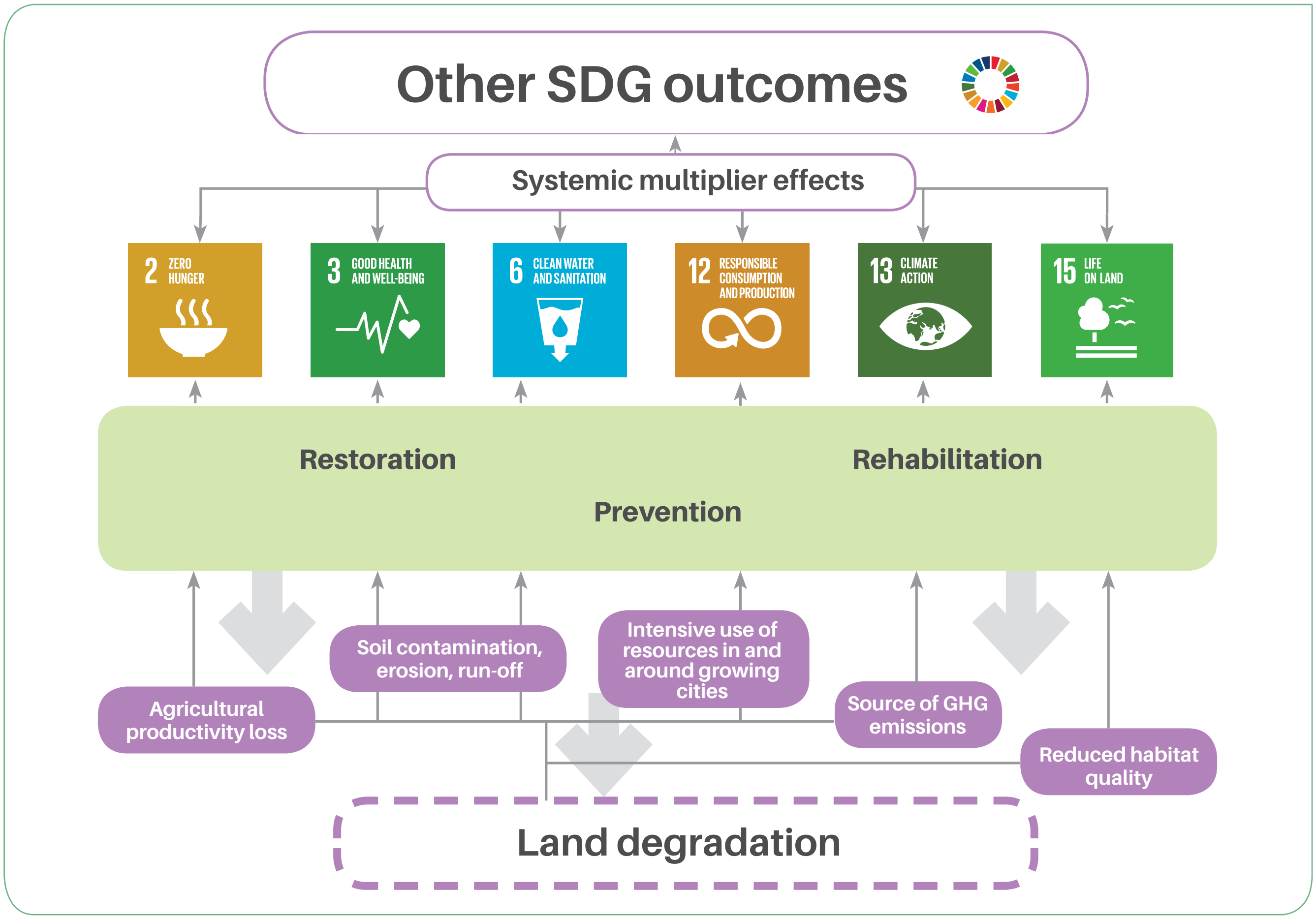

Figure 3.1 Functional links between land degradation and most directly affected sustainable development goals (SDGs).

3.2 SDG 15: Protect and restore terrestrial ecosystems and promote sustainable use of natural resources

Sustainable Development Goal 15 aims to "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss." While this is the only SDG linked directly to LD, due to the connection of land with food, energy and water, there are obvious links to other SDGs (Chapter 1, Figure 3.1). The pursuit of this SDG is at the core of the LD problem.

Sustainable land management (SLM) was defined in 1992 during the UN Earth Summit as "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."

It promotes a range of complementary measures that are adapted to the biophysical and socioeconomic context for the protection, conservation and sustainable use of resources (i.e. soil, water, biodiversity) and restoration or rehabilitation of degraded natural resources and ecosystem functions. Knowledge management, capacity development and coherence and alignment with policies and investments through integrated strategies of land resources planning, form the principles for SLM action. About two billion hectares of land can be subject to restoration and rehabilitation through the application of SLM tools (WRI, 2014).

In designing effective strategies to protect or reclaim degrading land, we need to know the types of LD that are in play and their causes. Although some LD can have its origin in natural phenomena (e.g. landslides and earthquakes) or in climate change, the most immediate causes are usually human activities in the landscape that result in the loss of ecosystem health and productivity. Examples are: exhaustive agriculture, over-harvesting of forests, overgrazing of pastures, and poor water management. The proximate causes vary and differ from region to region, as do the economic and political drivers. For instance, Hosonuma et al. (2012) showed that forestland degradation in Africa was due primarily to wood harvesting for energy (62%), while timber harvesting was less important (26%). In Asia and Latin America, timber harvesting was the major cause of forest degradation (67% and 70%, respectively). Harvesting for fuelwood and charcoal was important in Asia (20%), but it was reportedly a minor factor in Latin America (9%). Rangeland degradation in Africa was predominantly due to overgrazing (Varis, 2006). In East Africa, which hosts about 40% of the livestock herds in sub-Saharan Africa (SSA), about 65% of the semiarid grazing lands have been seriously affected (Nkonya et al., 2016a).

Understanding the proximate causes of LD is a necessary starting point as they determine, at least from a technical perspective, the remedies that are needed. Proximate causes lead to degradation processes such as loss of biodiversity, invasive species, reduced water storage, water and wind erosion, and soil degradation (e.g. loss of nutrients and SOM, salinity, acidification, pollution or compaction, water logging, subsidence) (GLASOD, 1991; Keesstra et al., 2016). Effective programs must target appropriate restoration and mitigation measures that are consistent with the value systems of local land users, particularly if the goal is to primarily provide global environmental services such as soil carbon sequestration. Many technical measures to counteract LD have been documented over the years (WOCAT, 2016).

Proximate causes have underlying political and economic drivers that must be addressed to enable better land husbandry. Understanding the drivers that lead to unsustainable land use may be relevant in finding a way of counteracting these causes and meeting SDG 15. They can steer political action and governments' investments that facilitate the restoration process and take technical solutions to scale. Building pathways to SLM for entire countries requires a balance between the rising demands for food, feed, fuel, fiber and natural resources and the restoration of degraded landscapes and environmental services that intact ecosystems provide (Steffen et al., 2011; Tscharntke et al., 2012). Both governance and market forces contribute to the outcomes of programs to improve natural resource management and support sustainable landscapes (Place et al., 2006). Governments have several tools at their disposal including regulatory, price based, and voluntary instruments (Mansfield, 2006; Cocklin et al., 2007). These approaches are not mutually exclusive, but international organizations tend to favor the latter two over regulatory approaches (Gómez-Baggethun and Muradian, 2015; Vatn, 2015).

Poverty and rent seeking are key factors in the unsustainable use of land and the depletion of land resources (Barbier and Hochard, 2016). Rent seeking may need to be combatted through regulation. For the poor, conservation and restoration efforts must generate income that offsets their costs and renders the system competitive for the land user. Stakeholders at the community, sub-national, national and international levels may need to provide financial incentives to preserve the land resources on which their well-being depends. Payment for ESSs is attracting increasing attention to transition to sustainable use of land resources. Experience from the United States (e.g. Napier, 1992) suggests that low returns on the additionally invested time and effort of the land user and more profitable off-land opportunities may dissuade the adoption of technologies that protect or restore land. Governments can promote SLM practices and restoration of degraded lands by many actions. Increasing profitability through market access by building infrastructure can lead to land improvement. However, as shown by Babigumira et al. (2014), as such regions become more profitable, there is usually encroachment of farmers into forestland. For infrastructure investments to be effective, government should mitigate the negative environmental impacts of creating the economic opportunities.

Tenure and security are prime prerequisites for investment in SLM practices and restoration. Individuals and groups that invest in improving the quality of land need assurance that they can benefit from these investments over time. However, customary and formal tenure systems both create and resolve problems. Formal tenure systems can give families and companies the certainty they need to invest in soil productivity enhancement as concluded for West Africa (Neef et al., 1995). Customary tenure systems are often adequate to ensure investment in maintaining land productivity at the subsistence level but may be insufficient to encourage major investments in land, as farmers are unable to use the land as collateral i.e. to gain access to credit. Replacing traditional tenure systems with formal titling of land should be targeted at areas where there is a demand for increasing access to credit. Such rights must be warranted, requiring a functioning legal framework (see Chapter 5).

Achieving SDG 15 needs public programs designed to jointly promote human development through poverty alleviation, tenure security and biodiversity conservation, and sustainable land management and restoration (Bridgewater et al., 2015). Yet, public expenditure on land-based sectors vary across the developing world. For example, in Latin America and the Caribbean (LAC), public spending is robust and there are significant direct foreign investments in agriculture and forestry. A comparison of the SLM practices among low- and middle-income countries showed that adoption was highest in the LAC region (Nkonya et al., 2016b). Nonetheless, vital parts of the Amazon and Cerrado continue to be under land conversion pressure. South Asian countries also invest significant public funds in agriculture, but have not attracted the direct foreign investment to the level of the LAC region. Expenditures in agriculture, forestry and wildlife on average amount to only about 4% of the total government budgets despite making up 25% of GDP. The 2003 Maputo Declaration on Agriculture and Food Security set the target for public expenditures at 10%; to date, only 6 out of the 48 countries in sub-Saharan Africa have met this target (Nkonya et al., 2016a). Donor funding accounts for a large share of investment in SLM in many African countries (Gondo, 2010; Nkonya et al., 2016a).

An important lesson learned is that even if researchers are convinced of the validity of an intervention, the farming population may not readily adopt that intervention because additional socioeconomic and institutional factors will influence their decision making. Consequently, measures to be developed by the research community must be assessed against several criteria: improved practices should be agronomically, ecologically and economically superior to existing practices, fit the socioeconomic environment of the rural community and production systems and must be sustainable. Governments need to create the enabling conditions through market and infrastructure investments and through incentives for better land husbandry, while putting in place disincentives for the continuation of degrading practices.

3.3 SDG 6: Ensure availability and sustainable management of water and sanitation for all

Although all the targets for SDG 6 have some relation to LD, the most relevant is Target 6.6: “by 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.” Therefore, SDG 6 is tightly knit with SDG 15 – with regard to both a cause and a consequence of LD. The current approach, in which water and land are managed largely as independent entities, is obsolete (UNEP, 2012). Bhaduri et al. (2016) who presented a renewed case for a shift in the management paradigm so that water and land are handled in an integrated fashion (Chapter 2) echo this position. Le Blanc (2015), in a mapping exercise of the SDGs, places SDG 6 in a web that includes seven other SGDs. These include; Goal 2 on hunger; Goal 3 on health; Goal 11 on cities and Goal 12 on sustainable consumption. In the frame of this review the three sub-indicators of LD (i) land cover and land cover change, (ii) land productivity and (iii) carbon stocks above- and belowground are used as a lens to examine in more detail some of the drivers of LD and the water connection, through urbanization, agriculture and loss of wetlands (mangroves and peatlands).

Over the past century, the growth in human population and the subsequent growth in agricultural and urban land use and land-use change has put enormous stress on water in terms of both its quantity and quality. Between 1990 and 2014, the human population in sub-Saharan Africa has grown by 94% (WHO/UNICEF, 2015). Issues of water scarcity have significant and growing social, environmental and economic consequences that threaten the survival of wildlife and people. Additionally, Africa will face increasing water scarcity and stress with a subsequent potential increase in the number of water conflicts as almost all the 50 river basins in Africa are transboundary (De Wit and Jacek, 2006). Land degradation undermines water availability; by 2030, it is estimated that water scarcity alone in some arid and semiarid places may displace up to 700 million people (WWAP, 2012).

Fresh water habitats have provided humans with essential resources from time immemorial (Gordon, 2002), and it is not by accident that almost all historical centers of human development are associated with rivers or lakes. Nowadays, at least two billion people depend directly on inland freshwaters, such as lakes, rivers floodplains and wetlands, for the provision of food (Tockner et al., 2008; Richter et al., 2010). Despite what should be a precious resource, the quality of water has decreased globally since the 1990s (UNEP, 2016). Ritter et al. (2002) presents an array of ways in which land-based, anthropogenic pollutants can adversely affect water quality which include construction, industrial development, waste disposal on land, sewage treatment plants and mineral resource extraction.

Poor agricultural practices reduce land productivity (Qadir et al., 2014). Currently, agriculture claims 70% of the global water withdrawals, and this water use is increasingly competing with other water-demanding sectors such as industries and households (WWAP, 2012), and water shortages already limit regional agricultural production in many countries (CA, 2007). About 310 million ha of irrigated lands exist worldwide but an estimated 20% of this resource is salt affected (62 million ha) (Qadir et al., 2014). The inflation adjusted cost of salt-induced LD in 2013 was estimated at US$441 per hectare, yielding an estimate of global economic losses of US$27.3 billion per year (Qadir et al., 2014). In the Indo-Gangetic Basin, crop yield losses on salt-affected lands for wheat, rice, sugarcane and cotton amounted to 40%, 45%, 48%, and 63%, respectively (Qadir et al., 2014). Employment losses were 50–80 man days per hectare, with an estimated 20–40% increase in human health problems and a 15–50% increase in animal health problems. In the Indus Basin in Pakistan, wheat grain yield losses from salt-affected lands ranged 20–43% with an overall average loss of 32%. For rice, the crop yield losses from salt-affected lands ranged 36–69% with an overall average loss of 48% (Qadir et al., 2014). The salinization of soils through poorly designed and managed large-scale irrigation schemes in Africa (Djagba et al., 2014) are a case in point. Globally, agriculture is the main contributor to both point and non-point source water pollution, especially for nitrogen (WWAP, 2012). This nutrient loss from agricultural land results in severe impacts on estuaries and marine ecosystems and can cause so-called “dead-zones”, due to eutrophication in marine coastal systems (WWAP, 2012).

Mangroves, which are a unique habitat needing land, sea and fresh water to survive, are increasingly recognized for their significant carbon storage capacities (link to SDG 13) and hence their contribution to mitigating climate change (Barbier et al., 2011). Mangroves are being converted rapidly, with current trends projected to lead to a 30 to 40% loss of tidal marshes and sea grasses over the next 100 years, and a loss of nearly all unprotected mangroves (Pendleton et al., 2012). Herr et al. (2015) have estimated that 1.9% of mangroves are lost each year globally, resulting in 240 million tonnes (t) of CO_2 emissions – equivalent to emissions from the use of 588 million barrels of oil or from 50.5 million passenger vehicles.

Peatlands, globally an important type of wetland, are threatened by conversion to oil palm and pulpwood, fire and hydrocarbon exploration and extraction. Petrenko et al. (2016) have reported that Indonesia is the world’s leading producer of palm oil, supplying approximately half of the commodity globally. In 2014, Indonesia produced 32.5 million t of crude palm oil and exported 80% of it, earning US$18.6 billion. Palm oil is the largest agricultural industry in Indonesia and its production is expected to continuously expand at 10% per year. Much of this expansion depends on the conversion of peatlands, which are up to 20 m in depth. Once peatlands are disturbed, they become susceptible to fire as they tend to dry up, releasing carbon and start burning. In Canada, the mining of oil sands was originally conducted in wetland rich areas, leading to their loss (Rooney et al., 2012). Peatland loss will also influence the region’s potential to sequester carbon in the future; for instance, the loss of 12,414 ha of peatland translates into 2,408–3,041 t of annual carbon sequestration potential. Scaling up, this equates to 5,734–7,241 t C $year^{-1}$ (21,025–26,550 t CO_2 $year^{-1}$) lost.

A detailed analysis by WWAP (2016) in the World Water and Development Report gives us an estimate that more than 1.4 billion jobs, or 42% of the world’s total active workforce, are heavily water dependent. It is further estimated that 1.2 billion jobs, or 36% of the world’s total active workforce, are moderately water dependent. In Central Asia, where irrigated agriculture is key to livelihood security, the consequences of a 10–20 % reduction in average irrigation water supply would lead to the abandonment of croplands (an estimated 6–9% of the current area), and would further escalate unemployment by 5–8% in the agricultural sector and 8–9% in the entire economy. The economic losses would add up to about US$461–588 million (Bekchanov and Lamers, 2016). Therefore, water impinges on SDGs 1, 8 and 10, which deal with poverty, employment and equity as well as SDG 6.

Clearly, SDG 6 will not be met if LD is not kept in check. Implementing integrated water resources management (IWRM) (UNEP/MAP/PAP, 1999) at all levels provides the framework for addressing the synergies and potential conflicts between the targets within SDG 6 and LD. It does this by balancing the demands from various sectors for water resources, as well as the potential impacts of different targets on each other, to form a coordinated planning and management framework (UN-Water, 2016). Although none of this is new, researchers are being challenged to develop solid business cases and adequate narratives for decision makers based on businesses that have been analyzed, and increase the understanding on what works, what does not and why. The SDGs need strategies and policies that are underpinned by a strong scientific and evidence basis, which again is not new (Zalewski, 2000). However, the links between the policy/practice and science communities is inadequate or deteriorating, hindering the development of concrete solutions for water and land management.

3.4 SDG 2: Food security and sustainable agriculture: the role of combating land degradation

One of the main forms of LD is the degradation of agroecosystems, which affects the food supply and income of the poor, increasing their vulnerability and creating a vicious cycle of poverty, further degradation and hunger (United Nations, 2012). To reach the key target of SDG 2 (i.e. “End hunger and achieve sustainable agriculture” (Target 2.4)) the challenge is twofold. First, to achieve food security by increasing production from an already extremely depleted natural resource base for the growing population,[1] and second, to sustain land productivity and ESSs, to complement ongoing international initiatives and contribute to the SDGs and their targets (FAO, 2011; UNCSD, 2012; UNCCD, 2013). Therefore, profound changes are needed to expand and accelerate the transition to sustainable food and agricultural (SFA) systems, which would enhance food security worldwide in the medium to long term. Moreover, these systems should provide economic and social opportunities and protect the natural resources base and ESSs from further degradation. Comparable and coherent baselines and indicators are needed to track progress and ensure efficient transition.

The recognized indicator for Target 2.4.1. is “the proportion of agricultural area that is under productive and sustainable agricultural practices.” The denominator is the total agricultural area under cultivation, which is collected by statistical bodies in countries and compiled internationally via a questionnaire by FAO (FAOSTAT) who acts as the custodian of such information. The denominator is not constant. In fact, there has been a steady increase in the extent of global arable land between 1961 and 2009 (Ausubel et al., 2013). Projections differ (Figure 3.2); Roser (2016) projects a decline over the next 50 years while FAO anticipates a slight increase. If the increasing trend holds, to keep the SFA fraction from falling there will have to be an increase in SFA proportional to the increase in agricultural territory. If LD is not kept in check and agricultural land declines, the fraction in SFA will improve concomitantly without further efforts.

Monitoring the numerator – the area under SFA systems – is a complex new endeavor that aims to capture the three dimensions of sustainable production: environmental, economic and social. Collecting such data should be done by farm surveys in which countries have the flexibility to identify issues related to sustainability that are relevant to their priorities within these three dimensions. Agricultural surveys or agricultural modules in integrated household surveys organized by national statistical agencies are used to collect data on sustainable production. International agencies will support these efforts to ensure methodological rigor and harmonization of data sets.

FAO (2014) proposed five interconnected principles for the transition to SFA. They involve: (1) improving the efficiency in the use of resources; (2) sustainability through direct action to conserve, protect and enhance natural resources; (3) the recognition that agriculture that fails to protect and improve rural livelihoods and social well-being is unsustainable; (4) enhanced resilience of people, communities and ecosystems as key to sustainable agriculture; and (5) sustainable food and agriculture requires responsible and effective governance mechanisms. These principles converge

1 It is estimated that food production will need to increase from the current 8.4 billion t to almost 13.5 billion t a year to provide for a population projected to reach 9.3 billion t in 2050 (FAO, 2014).

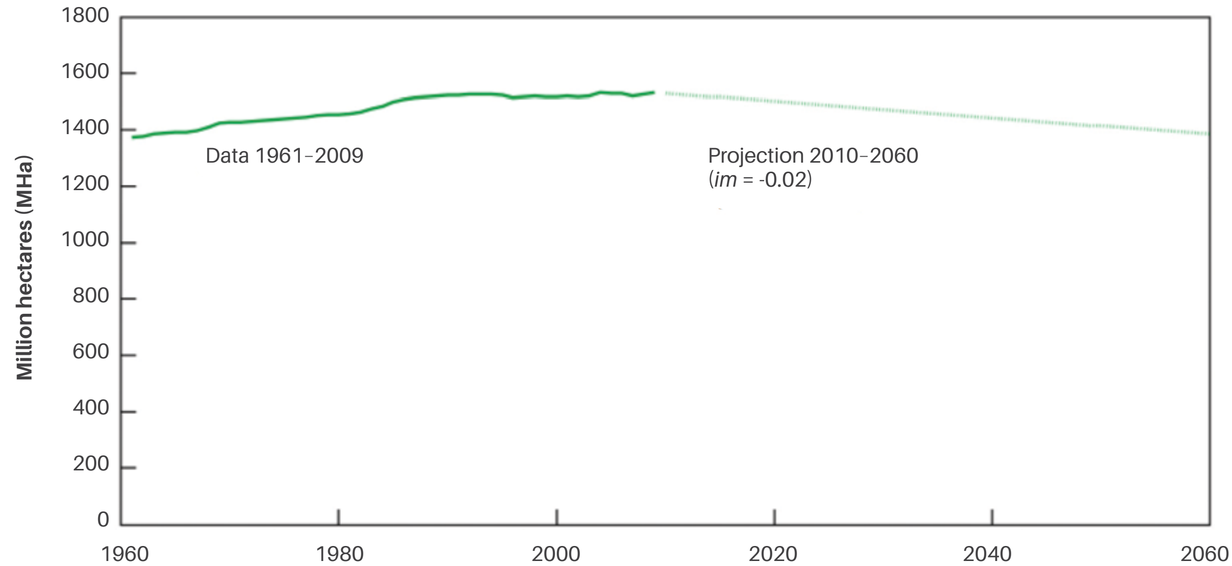

Figure 3.2 Peaking farmland: Extent of global arable land and permanent crops, 1961–2009 and projection for 2010–2060.
Source: Ausubel et al. (2013); Roser (2016).

with the concept depicted in Figure 2.1, i.e. avoiding a clockwise move of the line by increasing food production at the expense of other ESSs; alternatively, move the line counterclockwise by improving ecosystem service without compromising food production or move the line upwards and accomplish both.

The transition to SFA should be addressed at different scales. At the highest level, national policy makers should be sensitized to the problem and create the political will to act. One of the conditions to taking such action is scientists' ability to explain the magnitude and importance of the threat of LD to food security. Land-based measurements of LD are integrated and complemented by earth observation technologies, either by or under the overall supervision of national statistical agencies. But measuring the degree of LD, and finding the right indicators over larger areas remains a challenge (Chapter 4). However, there is growing awareness of the problem, and once such national commitments provide the necessary enabling environment, communities should be encouraged to undertake integrated landscape management (ILM).

Integrated landscape management is the hub for natural resources and ecosystem management through landscape design within agricultural areas; it offers a coordinated process across sectors and stakeholders in which a range of societal needs can be optimized in the short and long term. ILM examples include: integrated watershed management, community territorial development, forest landscape restoration, SLM, agroecosystem approach; land evaluation and land-use planning (FAO, 2016c). A prerequisite for ILM is the systematic assessment of land potential where an assessment is made of alternatives for optimal land use for improved economic, ecological and social returns. This involves multiple sectors with many stakeholders in a scale-dependent participatory process. Land resource planning tools help the decision makers to adopt appropriate options for the use of land resources based on their natural potential and hence avoid unsustainable exploitation and prevent further degradation. Proper planning should help communities to implement ILM and the land users to select and put into practice SLM options that protect land and restore soil in the already degraded areas. Land-use planning is part of the integrated land resources management continuum.

The interaction between land components and the influence of climate and human activities on them will determine the productivity and sustainability of any land-use system. Unfavorable climatic conditions (imposed by climate change/variability) coupled with mismanagement or misuse of resources will lead to degradation, vulnerability and poverty. Conversely, selecting proper land use types and implementing SLM practices will enhance sustainability and resilience to shocks and risks. Two examples of normative measures to support the implementation of sustainable land and soil management are: the Voluntary Guidelines on Sustainable Soil Management (FAO, 2016e) and the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security (FAO, 2012). Promising SLM options are available to reverse LD in Africa, the Near East, Asia, and LAC. Some examples are: The Great Green Wall for the Sahara and the Sahel Initiative (GGWSSI) and NEPAD's TerrAfrica Initiative.

Halting and reversing LD is crucial to achieving food and nutritional security through sustainable agriculture (and to achieve SDG 2). Sustainable land management options provide promising solutions, but participatory planning and identification of potential practices to suit the prevailing socioeconomic and biophysical conditions, coupled with a favorable enabling environment and support from policies, institutions and financial mechanisms, are needed to get tangible, positive impacts.

3.5 SDG 3: Healthier lives through avoidance of soil pollution

Goal 3 of the SDGs aims to: "Ensure healthy lives and promote well-being for all at all ages" under which Target 3.9 calls for "a substantial reduction in the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination by 2030." Soil contamination as one form of LD (Chapter 1) results from the entry of toxic chemicals into the natural soil environment or the water that passes through it. Health consequences from direct and indirect exposure to soil contamination vary greatly depending on pollutant type, pathway of contamination, and vulnerability of the exposed population (Huber and Prokop, 2012). Chronic exposure to chromium, lead, and other metals, petroleum, solvents, and many pesticides can be carcinogenic; can cause congenital disorders, or other chronic health conditions. Industrial or other human-induced concentrations of naturally occurring substances, such as nitrate and ammonia associated with livestock manure from agricultural operations, have also been identified as health hazards in soil and groundwater (Jechalke et al., 2014).

Soil pollution is induced by industrial activity, agricultural chemicals or improper disposal of waste. In general, contamination is positively correlated with the rates of industrialization and chemical usages (Huber and Prokop, 2012). The concerns about soil contamination stems primarily from health risks, which are associated with direct contact with the contaminated soil, vapors from the contaminants, or from secondary contamination by contaminated water used for irrigation and by livestock and humans.

Soil and land degradation through pollution can be either point pollution or diffuse pollution. Diffuse pollution is caused by contaminants entering the soil over wide areas from diffuse sources. One example of diffuse pollution is sulphur oxide (SO_x) and nitrogen oxide (NO_x) emissions from industry and transport, which can cause soil acidification and threaten vegetation and water quality in locations away from the original emissions sites. Such examples of diffuse pollution are widely documented in the Sudbury region of Ontario, Canada, where mining and ore smelting has released more than 100 million t of SO_2 over the past century, resulting in soil acidification with increased weathering of soil minerals and, in turn, a release of metals into the soil (Powers, 2016). Acidification and metal enrichment substantially damaged the natural forest system (Narendrula et al., 2012). Another example is the global increasing demand for copper with increasing prices for copper ore, which has motivated countries such as Zambia and the Democratic Republic of the Congo to extend their copper mining. This has caused heavy pollution of water, air, and soil. Both countries are categorized within the ten most polluted areas worldwide (Banza et al., 2009).

Heavy metals (e.g. Cr, As, Zn, Cu, Cd, and Ni) pollution resulting from improper handling or disposal of toxic wastes, wastewater irrigation and fertilization, residues from coal combustion etc. has caused many environmental hazards. Bio-accessibility of such contaminants may pose health hazards via entry into the food chain and water cycle (Huber and Prokop, 2012). Community-based approaches, both at national and international levels, have been developed in some countries (mostly EU Member States, Australia and North America) to provide an insight into the remediation strategies of such toxic metals and to maintain a viable ecosystem and public health (Jechalke et al., 2014). Additionally, risk assessment strategies have been adopted as a cost-effective scientific tool by the federal states for addressing social, food, and land security issues resulting from LD related to heavy metal pollution.

According to a global economic survey conducted by Industry Canada (2005), around US$12–35 billion was invested annually in cleaning up of contaminated sites. Although a global inventory of contaminated land is lacking, global regions with key soil pollution problems have been summarized in Table 3.1 based on contamination sources as reported by various agencies.

Table 3.1 Global distribution of soil pollution.

Country/region/cities	Types of pollutants/ Origin of contamination	Reference list
North America	Dioxins, furans, Hg, Pb, As, PCBs, benzene, Cd, PAHs	UNEP, 2002; USEPA, 2010
Australia and New Zealand	Hydrocarbons, Cr^{6+}, Pb, As, tri- and tetrachloroethylene, pesticides, Cd	UNEP, 2002
Caucasus and Central Asia	Cd, pesticides, As, radionuclides (uranium and metal ore), Cr	EEA, 2007a, b
North-Western and Eastern Europe	Heavy metals (37%) and mineral oil (33%), PAHs, phenols, cyanides, chlorinated hydrocarbons	EEA, 2007a, b
Japan and Korea	Fertilizers and pesticides, wastes from mining, electroplating and chemical industries	UNEP, 2002
Africa	Saltwater intrusion, illegal/ improper application of radioactive wastes and pesticides, acid-mine drainage etc.	Kao, 2004; Coles, 2008
Latin America (major areas of Sao Paulo, Rio de Janeiro and Buenos Aires)	Oil spills, wastes from metal and chemical industries, landfills, etc.	Marker et al., 2007
Parts of South and Southeast Asia	As, Pb, Cr, abandoned chemical weapons, asbestos, fluorides, Hg, cyanides	Ericson, 2011
California	Se (from natural deposits), Pb, Cd	UNEP, 2002; Ericson, 2011

Pollution has severe implications for sustainable development as it exacerbates the poverty cycle, harms the environment and biodiversity, causes lifelong disabilities and slows economic growth. People in emerging economies usually intimately feel the connection between an overload of pollutants in their environment and their health – as Chai Jing's controversial movie Under the dome clearly shows (Powers, 2016). It depicts the adverse effects of heavily subsidized, investment-driven industries of China, and its increased pollution associated with rapid urbanization. WHO estimated that in 2012, 8.9 million deaths worldwide were caused by human exposure to polluted soil, water, and air – of which 8.4 million deaths occurred in low- and middle-income countries (Miller, 2004). In comparison, HIV/AIDS causes 1.5 million deaths per year and malaria and tuberculosis cause less than one million (WHO, 2015). Overall, more than one death in seven worldwide is directly or indirectly caused by environmental pollution (WHO, 2014).

Diverse negative environmental impacts are caused by various extractive and processing industries, as well as by waste disposal, especially during dumping and burning near urban areas. The release of chemicals continues to affect the atmosphere, water, soil, wildlife, ecosystems, and food chain, with associated impacts on human health. Chemicals, when released to the atmosphere, act as pollutants, contributing for example to acid rain, increase of GHG and ozone depletion. They also contaminate water through direct discharges to water bodies or via deposition from the air. Waste generation is projected to increase dramatically in the next decades, from 1.3 billion t per year today to 2.2 billion t per year by 2025, with higher increases in middle-income developing countries (World Bank, 2016). In addition to fertilizers, the use of other agrochemicals (especially pesticides) threatens soil biodiversity and the ESSs it supports, including carbon storage, water retention and nutrient cycling (Giller et. al., 1997). Economic growth should be decoupled from resource use and environmental degradation so that socioeconomic development can be sustained (UNEP, 2016).

International awareness about the importance of sound management of chemicals, waste, pollution prevention, and clean up, for the protection of human health and the environment, is growing (Murphy et al., 2009). Yet, much is left to reach the targets set by SDG 3. In Johannesburg, the governments agreed in 2002 to minimize the adverse effects of chemicals on human health and the environment by 2020. This 2020 target was further recognized in the Rio+20 outcomes "The Future We Want". However, the 2006 Dubai Declaration reoriented this commitment by founding the Strategic Approach to International Chemicals Management (SAICM) and by a commitment to achieve the Millennium Development Goals by 2015. Moreover, it aimed for the sound management of chemicals and hazardous waste by 2020 at the Conferences of the Parties to the Basel, Rotterdam and Stockholm conventions in Geneva in May 2013. The problem of pollution and mismanagement of chemicals and waste is a critical, cross-cutting issue that affects all areas of sustainable development. It was and still is important to ensure integration of the sound management of chemicals, wastes and pollution into the declaration as part of the Post-2015 Development Agenda (Landrigan et al., 2002). Target 3.9 of the SDGs is arguably one of the most important agendas addressing the large impact of pollution on human health. It is therefore imperative that measurable and technically rigorous indicators for all types of pollution, chemicals and wastes are included in the SDG monitoring framework.

3.6 SDG 12: Target 12.5 Ensure sustainable consumption and production patterns: Resource recovery and land degradation

SDG 12 covers a large set of targets, some of which are dealt with in other SDGs as well (e.g. Target 12.2). However, 12.3 and 12.5 deal with the avoidance of waste, recycling and reuse. The scourge of nutrient depletion and accumulation on a worldwide scale associated with agricultural trade has been well documented (Craswell et al., 2004), but less information is available on the regional waste of valuable nutrients associated with the rural–urban food connection. A major driving force of LD is the intensive use of resources, especially in and around growing cities. City sprawl is accompanied by a steady supply of natural resources, including food, water, land, fuel, and raw materials, making cities epicenters of consumption and livelihood support, but also dependent on those areas which supply the needed resources (Chen, 2007; Drechsel et al., 2007; Seto et al., 2011).

The rural–urban relations affect land health in different ways:

- Urban expansion for infrastructural development inevitably changes land use, transforming prime agricultural land into built-up areas at an estimated rate of 15,000 km^2 annually (Hooke et al., 2012).
- Farming systems beside urban areas intensify in response to new market opportunities, with shorter periods for soil regeneration and increasing soil nutrient depletion (Drechsel et al., 2001; Drechsel and Zimmermann, 2005). In addition, water demands usually increase, which can compete with urban needs (Thebo et al., 2014), while changes in land value drive farmers to marginal areas for production, where only high inputs can maintain soil productivity.
- With increasing urban populations, food demand and living standards, urban waste generation is outpacing municipal services. Collection of municipal solid waste (MSW) for example in South Asia and Africa, is ranking lowest at 65% and 46% collection rates, respectively, making urban and peri-urban areas hotspots of land and water pollution (Hoornweg and Bhada-Tata, 2012; Keraita et al., 2015).

However, urbanization also offers opportunities to address LD. The concentration of large amounts of waste may enable economics of scale in its management, including options for the recovery of valuable resources, such as crop nutrients and carbon (organic matter) needed in intensified peri-urban production areas. The global wastewater and excreta production contains sufficient nutrients to replace 25% and 15% of the applied N- and P-fertilizers, respectively, and enough water to irrigate 15% of the currently irrigated farmland in the world (Mateo-Sagasta et al., 2015). However, to date, the bulk of our liquid and solid waste ends either in landfills, street drains or the environment, making especially urban centers nutrient 'sinks' not recycling hubs, with significant implications for the degradation of land and water resources (Craswell et al., 2004; Drechsel and Hanjra, 2016).

For example, the analysis of food-embedded nutrient flows in and out of four West African cities (Ouagadougou, Accra, Kumasi and Tamale), showed a clear, one-way redistribution of crop nutrients (Figure 3.3) resulting in nutrient mining in rural and peri-urban areas and nutrient accumulation in urban centers (Drechsel et al., 2007). To visualize this, the quantity of nitrogen that flows annually to the city of Kumasi, for example, is more than the total amount of all annually imported N fertilizer into the whole of Ghana over several years (Drechsel et al., 2007).

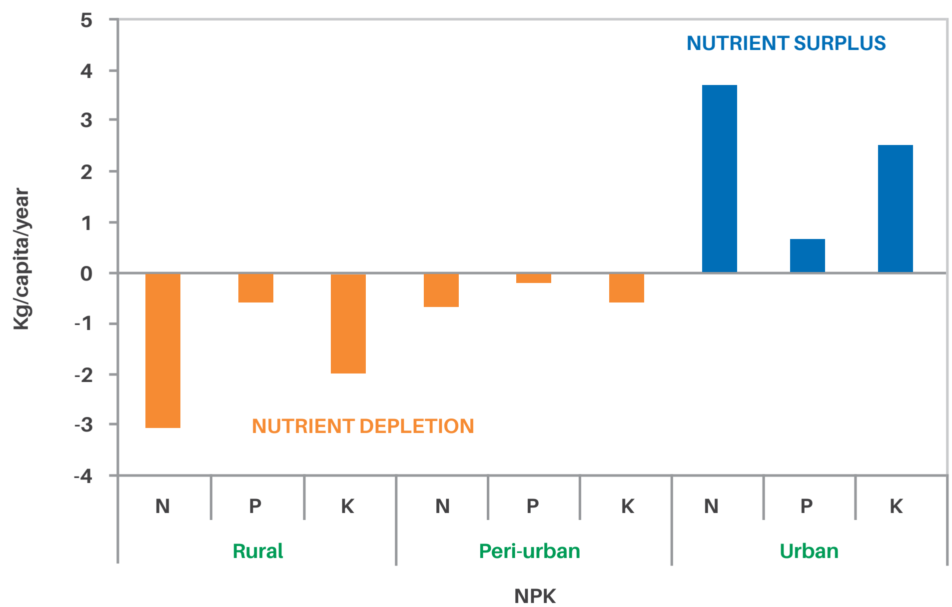

Figure 3.3 Urban nutrient accumulation and rural nutrient mining standardized in kg/capita/year for four West African cities of Ouagadougou, Accra, Kumasi and Tamale. N = nitrogen, P = phosphorus and K = potassium.
Source: Drechsel and Hanjra (2016).

A material flow analysis combining solid and liquid flows showed that between 70 and 80% of the N and P consumed in Kumasi pollutes the urban environment, with soils, groundwater and surface water receiving the largest share (Drechsel and Hanjra, 2016).

Limited productive capacity of nutrient depleted soils and environmental degradation due to excessive nutrient inflow can therefore be two sides of the same coin, where resource recovery and reuse (RRR) offers solutions to redirect nutrient flows between sectors and across scales. This is especially opportune where industrial fertilizer is out of reach to farmers, or the amounts needed are not affordable.

However, what looks like a 'win-win' situation for waste management and farming, remains an exception in most developing countries. The primary concern of city authorities in such cities is to offer basic waste collection and to find landfill sites. Waste reduction, recycling and reuse do not move beyond strategic plans. This situation might change now if the SDGs are taken seriously. To support the hungry and thirsty urban consumer while reducing their significant water, nutrient and waste footprint, several SDGs targets such as Target 6.3 and Target 12.5 call for waste reduction, RRR, as well as positive environmental links between urban, peri-urban and rural areas (SDG 11a).

Resource recovery offers in this context a double value proposition; it can: (i) reduce the waste volume and its transport and disposal costs, as well as potential pollution; and (ii) return valuable resources back into the production cycle. While the first proposition is most popular among waste managers, the second is gaining momentum amongst the proponents of land conservation and there is a shift towards a 'circular economy'. This shift is supported by a large range of technical options for on-farm and off-farm food waste reduction to nutrient recovery from various waste streams for soil replenishment. The most common is composting of the organic fraction of MSW, largely food waste, which reduces the organic waste volume by half, and so reduces the production of GHGs in landfills. It can create a valuable product of high quality at relatively low cost that can be used for the amelioration or regeneration of degraded soils for agricultural purposes, forestry or landscaping (Wolkowski, 2003). The carbon footprint of food produced and not eaten is estimated globally at 3.3 Gt of CO_2-equivalent, making food wastage the third top emitter after the US and China (FAO, 2013).

Success stories of MSW composting range from community-level projects to large-scale composting (Otoo and Drechsel, 2017). An often-cited example is Waste Concern, which, since 2009, in Dhaka City has managed to treat more than 100,000 t of waste. It is tapping into carbon credits as an additional revenue stream and, between 2001 and 2006, has produced compost in the greater Dhaka area worth more than US$1 million in local currency. Such models are driven by well-defined business plans that are usually missing in the majority of compost projects that struggle to break even. However, public subsidies are usually a well-justified revenue stream, given that the benefits of RRR are not only based on increased soil fertility and crop yields, but also on economic and environmental benefits, including reduced costs of fertilizer import, soil and water rehabilitation, or reduced GHG emissions, embracing the total value of nutrient recovery (Mayer et al., 2016).

According to FAO (2013), up to one third of food is spoiled or lost before consumption. However, the even larger nutrient fraction is found in the consumed food. With nutrient outputs (via excreta) being equal to nutrient inputs (via food), resource recovery from human wastewater and fecal matter should be a cornerstone for RRR programs with benefits in terms of reduced environmental and human health hazards. However, such an approach requires a shift away from the traditional sanitation paradigm of treatment for safe disposal to treatment for reuse. Nutrients such as nitrogen (N) and phosphorous (P) are not to be perceived as hazards but as resources. In Guanajuato, Mexico, for example, the estimated cost for farmers for replacing nitrogen and phosphorus loss using products from improved wastewater treatment was estimated at US$135 ha^{-1} $year^{-1}$. To transition into a post-modern waste and sanitation system, wastewater treatment and landfill facilities must be planned as resource recovery centers in the future (Ushijima et al., 2015; Drechsel and Hanjra, 2016).

In a recycling scenario developed for the city of Kumasi, Ghana, which considered the actual waste collection capacity of the city, the entire N and P demand of urban farming could be covered through co-composting of fecal sludge collected from household-based septic tanks, and other organic waste. Moreover, 18% of the N and 25% of the P needs of peri-urban agriculture within a 40 km-radius around Kumasi could also be supplied. With improved waste collection capacity, these gains would multiply (Belevi, 2002) but careful market assessments and business planning will be required, as many farming systems only have seasonal demands, and willingness to pay can vary significantly. Thus, what is often perceived as an engineering challenge is increasingly understood as an institutional, social and economic challenge in need of profound business models, financial mechanisms, and policy instruments, especially if scalability is targeted. Government support, such as extending public subsidies from industrial fertilizers to compost from urban waste, as initiated for example in Ghana, are crucial support mechanisms for both the compost industry and farmers.

Understanding the agricultural market is a challenge for many compost producers. In India, the government asked fertilizer traders to sell to farmers a certain amount of waste-based compost with every unit of chemical fertilizer. Such support of the enabling environment is welcome, as otherwise many compost plants can only support farmers on agricultural land and as the area of land in urban and peri-urban areas is decreasing, transport costs are becoming an increasing challenge for financial sustainability of RRR systems.

3.7 SDG 13: Integrate climate change measures into national policies, strategies and planning

SDG 13 urges all nations to act to combat climate change and its impacts and is strongly aligned with international commitments under the United Nations Framework Convention on Climate Change (UNFCCC). Among its targets are the integration of climate change mitigation strategies and measures to strengthen the adaptive capacity of countries to climate-related hazards into national policies. Given their important role in carbon and nutrient cycles and as a source of food and livelihoods, soils and land-based resources will become crucial elements of such strategies and measures.

Land degradation can jeopardize land-based efforts to achieve SDG 13, for example, by reducing the capacity of vegetation to capture and store carbon or by releasing additional GHGs, such as methane from peatlands (van der Werf et al., 2009; Carlson et al., 2012). However, measures to mitigate and adapt to climate change can contribute to forms of LD that negatively affect the provision of ESSs, such as local and regional hydrological cycles, and the quality of natural resources for local livelihoods (Trabucco et al., 2008; Lele et al., 2010).

As a process, LD thus represents an important systemic link with potential for both synergies and trade-offs between SDG 13 and multiple other SDGs. This needs a critical assessment of key land-based climate change mitigation and adaptation measures, as stated in countries' proposals for Intended Nationally Determined Contributions (INDC) in terms of how they could affect this systemic link.

Agriculture, forestry, and other land uses are responsible for nearly a quarter of anthropogenic GHG emissions (Chapter 1). Thus, the land-use sector is the second largest emitter globally just after the energy sector, especially in least developed countries (IPCC AR5 WGIII Chapter 11).

The INDC documents the efforts that the Parties to the UNFCCC intend to adopt to achieve the goals of the Paris Agreement and, hence, SDG 13. Roughly 86% of countries that submitted INDC so far, plan to implement measures in agriculture and land use, land-use change and forestry (LULUCF) (Figure 3.4). Most countries, especially among the least developed countries, also considered adaptation measures.

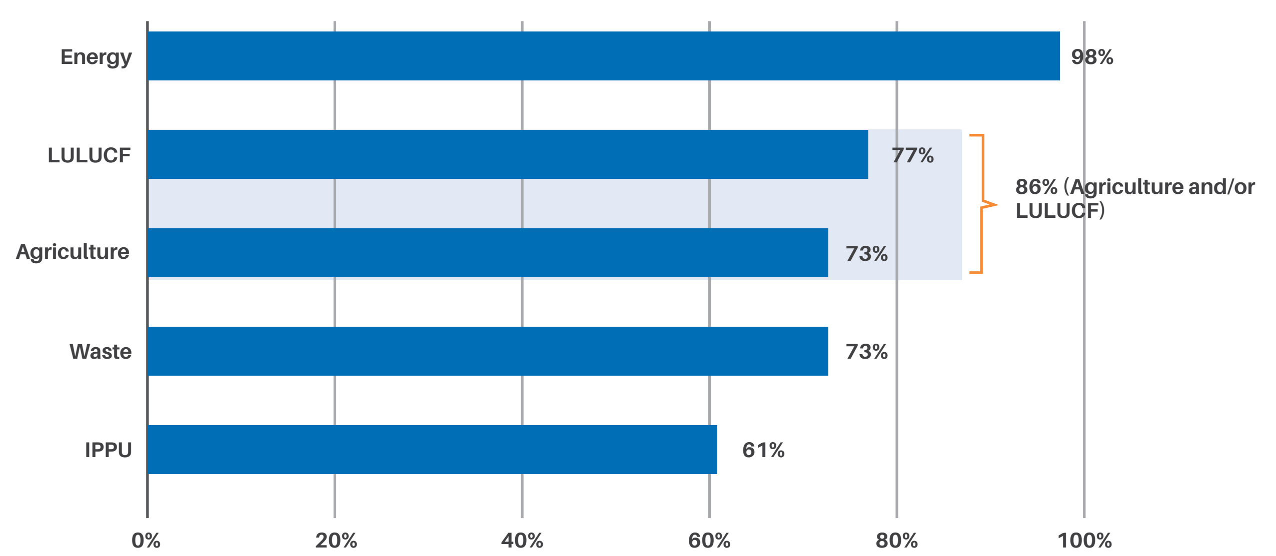

Figure 3.4 Percentage of countries addressing mitigation by sector.
Source: FAO (2016f).

Common mitigation measures in agriculture include improved management of plant nutrients, water, residues, and manure. Many countries also rely on improved soil preparation technologies (including CSA), and agroforestry (FAO, 2016f). In the forestry sector, many countries propose afforestation and reforestation measures, forest conservation, more efficient use of forest biomass, and more sustainable forest management (Petersen and Varela, 2015). Various INDC emphasize potential synergies among mitigation and adaptation measures. The latter rely on disaster risk management, especially in agriculture, and water management.

Some of the mitigation strategies put forward in INDCs clearly contribute to reducing LD and could therefore be classified as 'win-win' options. These include soil and nutrient management approaches, such as zero tillage and cover crops, and the introduction of trees in agricultural systems. Other measures, such as residue management and afforestation, will not improve ecosystem service provision from land. Outcomes will depend on how these measures are implemented and in which contexts. For example if crop residue management leads to the excessive removal of biomass from soils, soil quality and water retention capacity may be compromised in the long term (Lemke et al., 2010). Similarly, afforestation schemes, depending on the species used and local climatic conditions, can interfere with local and regional hydrological cycles and induce indirect land-use change, depending on competition with food and feed crops (van Dijk and Keenan, 2007; Ravindranath et al., 2011), making a strong case for management at the landscape level. Assessing the risk of such negative impacts with implications for soil quality requires us to examine some examples from individual countries' INDC (Table 3.2).

Brazil's INDC highlights the country's success in reducing emissions by reducing illegal deforestation. Restoration of forests and pasturelands, as well as the expansion of biofuel consumption and CSA (including integration of crop, livestock, and forestry systems) are cited as prominent strategies to achieve the ambitious mitigation targets. Integrated production systems are indeed promising mitigation measures with co-benefits in terms of soil quality enhancement (Loss et al., 2011). However, the expansion of energy crop production (i.e. sugarcane) is associated with deforestation in the Amazon through indirect land-use change that shifts crop production to those areas (Andrade de Sá et al., 2013). Moreover, after a reform of the Brazilian forest law in 2012, a substantial additional area of forestland has become available for legal deforestation (Sparovek et al., 2012). Finally, the Brazilian INDC stays silent in terms of how opportunity costs and other barriers to the adoption of climate-smart agricultural and forestry practices can be overcome (Börner and Wunder, 2012).

Table 3.2 Summary of selected Intended Nationally Determined Contribution (INDC) characteristics.

	Brazil	South Africa	Indonesia
INDC	Reducing GHG by 37% below 2005 levels in 2025	Emissions between 398–614 Mt CO_2-eq by 2025–2030	Reducing business-as-usual emissions by 26% up to 2020
Key measures related to agriculture	Expanding biofuel consumption, integrated crop-livestock-forestry systems, pasture rehabilitation	Fire management	Sustainable agriculture and plantations, use of degraded land for bioenergy production
Key measures related to the forestry sector	Reducing illegal deforestation, forest restoration, forest management	Water and wetland management, land restoration	Forest protection/conservation, restoration, sustainable forest management
Land degradation as a risk to mitigation/ adaptation	Emissions from legal/illegal deforestation	Increase cost of implementation/ reduce potential of carbon sequestration and storage	Emissions from legal/ illegal deforestations
Mitigation/adaptation as a driver of land degradation	Expansion of biofuel production could be associated with indirect land use change	Depends on renewable energy strategy	Depends on renewable energy strategy

South Africa's INDC is conditioned on the country's primary goals of poverty and inequality reduction as stated in their National Development Plan to 2030. It envisions a strong investment in the energy sector including renewable energy projects. It also details public expenditures needed for planned mitigation and adaptation measures. Existing adaptation-related programs such as Working for Water, Working on Fire, and land restoration are planned to be up-scaled with positive expected benefits for land and soil quality. Carbon sequestration and storage is mentioned as a land-based mitigation strategy, but no specific policy is provided, due to uncertainties about this sector's contribution. Yet South Africa is expecting serious climate change impacts, especially in the agricultural sector (Turpie and Visser, 2012). The lack of concrete policy proposals in the INDC limits our ability to assess potential synergies and trade-offs between LD and climate change mitigation or adaptation strategies. However, better land management will ultimately also help to achieve poverty and inequality objectives (Nel, 2016) in addition to climate related goals.

Indonesia's INDC is kept relatively general and suggests that the government is primarily concerned with emissions related to the expansion of bioenergy from oil palm plantations into primary forest and peatlands. The INDC provides no details on how Indonesia's renewable energy target of 23% by 2025 will be met. A "landscape approach" to the LULUCF sector is advocated, but no reference is made to specific policy or mitigation measures. Estimates of the effectiveness of conservation measures in Indonesia vary substantially. Protected areas have shown moderate levels of effectiveness in accruing carbon (Gaveau et al., 2009). However, a moratorium on concessions for oil palm plantations was estimated to have had little impact (Busch et al., 2015), whereas the certification of timber concessions was shown to have significant potential to reduce forest loss and improve socioeconomic outcomes (Miteva et al., 2015).

Bidirectional systemic links exist between LD and the specific targets of SDG 13. These links are likely to be affected by the mitigation and adaptation actions that countries plan to adopt to achieve the objectives set out in their INDC. Against the backdrop of an emerging literature on the effectiveness of climate change mitigation measures in forestry and agriculture (Börner and Wunder, 2012; Baylis et al., 2016), it is unfortunate that most countries provide little or no detail on how INDC targets will be achieved. Both the costs and the effectiveness of pursuing these targets will depend on the choice and design of climate policy instruments.

Concluding remarks

Land degradation can reduce our ability to achieve various SDGs through direct and indirect mechanisms. This chapter has illustrated these potential impacts for the SDG on food security, health, agricultural production, climate and responsible consumption. The mechanisms that drive relationships between LD and SDGs are diverse and depend on the type of LD, such as erosion or soil contamination.

However, LD can also be induced by private and public efforts towards achieving specific SDG targets, for example, if measures to counteract climate change compromise certain soil ecosystem functions, with impacts for local ecosystem service users. These systemic relationships must be considered in efforts to govern land use and land-use change.

To counteract the negative systemic effects of LD, governments must adopt a global perspective when creating locally adapted enabling conditions, for example, through infrastructure investments, incentives for better land management, and interventions to regulate the use of degrading practices. This global perspective must be based on a holistic understanding of how LD mediates trade-offs and synergies between the SDGs.

4. The extent and cost of land degradation

Q.B. Le and A. Mirzabaev with

E. Nkonya, and G.W.J. van Lynden

4.1. Assessing global land degradation

In any effort to curtail or remedy LD, the location and extent of the problem must be assessed and monitored. Indicators for LD assessment have generally included soil-based and vegetation-based parameters. The earlier global LD assessments used the soil-based approach (Dregne, 1977; Oldeman et al., 1990; Eswaran et al., 2001). The Global Assessment of Soil Degradation (GLASOD) in 1987–1990 (Oldeman et al., 1990) evaluated the LD stage using four severity classes based on expert opinions on degradation intensity and extent. Land Degradation Assessment in Dryland (LADA) also evaluated degradation stages based on indicators such as sightings of soil erosion, which can be observed in the field but are hard to capture at regional scale (Caspari et al., 2015). Measuring temporal changes in soil properties is difficult at regional and global scales and the magnitudes of errors of the resulting global soil degradation maps are unknown.

Due to these uncertainties and because LD encompasses more than soil degradation alone, the vegetation-based approach has been increasingly used in recent global LD studies using globally available remotely sensed data. These vegetation-based LD assessments look at the historic loss of net primary production (NPP) through a proxy parameter (e.g. Normalized Difference Vegetation Index – NDVI) such as demonstrated by Bai et al. (2008), Vlek et al. (2010), Fensholt et al. (2012) and Le et al. (2012, 2016). Alternatively, NPP is based on ecosystem production models using global data sets of remote-sensed vegetation, climate and biomes (Nemani et al., 2003). A more elaborate method relies on this modeling approach but focuses on the shift from modeled potential to actual NPP or the NPP gap and the degree of human appropriation of the natural NPP as LD indicators (ELD Initiative, 2015; Sutton et al., 2016). Both methods have their limitations and drawbacks that can be mitigated but not eliminated (Pettorelli et al., 2005; Tucker et al., 2005; Le et al., 2012, 2016). These limitations should be communicated with the assessment results to avoid their over-interpretation (Le et al., 2016).

Land degradation assessment provides information to guide management and policy of land which may vary in nature depending on geographic scales. A degradation phenomenon at a certain scale may be explained by the processes operating at the scale immediately below it and constrained by the processes operating at a higher scale. Different data and methodological approaches are needed to satisfy management goals at specific scales (Vogt et al., 2011). Trade-offs often occur in dealing with LD at multiple scales with a variety of stakeholders. Scale dependency thus will play a role in the selection of assessment instruments.

4.2 Mapping hotspots of land degradation

In a recent comparative review, global LD assessments estimates of total degraded area varied from less than 1 billion ha to over 6 billion ha, with equally wide disagreement in their spatial distribution (Gibbs and Salmon, 2015). This large divergence can be related to a wide spectrum of methodologies in terms of data sources and data versions, types of indicators, temporal and spatial aggregation of data, calculation metrics and ways of treating confounding factors (Le, 2012). This results in a high degree of uncertainty in the LD maps, making it difficult to target remedial action of degraded areas. The hotspot mapping approach is a way of dealing with the current poor convergence in global LD assessments. The aim of hotspot mapping is different from efforts that aim to map all degraded areas accurately. It aims to delineate only the degraded areas where there is high confidence in the results using the current methods and data and focuses on areas where LD is affecting large numbers of people. This will help in better geographical targeting and resource prioritization in preventing, mitigating and reversing LD.

Procedures used in hotspot mapping can include:

- Factors confounding the relationship between indicators and LD are corrected as much as possible, i.e. the 'specific' criterion in SMAR (Specific-Measurable-Achievable-Relevant) standard
- Degraded areas must emerge concurrently from different indicators and methods, i.e. convergent validity
- Degraded areas are those with persistent signals of LD indicators that are stronger than background noises
- Hotspot areas are those that affect the livelihoods of sizable human populations, i.e. 'relevance' criterion.

Land degradation may indeed be largely driven by a diminishing soil resource base. However, when other factors are playing a major role in vegetation production, such as variation in inter-annual rainfall (Herrmann et al., 2005) or regular irrigation and intensive use of chemical fertilizers (Potter et al., 2010) or atmospheric fertilization (Boisvenue and Running, 2006; Reay et al., 2008; Lewis et al., 2009; Buitenwerf et al., 2012; Le et al., 2012), the reliability of NPP-based indicators are reduced. Maps can be corrected for the effects of these factors (Vlek et al., 2010; Le, 2012, Le et al., 2016).

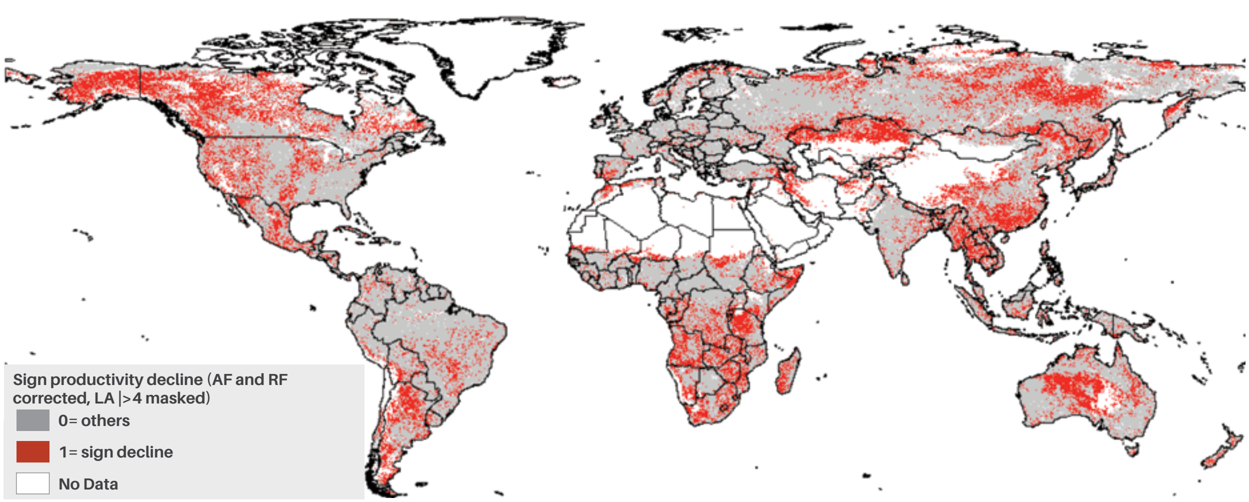

Figure 4.1 Areas of human-induced biomass productivity decline over the period 1982–2006 (red area) with significant trend ($p < 0.1$, trend magnitude >10% of baseline year/25 years), rainfall and atmospheric effects corrected.
Source: Le et al. (2016).

The most recent global LD mapping based on remote sensing was carried out using the long-term trend of biomass productivity as a proxy for land degradation (Le et al., 2016). In this study, factors confounding the relationship between mean annual NDVI and land-based biomass productivity – such as inter-annual rainfall variation, atmospheric fertilization and intensive use of chemical fertilizers – were considered. Moreover, biomass productivity decline was considered to indicate LD only if the trend was statistically significant and exceeded 10% compared to NDVI of the baseline year over the 25 years (i.e. 0.4% annually). The results are presented in Figure 4.1. Over this period, about 29% of the global land area (or 3.6 billion ha) has been degraded, covering all agroecologies and land-cover types. About 3.2 billion people reside in these degrading areas. Follow-up analysis shows that > 90% of the total LD area had the annual reduction rate of NDVI < 1% / year, falling within the noisy zone for NDVI signals. Thus, the actual hotspots are a subset of the total degraded area delineated using this method.

Identification of hotspot areas is more effective when it is carried out on a more local scale where knowledge on degradation processes and their drivers can help interpret the findings from global analyses. The contextual geographic setting can be helpful in pinpointing the relevant hotspots such as the combination of climate zone, general soil and terrain constraints, population density and land-use type (Vlek et al., 2010; Sommer et al., 2011; Vu et al., 2014a, b). In a LD assessment across Vietnam, Vu et al. (2014a) found that such combined contextual settings provided an understanding of the degradation process involved as the drivers of these processes. The authors found, for instance, that the growth of rural populations promoted degradation of forestland with unclear tenure rights which, in turn, mitigated degradation of agricultural land where long-term land-use rights of smallholder farmers were clear and secured. Were there were better tenure security and links to urban markets and extension services, the high land pressure stimulated lowland Vietnamese farmers to intensify their farms and adopt relevant technologies leading to increase crop production. This situation agrees with Boserup's hypothesis on the population- technology-resources degradation nexus, or the relationship 'more people, less soil erosion' documented areas in East Africa (Tiffen et al., 1994).

As LD is man-made, there are probably remedial interventions in the management of the land that can mitigate or reverse the process. Deforested land can be afforested but a better option would be to avoid deforestation by adopting sustainable selective tree harvesting techniques. Similarly, salinized irrigated land can be retroactively equipped with pipe drainage, but it might be better to install these during construction of the perimeter. Mine tailing can be reclaimed but avoiding their development is environmentally preferable. If a land ecosystem is disturbed or degraded but has not yet crossed the threshold of the system buffering capacity (tipping point), mitigation is a relevant management strategy. In that situation, current land-use regimes may be retained with improved land management practices including temporary resting of the land. However, when the land resources are degraded beyond the tipping point, combatting LD needs a restoration strategy that brings the productivity of the land back to an earlier stage. Reversing LD (i.e. restoration or reclamation) is usually much costlier in terms of resources and time needed, than preventing or mitigating LD in the first place (Figure 4.2).

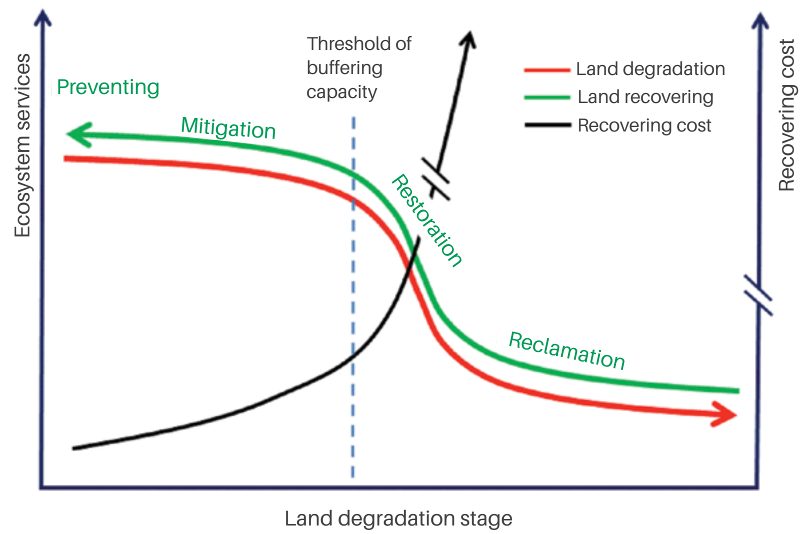

Figure 4.2 Stages of land degradation (red line) and the relevant management strategies at the various stages of this process and the associated cost. The reversal (green line) often takes much longer than the degradation process.
Source: Modified from Le (2012).

4.3 The costs of land degradation

Human activities usually result in a trade-off between the provisioning and non-provisioning land ESSs, where maximization of a provisioning service, such as food production, could lead to the reduction in non-provisioning ESSs of land (Figure 2.1). Unfortunately, most non-provisioning ESSs do not have market values, and thus are significantly undervalued (von Braun et al., 2013; ELD Initiative, 2015). Land degradation will reduce the production of both food and other ecosystem services of land (a1 shifting to b1 in Figure 4.3), while also putting pressure on prices of both food and other ecosystem services (shifting a to b).

The higher prices of food and other ecosystem services are likely to set back the poorest households the

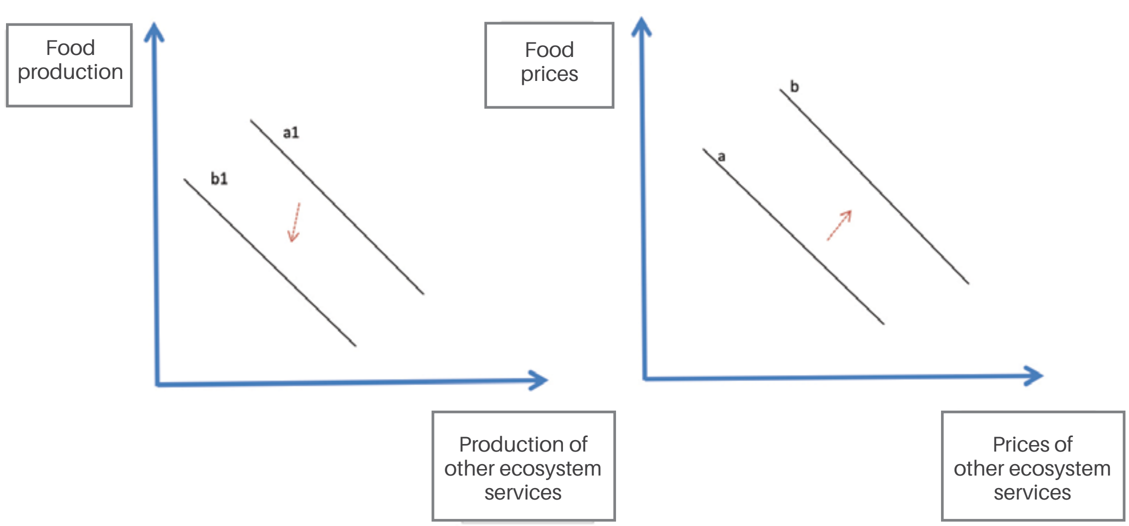

Figure 4.3 The impact of land degradation on the prices of food and other ecosystem services.

most as food expenses constitute a larger share of their household budgets. The increase in food prices, reducing people's disposable income, would lower their willingness-to-pay for non-provisioning ESSs, which are primarily global public goods, thus limiting the funds available to protect the land.

Estimates of the costs of LD should be comprehensive and should include: losses in both provisioning and non-provisioning ecosystem services across various time scales; and direct as well as indirect costs of LD (ELD Initiative, 2015; Nkonya et al., 2016a,b). Direct costs of LD relate to the diminished provision of ecosystem services by degraded biomes whereas indirect costs are subsequent economy-wide costs of LD in terms of their impacts on various sectors of the economy. These would include effects on poverty and other domains of social wellbeing as well as their feedback loops on sustainable land management. Such complex interactions between food production, provision of non-food ESSs and social wellbeing need to be studied through an interdisciplinary systems research.

There have been several efforts to estimate the costs of LD at the global level using different approaches (Mirzabaev et al., 2016). These studies showed that the costs of LD are substantial and could reach up to US$10.6 trillion annually. Dregne and Chou (1992) estimated that the global cost of degradation in croplands and rangelands was about US$43 billion. A UNCCD (2013) review showed that the global cost of LD could be US$450 billion annually. Trivedi et al. (2008) projected that cutting down of tropical rainforests alone resulted in about US$43–65 billion in losses in ESSs a year. Myers et al. (2000) estimated that annual investments of up to US$300 billion are needed to prevent loss of biodiversity. Basson (2010) estimated that soil erosion is causing about US$18.5 billion in losses each year due to siltation of water reservoirs. Costanza et al. (2014) using the total economic value (TEV) approach, including the value of all terrestrial ecosystem services, estimated the cost of degradation of terrestrial ESSs at about US$9.4 trillion annually, with the costs of wetland degradation making up an important part of these costs. These estimates, high as they are, might still be conservative. The current TEV methodology is likely to undervalue non-provisional ESSs and annual losses might exceed US$10.6 trillion globally, representing 17% of the world's GDP. Even then, there are a range of non-anthropocentric values – defined as biocentric values – that are not always captured in the TEV analysis (Sagoff, 2008; ELD Initiative, 2015).

Nkonya et al. (2016b) found that the annual costs of LD, excluding wetlands, are equal to about US$295 billion. They found that the global community bears 54% of the LD costs (corresponding to supporting, regulatory and cultural ecosystem services), whereas the land users where degrading biomes are located bear the remaining 46% of the costs in the form of losses in provisioning ecosystem services. This finding shows that land degradation is not just a local problem, but affects all of us. Moreover, Nkonya et al. (2016b) found that globally, each dollar invested in land restoration and SLM will return US$5 over 30 years. Several national studies also find high returns to actions for addressing LD. For instance, the costs of restoring degraded lands were found to be less than the costs of allowing LD to continue by a factor of about 4.3 and 3.8 over a 30-year period in Malawi and Tanzania, respectively (Kirui, 2016). Similarly, each dollar invested in land restoration was found to generate US$5 of returns during a similar period in Central Asia (Mirzabaev et al., 2016). An economic assessment of Turkmenistan's desert pastures shows that: (i) maintaining pastoral plant communities all year round; (ii) establishing seasonal pastures with planting in gypsum deserts; and (iii) improving forage productivity of the halophytic pastures in clay deserts, increased the economic benefit to US$64 ha^{-1} compared to US$29 ha^{-1} of the baseline (Nepesov and Mamedov, 2016; Quillérou et al., 2016). Analyses of global scenarios based on different development pathways indicate that the adoption of SLM-enabling environments can provide an additional US$75.6 trillion annually (ELD Initiative, 2015).

Far fewer studies have included the indirect costs of LD. For example, Kirui (2016) estimated that LD in Tanzania and Malawi amounted to the equivalent of 15% and 10% of their respective gross domestic products (GDP). Similarly, Mirzabaev et al. (2016) found that Kyrgyzstan and Tajikistan were losing the equivalence of about 10% of their GDP annually to LD. Diao and Sarpong (2011) showed that LD over the last decade increased the national poverty rate by 5.4% in Ghana.

Because they are based on differing approaches and methodologies, the estimates of costs of LD vary substantially but are invariably high. What is not disputed is that investing in land restoration is economically more sensible than inaction (ELD Initiative, 2015; Nkonya et al., 2016b). Nevertheless, the levels of investments in restoration and rehabilitation of degraded lands remain low. To stimulate investments, there is a need to internalize the benefits from SLM by enabling frameworks that allow for valuation of ecosystem services. Only then will it be possible to reward SLM through subsidies and payments for ESSs. It would also make it easier to remove existing barriers to SLM and promote access to markets, agricultural advisory services, agricultural inputs, and credit.

4.4 Bright spots of land restoration and rehabilitation

Efforts have been underway around the world to mitigate or reverse LD and some of these efforts have met with remarkable success. In a review on the extent and cost of LD an assessment of efforts to combat and prevent degradation should not be missing. In the context of LD “bright spots”, can be considered as the opposite of LD hotspots, i.e. areas where the land is improving in quality (Bai et al., 2010). Such improvements may occur due to natural rehabilitation of the land due to abandonment of degrading practices or the land, or because of SLM practices (WOCAT, 2016).

The World Overview of Conservation Approaches and Technologies (WOCAT) initiative, in a reaction to the GLASOD map in 1991, made a first attempt to consider land improvement in a comprehensive way (WOCAT, 2007). WOCAT developed a method for documentation and evaluation of SLM “technologies” (what is implemented in the field) and “approaches” (the enabling conditions that allow successful implementation of a technology), as well as a mapping method like that used in GLASOD. Although WOCAT has established an impressive database with many case studies of SLM from all over the world, it has not yet succeeded in making a new global map of LD and SLM, which was its original goal.

The WOCAT sites where SLM technologies are documented to have improved the status of the land are displayed in Figure 4.4, without specifying the practices’ details the extent of their adoption. It is encouraging to see the widespread successful adoption of SLM practices, but the map does not give any insight into the failure rate of introducing SLM as those tend to be under-reported. Also, few reports have been provided to WOCAT from North America, Australia or large parts of Russia. The regional success stories reported may serve as useful experiences for other areas with similar conditions.

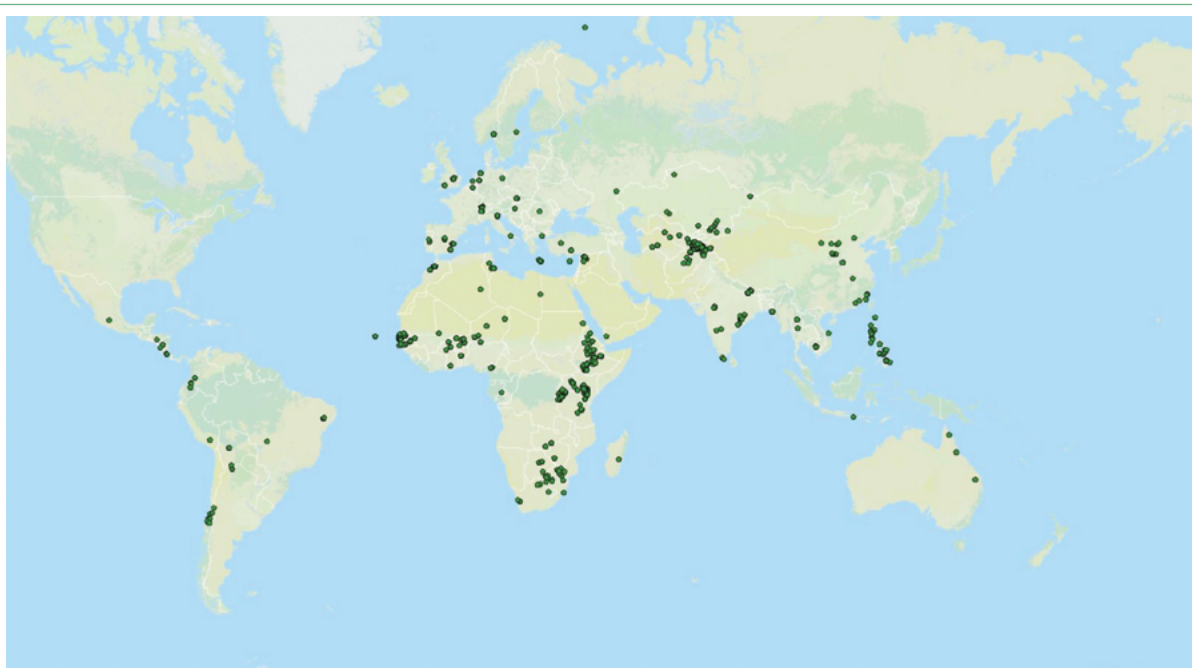

Figure 4.4 Location of documented sustainable land management (SLM) technologies with claimed land conservation outcomes in the WOCAT database.

Based on the many years' experience in documenting a range of SLM case studies worldwide (see Figure 4.4), WOCAT identified several key elements, which, if missing or not properly addressed, will limit the effectiveness of efforts to achieve SLM (Liniger et al., 2004). These include: preconceptions, biases and wishful thinking, poor understanding of LD processes, lack of impact assessment of conservation, lack of a holistic assessment and failure to understand the context, insufficient use of land users' experiences, corruption and greed and the inflexibility of interventions. Knowledge gaps and fragmented information were also obstacles to successful implementation of SLM. Reij and Steeds (2003) and McDonagh and Lu (2007) discussed several criteria to assess success in an SLM project. However, the indicators of success are somewhat arbitrary and depend on the envisaged goals.

From an evaluation of many WOCAT case studies, the success stories cannot be considered to represent blueprints for success elsewhere. Many of the SLM technologies are site specific and not amenable to out-scaling. Moreover, many 'success stories' are often partial failures when one considers the original objectives, given the overall outcomes rather than the immediate outputs. After all, it depends on the intended goal of the action undertaken to determine whether it was a success. If the goal was "only" to reduce erosion, by say, 50% in terms of soil loss, the intervention may be considered a success if just that goal was achieved. But in a broader context, it may have been less successful if, for instance, it did not also lead to better livelihoods for the stakeholders involved or improved food security and enhanced carbon sequestration.

The SLM concept aims for more holistic outcomes. A comprehensive analysis of the factors determining the success rate of SLM was described in "where the land is greener" (WOCAT, 2016).

Noble et al. (2008) summarized the basic characteristics of LD bright spots. They considered that the more efficient resource utilization derived from appropriate technologies must lead to increased income and employment opportunities, making better use of local skills and resources, improving the health of the community and/or environmental quality and building the capacity of individuals within the community for effective technology transfer. Finally, mechanisms should be developed that ensure there are long-term benefits to the communities by ensuring their involvement. The challenge is to find ways and means to create such bright spots and scale them up.

Halting or reversing LD is an essential pillar in the quest to attain the SDGs. Various United Nations agencies have captured this task as attaining land degradation neutrality (LDN). The arguments presented in this chapter regarding the cost of inaction on LD are convincing support for this goal. However, it is clear from this research that society is poorly equipped with the tools to target this issue globally as we have a poor understanding of the location, extent and rate of LD. Locally, enough knowledge is often available to act on the problem, but due to contention among stakeholders on the issues, corrective action may often be prevented or sabotaged. Political support and an enabling institutional environment are key to accomplishing land degradation neutrality (LDN), without which a host of SDGs will be difficult to reach.


Photo: Georgina Smith/CIAT

5. Strategies and policies to reach a land-degradation neutral world

A.M. Whitbread with

M. Akhtar-Schuster, A. Erlewein, F. Kizito, E. Nkonya, S. Scherr, S. Shames, L. Tamene, and L. Winowiecki

Despite the difficulties in quantifying the extent and degree of land degradation or restoration, evidence shows that continued land degradation will be an impediment to meeting several SDGs. The United Nations states that it aims for land degradation neutrality (LDN) which in 2015 became firmly established as an agreed-upon objective in the realm of international environmental politics. First, as part of the SDGs whose Target 15.3 calls 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, 2015). The Conference of Parties (COP) of the United Nations Convention to Combat Desertification (UNCCD) took the decision to align the implementation of the Convention with SDG 15.3 and invited its Parties to set voluntary LDN targets (UNCCD, 2015). From that point onwards, the key question is how to implement these global aspirations at the national level and what is needed to operationalize the LDN concept and translate it into concrete strategies to meet LDN at scale.

5.1 Strategies to meet land degradation neutrality

The interpretation and operationalization of LDN is still in its early stages. The idea of a "land degradation neutral world" (UNCCD, 2012) was first introduced to the international environmental arena at the Rio+20 conference. Several scholars and organizations have since discussed possible interpretations and implications of this topic (e.g. Welton et al., 2014; Altvater et al., 2015; Chasek et al., 2015; IUCN, 2015; Tal, 2015; Akhtar-Schuster et al., in press). The interpretation of neutrality in the context of LD is challenging and will require further elaboration to provide guidance for its implementation. An essential step in this direction was the establishment of a definition of LDN by an Intergovernmental Working Group (IWG) under the UNCCD. The IWG defined LDN as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems." (UNCCD 2015, dec.3/COP.12). Based on this definition, the Science-Policy Interface (SPI) of the UNCCD was requested to develop a scientific conceptual framework for LDN that aims to provide guidance for implementing LDN at the country level (UNCCD, 2016a, b).

Starting with the vision of what LDN is expected to achieve, the conceptual framework focus is "on maintaining or enhancing the land resource base, (the stocks of natural capital associated with land resources), in order to sustain the ecosystem services that flow from them, including food production and other livelihood benefits" (UNCCD, 2016b). The year 2015 was accepted as the baseline year. Following the neutrality logic, the target state should be equivalent to the baseline.

To translate the LDN target into strategies for implementation, the so-called LDN response hierarchy plays a central role and is proposed as a guiding principle for land-use planning. Following the recognition that 'prevention is better than cure', the response hierarchy prioritizes avoiding degradation, followed by reducing ongoing degradation. Once the possibilities for avoiding and/or reducing LD have been sufficiently used, reversing land degradation through restoration and rehabilitation or reclamation of already degraded land should be an option to counterbalance the remaining part of what might be termed 'unavoidable degradation'. The LDN lens acknowledges that land degradation cannot be stopped completely and everywhere, and it suggests that a balance can be reached through the restoration and rehabilitation of already degraded lands: "counterbalancing anticipated losses with measures to achieve equivalent gains" (UNCCD 2016b). However, given the vast heterogeneity of land and its associated ESSs, the great challenge is in ensuring equivalence between losses and gains.

Recognizing this challenge and the associated risks, UNCCD suggests several principles to ensure positive and prevent unintended negative outcomes. A key principle is 'like for like', in terms of quantity (area) and quality (ecosystem services) (UNCCD, 2016a). These considerations are expected to be integrated into existing policies and plans at the national and sub-national level. Land-use planning is the key entry point for implementing LDN. If land-use plans exist and correspond with actual changes in land use and management, they allow for anticipating 'losses' and planning of corrective measures (UNCCD, 2016b). Thus, the conceptual framework proposes a comprehensive and systematic approach for LDN implementation. It fully embraces the notion of neutrality and aims at operationalizing the various implications of a no net loss approach with a view to integrate them into land use planning.

First steps are now being taken in implementing LDN at country level. In 2015, the UNCCD ran a LDN pilot project together with 14 countries to test a monitoring approach for LDN, which was followed by the LDN Target Setting Program (TSP) implemented by the UNCCD's Global Mechanism. So far, more than 100 countries have expressed their interest in participating in the TSP, setting LDN targets, identifying strategies and measures to achieve these targets and establishing a corresponding monitoring scheme (UNCCD 2016c, d). It is expected that countries wishing to engage in the LDN process will present their targets at the COP in late 2017 (UNCCD, 2015). The TSP covers many of the ideas of the LDN conceptual framework, but is more flexible in the setting of targets (Minelli et al., 2016). While it pursues comprehensive national LDN targets, it also accepts that LDN targets might be defined for sub-national territories or, with a more limited scope as steps towards an LDN state. Thus, targets may be defined for specific land-cover classes, as commitments to restore a certain area of degraded land or activities to incentivize the adoption of practices for sustainable land management in each region or watershed.

Establishing a monitoring scheme that allows for tracking progress towards LDN targets is critical. UNCCD has developed a tiered monitoring scheme based on the Convention's progress indicators: land cover (metric: land-cover change), land productivity (metric: NPP) and carbon stocks above/below ground (metrics: organic carbon). Other relevant indicators can complement these basic indicators. This scheme is also proposed as the official methodology for monitoring SDG 15.3. UNCCD is exploring synergies with the reporting mechanisms of the other Rio Conventions UNFCCC and the Convention on Biological Diversity (CBD) (Akhtar-Schuster et al., 2016; Minelli et al., 2016; UNCCD, 2016c, d).

5.2 The management of landscapes in meeting the SDGs

As LDN has been designated a prerequisite for meeting the SDGs, the development community is increasingly recognizing that this issue needs to be addressed at different scales with a spectrum of stakeholders that seek concepts to achieve sustainable landscapes. Restructuring landscapes offers opportunities to capture synergies where possible and minimize trade-offs among economic, social and environmental goals where these objectives compete (Denier et al., 2015). Approaches to achieving sustainable landscapes, that prioritize collaboration among multiple stakeholders from different sectors and social groups, are often referred to collectively as 'integrated landscape management' (ILM). Thus, ILM is an important component of sustainable land management and LDN.

ILM can take a wide array of forms depending on the governance structure, size and scope of the landscape in question, 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 be simply information sharing and consultation; in others there are more formal arrangements with shared decision making and joint implementation of activities. While there are numerous communities of practice for ILM, a decade of experience, observation and comparative analysis identified five common core features. They include: (1) shared or agreed management objectives; (2) land-use practices contributing to multiple objectives; (3) interactions among land uses and land users in different parts of the landscape; (4) collaborative, community-engaged processes for dialogue, planning, negotiating and monitoring decisions; and (5) markets and public policies that are shaped to achieve agreed landscape objectives.

Reviews in sub-Saharan Africa (Milder et al., 2014), Latin America and the Caribbean (Estrada-Carmona et al., 2014), South and Southeast Asia (Zanzinaini et al., 2015) and Europe (Martin et al., 2016) documented more than 420 established ILM initiatives. Of those in the first three regions, land degradation was a frequent motivation for landscape partnerships – to reduce the environmental impacts of agriculture (78%); to conserve soil/increase soil fertility (83%); to stop or reverse natural resource degradation (86%); and to enhance sustainable land management and ecosystem rehabilitation, restoration and/or maintenance (70%). More than 40% of countries reported that they achieved: reduced environmental impacts from agriculture, improved water quality, quantity or regularity and ecosystem service restoration or protection. ILM can thus be an effective means of achieving LDN in the quest of reaching the SDGs for several reasons.

There is an emergent literature documenting the important role of an enabling policy environment for the effective implementation of ILM in areas such as as sustainable land management, forest and landscape restoration, territorial development, and watershed management. Shames et al. (2016) synthesizes key policy guidelines for ILM. The key roles for government include establishing norms, policies, markets and financial conditions to support ILM. The importance of shifting from reactive to proactive policies to address land and resource degradation was highlighted in Scherr et al. (2015), illustrated with cases from intensive commercial agriculture in South and Southeast Asia. The wide variety of products and services that can be derived from sustainable landscapes are often not properly valued in markets, increasing the likelihood of land-use decisions that lead to negative or suboptimal outcomes.

A variety of market barriers constrain producers from adopting ILM practices or investing in them. For individual farmers or operations, degrading practices may be more profitable in the short term; financial resources may be inadequate for them to transition to more sustainable practices; or land managers and businesses may have inadequate technical know-how. Other barriers arise at community or landscape levels, such as the need for collective action, weak connections between land managers and beneficiaries of good practice, weak disincentives or enforcement, insecure tenure; weak market demand, as well as cultural or social barriers. Numerous market innovations are emerging to incentivize sustainable land management and restoration for different niches in the landscape. These include: product certification, payments to farmers or farming communities for ecosystem services, cooperation to reduce marketing costs; sustainable procurement policies by companies and governments, and others (Thomas et al., 2017).

Sustainable landscapes require both asset and enabling investments by a wide range of land managers. Asset investments create tangible value that is returned to the investor, and enabling investments lay the institutional and policy foundation for asset investments. All integrated landscape investments require some degree of strategic planning or coordination through a landscape stakeholder platform and/or a landscape investment facilitator (Shames and Scherr, 2015). There are now a wide variety of public and private actors who are interested in investing in sustainable landscapes and landscape restoration or rehabilitation (Shames et al., 2014; FAO and Global Mechanism of the UNCCD, 2015).

5.3 Landscape restoration and rehabilitation

Once a landscape has been altered to the point that ecosystem services delivery is impaired, communities or governments may intervene to restore a landscape to its pristine state or to rehabilitate it to a healthy and productive state to provide multiple benefits to society and the environment with limited trade-offs and best possible synergies (SER, 2004; IUCN and WRI, 2014). These efforts will be collectively referred to as 'restoration' in this chapter. Restoration efforts planned at the landscape level require an integrated approach to assess various land uses and processes, their connections, and interactions in relation to a mosaic of interventions rather than focusing on a single entity (Maginnis and Jackson, 2003; GLF, 2014).

Restoration starts with defining clear goals that consider all land-use types and stakeholders. Goals may involve aesthetics, habitat recovery, ecosystem services delivery or strengthening of resilience (Suding, 2011). While aiming to achieve any of these, it is also important to ensure that multifunctionality is maintained or restored, including biodiversity at all relevant levels (Aradottir and Hagen, 2013). Site and socio-culturally acceptable and environmentally adaptable interventions to meet a set restoration goal should be identified in a participatory manner (Burke and Mitchell, 2007; Reed et al., 2009; Reyes, 2011). These technologies or policies should undergo an ex-ante trade-off analysis to evaluate their impact and the interactions and feedback between options (over time and space). The success of any restoration project depends on the availability of adequate resources to support its implementation and the returns on these investments should be monitored and evaluated. Additionally, learning from successes and failures is invaluable for subsequent restoration efforts (Suding, 2011; Aradottir and Hagen, 2013). Figure 5.1 depicts the possible effects of restoration interventions over time.

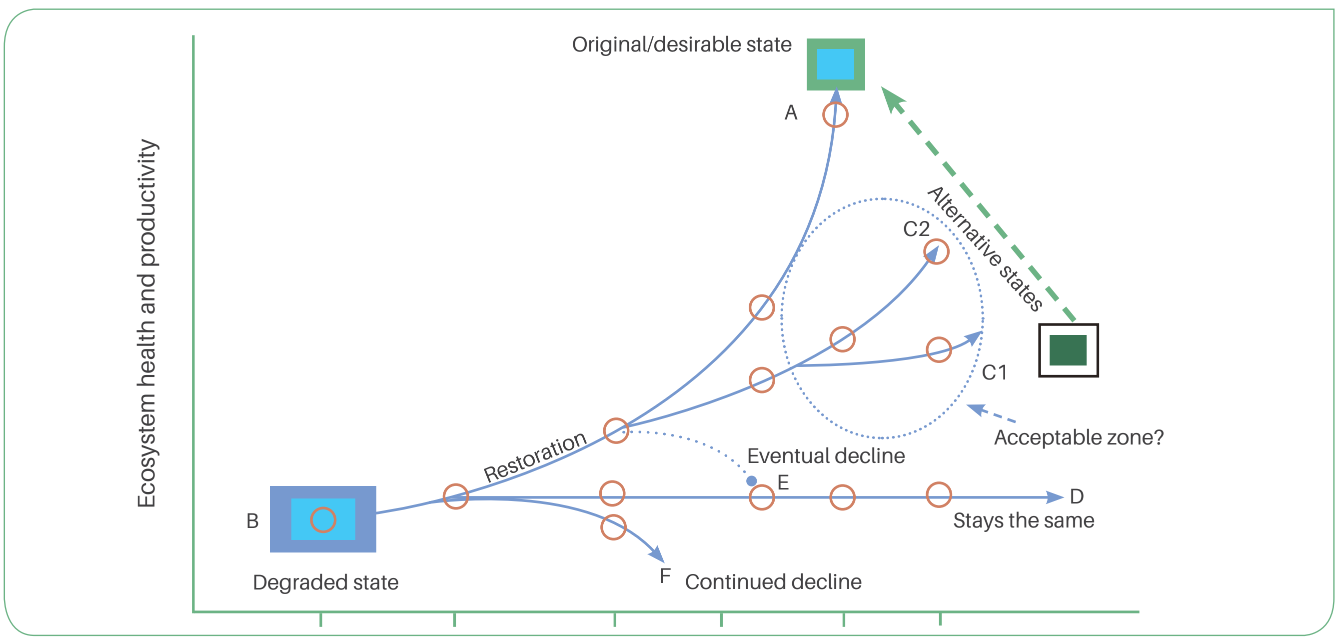

Figure 5.1 Possible trajectories or scenarios that can be pursued or achieved when restoring a degraded system.
Source: Modified from Lugo (1988); Meffe et al. (1994).

Following degradation that has moved the system from its original state (A) to a degraded state (B), it may continue to degrade (F) or recover naturally after it has been abandoned. Restoration to full recovery is rare and may not be desirable. Instead, the recovery goal may be at the C level, dependent on the stakeholder priority, e.g. (C2) where most structure and productivity can be improved or (C1) where most of the former biodiversity but less of the structure and productivity can recover. Monitoring progress towards the desired state and projecting the outcome will provide early insights with respect to the set needs of the stakeholders and the community and to a well-defined base situation. An integrated systems approach may help in this assessment and identify the causes of success and/or failure along the desired pathway (i.e. red circles in Figure 5.1). Such an analysis should include gains in terms of biomass, biodiversity or other associated ESSs and the overall functioning of the system (Costanza and Mageau, 1999; Suding et al., 2004; Stone and Haywood, 2006). A comprehensive 'ecosystem health' index that can assess the overall impacts of restoration efforts at various scales and social dimensions would be helpful (Rapport, 1989; Rapport et al., 1999; Lu et al., 2015).

Experiences in restoration efforts in various regions (including the highlands of Ethiopia) have offered us key lessons on the necessary ecological, social, economic and institutional conditions that must be fulfilled successful restoration (e.g. Hanson et al., 2015). They include: (i) conducive policies and institutional set ups; (ii) site and context specificity (including gender sensitivity) while considering the landscape continuum; (iii) direct economic benefits to the community at large; and (iv) synergies facilitated and trade-offs minimized.

In summary, landscape restoration involves an inter-sectoral and comprehensive analysis of the main agents and drivers of degradation. It should weigh up restoration options, promote enabling environments (policies, regulations and laws) and understand and deal with institutional settings and governance issues (e.g. tenure, right to use of natural resources, local community and its involvement, etc.). Only then should the steps be taken to identify and develop appropriate technologies and approaches and mobilize resources (including private-sector investment, capacity development for implementation, monitoring and evaluation and dissemination) (Hobbs et al., 2011; Sabogal et al., 2015).

5.4 The institutional realm for LDN

Land degradation neutrality requires strategies that will create an enabling environment and incentives for acting against land degradation at the farm, community, sub-national, national, and in some cases, regional or global levels. For example, restoration of eroded soils requires the use of soil and water conservation (SWC) structures and other strategies at farm and watershed levels to ensure effective control of soil erosion. Adoption of SWC by only a few farmers may not be as effective as erosion from upstream farms could wash away the SWC structures downstream. Regulations and disincentives to prevent land-degrading practices such as forest fires should be enacted and enforced at community or higher administrative levels as a forest fire from one farm could spread to a much wider area. Incentives play a key role in convincing land users to use sustainable land management practices. Depending on governance and other mediating factors, access to market could improve access to inputs and markets for land-based products and services (Laurance et al., 2009). Using empirical results, this section discusses the role of laws and incentives that create the enabling environment for achieving the LDN goal.

The key components of an enabling environment for appropriate land user behavior include: laws and governance, structured governmental coordination and secure land and property rights (Lawry et al., 2014). In an environment where these conditions are met and effectively enforced, deforestation and other land degrading practices will be prevented – if certain conditions, such as incentives and disincentives – are held constant. A global study by Nkonya et al. (2016a) showed that land improvement in developing countries was related to an improvement in government effectiveness while continued land degradation was observed where government effectiveness had declined. In sub-Saharan Africa, between 1996 and 2015, the rate of deforestation decreased consistently in countries that experienced improvement in government effectiveness (Figure 5.2). In fact, these countries experienced net forest area gain in the period 2010–2015. For countries that experienced worsening government effectiveness, deforestation rate increased between 1996 and 2010 and fell only in the period 2011–2015. The Government of Niger enacted the Rural Code in 1993 and Forest Law in 2004, which provided tree tenure which in turn incentivized farmers to plant or protect trees on their farms (Stickler, 2012). This led to the success story of the regreening of the Sahel in Niger. The government's commitment to public policies (Kaufman et al., 2010) improved Niger Government's effectiveness (GE) index by about 43% in the period 1996–2012, while it fell in sub-Saharan and West Africa during the same period. Without tree tenure, the regreening of Niger might not have been realized. In most of sub-Saharan Africa, the lack of rights to land and natural resources are serious impediments to land restoration (Mennen, 2015).

Policy making, planning and decision making should be coordinated across technical sectors (horizontal integration) and between levels of government (vertical integration). Most government administrations are organized according to individual sectors (e.g. agriculture, environment, rural development, water, etc.) and jurisdictions. This is a significant barrier for sustainable land management, particularly in landscape management, in which stakeholders seek to achieve multiple, cross-sectoral objectives that do not conform to administrative boundaries. This institutional and policy harmonization at the national, sub-national and landscape levels can help to eliminate unintended negative interactions that arise in landscapes when multiple laws and regulations are adopted and implemented independently of each other. Meanwhile, cross-sectoral collaboration can help policy makers recognize multiple benefits at landscape scale.

Economic theory posits that incentives play a big role in decision making by rational investors (Baiman, 1982). This theory has been shown to apply to restoration of degraded lands. The well-documented empirical result "more people, less soil erosion" in Machakos (Kenya) is attributed to high market access that allowed farmers to benefit from SWC investment (Tiffen et al., 1994; Boyd and Slaymaker, 2000). Using a 60-year (1930–1990) data set, this study showed that population density in the district increased from less than 100 people/km2 in the 1930s to 400 people/km2 in the 1990s, yet the previously severely degraded semiarid areas of Machakos, Kenya recovered due to high adoption rate of SWC (Tiffen et al., 1994). The adoption of SWC was motivated by improved market access and attractive producer prices (Tiffen et al., 1994; Boyd and Slaymaker, 2000). In sub-Saharan Africa, countries with improved government effectiveness combined with high market access experienced land improvement, while those with even poor market access experienced LD in cases where government effectiveness had improved (Nkonya et al., 2016b).

Some market issues are unique to larger companies and are beginning to play a more significant role in integrated land management. Consumers, shareholders and other stakeholders expect that companies can trace their supply chain all the way to the natural resource extraction or production level, and manage the environmental and social risks and impacts associated with each stage of the chain. Risks such as water scarcity, land degradation, climate change impacts, or competition for natural resources and energy can only be effectively addressed at scales beyond the site level. Hence, solutions to effectively mitigate and adapt to such risks depend on collective or shared approaches at landscape or watershed scales. To retain their long-term license to operate and manage regulatory, reputational and operational risks, many businesses are making commitments to halt deforestation, improve water management practices and generate positive social and environmental impacts (Kissinger et al., 2012). Such actions to reduce degradation and restore land in the context of sustainable development should not ignore poor populations and marginalized groups within communities.

In addition to market access, direct monetary and nonmonetary incentives are critical drivers of restoration (de Groot et al., 2007; McGhee et al., 2007). Payment for EESs for targeted gains in terms of biodiversity conservation, carbon sequestration and storage, watershed protection, and landscape beauty and recreation, is a growing source of income for rural societies which can incentivize communities to invest in restoration (Kleijn and Sutherland, 2003; Wade et al., 2008; Wunder and Alban, 2008; Milder et al., 2010).

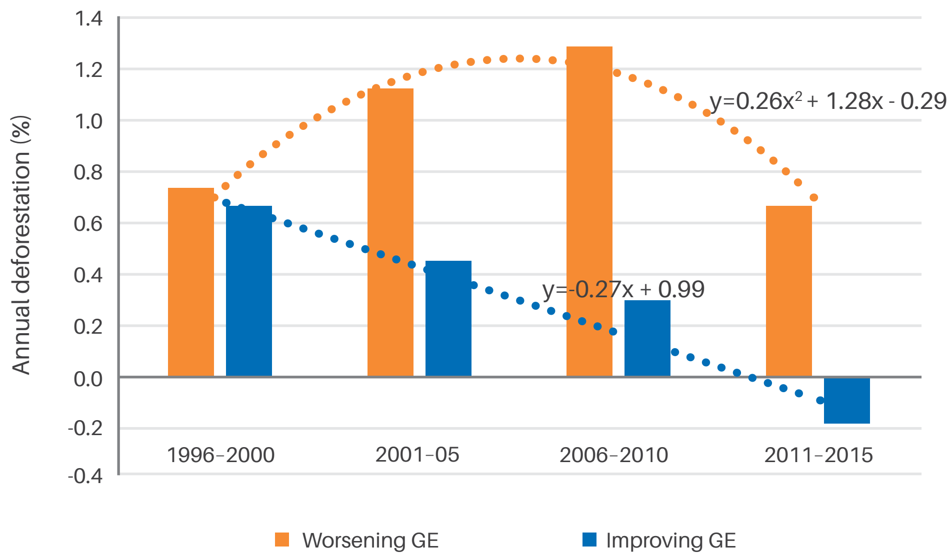

Figure 5.2 Relationship between government effectiveness and annual deforestation trends in sub-Saharan Africa.

Note: Government effectiveness index (GEI) Scale: −2.5 weak to 2.5 Strong.

Worsening GE

$$\Delta GE = \frac{\overline{GEI_2} - \overline{GE_1}}{\overline{GEI_1}} * 100$$

Where ΔGE = Change in Government effectiveness, $\overline{GE_1}$ = Average GE, 1996–2000, $\overline{GE_1}$ = Average GE, 2010–15. GE improving if $\Delta GE > 0$; Worsening GE if $\Delta GE < 0$

Sources: Deforestation rate: FAO (2015); Government effectiveness: Kaufmann et al. (2010).

Conclusions

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The concern for the well-being of land is often directly related to one's proximity to the land, be it physical, economic or cultural. Land is more precious if one's livelihood depend on it immediately than if one is merely a visitor. Land is valued differently if it is the base of one's power or wealth than if one's community needs its integrity and depends on the ESSs that it provides. To some extent, this may explain the great challenge UNCCD has experienced in mustering international support for its mandate. The degradation of land has long been a local concern, and in contrast with climate change and water pollution, not one that would affect populations beyond the location where the problem originated. The arrival of environmental migrants far from the affected regions is contributing to a change of vision and increased urgency to counter land degradation.

With the international community taking note of this paradigm shift, the SDGs have addressed the issue head on in SDG 15 and in formulating the objective of LDN. However, development has several aspects that may not easily be reconciled with sustainable development. Urbanization, alleviating pressure on land resources, involves the loss of often prime land and ESS-saving urbanization concepts such as near-natural urbanization and waste recycling are in their infancy. Globalization distributes jobs and wealth on a large scale but also moves large amounts of nutrients around the world, often to the detriment of the delivering and receiving regions. On a local scale, SDGs may be difficult to reconcile as the pursuit of one SDG may be at the expense of another. Many of these dilemmas are grounded in the multiple ESSs that are derived from land and their complex interaction and the different scales at which stakeholders are demanding these services. Research on these complex socio-ecological systems is rapidly evolving with the help of modern tools including systems modeling, big data and geo-observation equipment, but given the SDG aspirations for 2030, the scientific community is engaged in a game of catch up. Society as a whole is conflicted as it is polarized when it comes to acknowledging the seriousness and complexity of the problems of sustainable development and its associated costs and benefits.

Land degradation is a complicating factor in reaching not only SDG 15 but many of the others such as the elimination of hunger, the provision of biodiversity, clean water and renewable energy, climate change mitigation and sustainable urban environments that all depend on healthy land resources. Through its effect on individual SDGs, land degradation can have systemic effects on other, both land and non-land related SDGs, e.g. land degradation that reduces food security in marginal areas contributes to increasing global and national inequalities. Although the phenomenology of land degradation is well known, knowledge on its extent and cost is patchy and far from precise. Whatever the approach or methodology that is used to calculate the costs of land degradation, the cost is high. There is an urgent need to develop tools and databases that will take stock of the state of our land, which then can serve as a baseline against which LDN can be monitored. Despite the uncertainties, the consensus is that the cost of land degradation is enormous and if not arrested, will be a serious drain on the world economy and particularly on the weaker economies of the world.

In the quest against land degradation, the scale of engagement is paramount. The scope of a traditional custodian of our land, the farmer, in combating land degradation is often limited to the benefits he might reap from taking that action. Many of the measures that can combat land degradation involve investments and for the farmer to do his share, he will have to be secure in the rights to or use of the land and he should have the resources to adjust the management of his land. Climate-smart agriculture practices and conservation agriculture are management options for sustainable agriculture, but their effect is limited in the context of the SDGs if they are not brought to scale and tied in with a sustainable land and landscape effort. The public benefits will become obvious only at this scale. This requires collective action, based on stakeholder involvement and the latest science and should be based on the principle of development, equity and social justice.

There is an increasing awareness of the need for integrated management of land and water resources (ILWM) at the watershed and landscape level. Land management needs to spare water and water management needs to optimize ESS from land while satisfying the needs for water in multiple sectors. Keeping in mind the many purposes of these resources, ILWM should derive the optimal mix of ESS without diminishing the resource base. Finding win-win options or the best trade-offs of land use and management based on resource endowment and stakeholder needs is a novel endeavor with which the scientific community is slowly coming to terms with. The need to manage landscapes is increasingly recognized at the community level. Integrated landscape management aims to allocate land to different uses to retain or regain the integrity of the landscape.

Policy makers recognize the need for action and aim to provide the institutional environment, markets and (dis-) incentives to support communities that are ready to act. Given the complexity of the socio-ecological systems, the scientific solutions and recommendations are often unknown or untested. Aware of the urgency of action, many communities and policy makers are experimenting with potential solutions of their own. The scientific community is following these experiments and documenting them.

We can draw several lessons from the experiments of past decades. Agricultural research must expand its focus from field and plot research to landscape research and in the process, should look at the cost of production by internalizing its environmental cost. In some situations, the public cost of agriculture in marginal environments outweighs the private gains, even with the best technologies in place. Land use and city planners increasingly will need to address the cost of occupying productive agricultural land or the conversion of natural habitats. There is a need to close nutrient cycles and improve the efficiency of external inputs. Landscape design and urban planning should aim to conserve resources, restore biodiversity and deliver ESS. Land degradation issues are local in nature as the problems, social context, and stakeholder communities are rarely the same. As a result, solutions to land degradation can rarely be generalized. Consequently, LDN will be met only through a multitude of efforts, tailored to the conditions of the landscape, community and national interests in a process of negotiations at each level. If land degradation is not held in check, the grounds on which the SDGs are build may slip beyond reach.

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