LAND MANAGEMENT, ENVIRONMENT & SOLID-WASTE: INSIDE EDUCATION AND BUSINESS IN CENTRAL ASIA
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MICRO-CREDENTIAL

CLIMATE CHANGE FOR SUSTAINABLE LAND MANAGEMENT IN CENTRAL ASIA

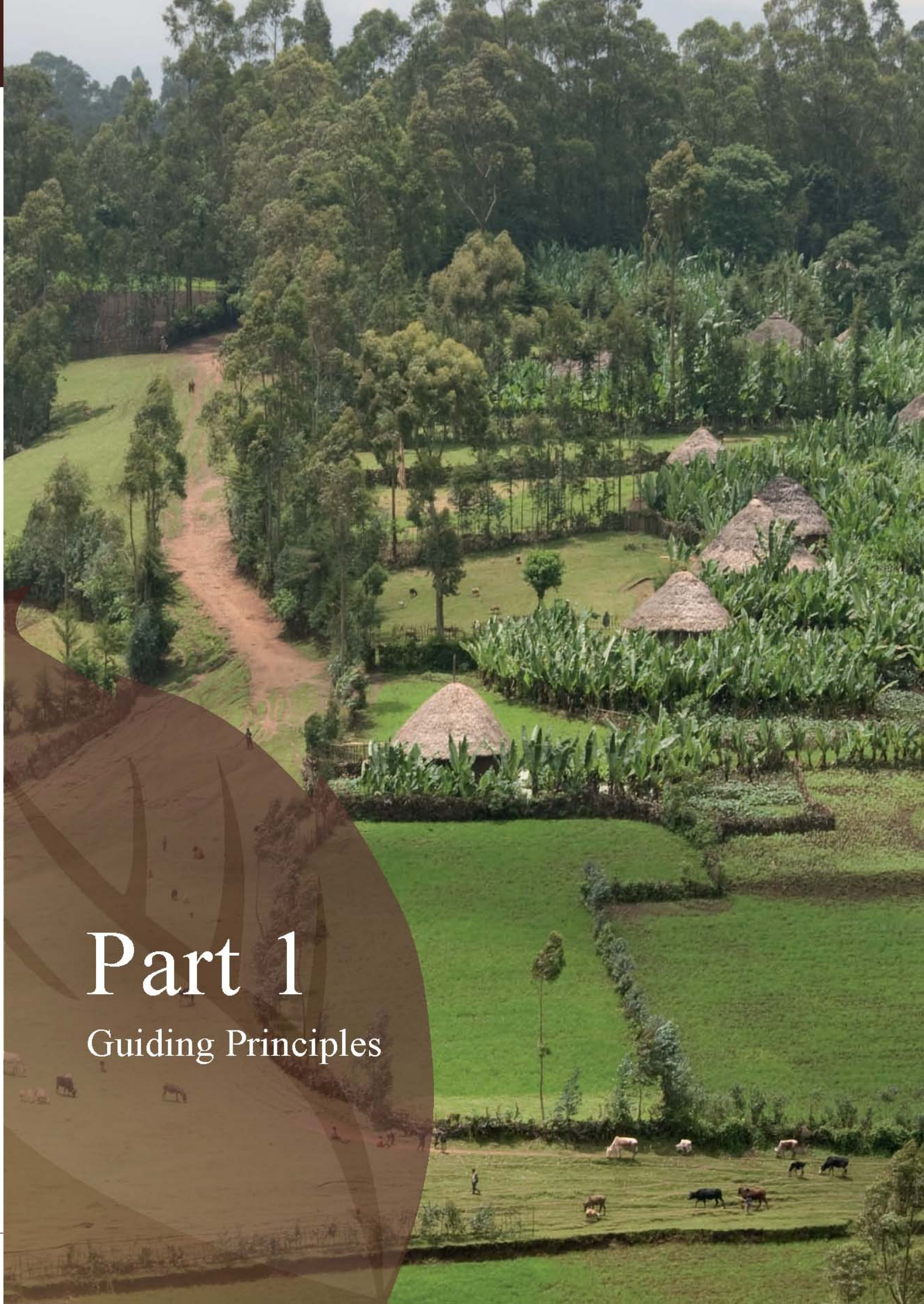
3.- The Carbon Cycle, Land Use and SLM

Reading

Sustainable Land Management definition and principles

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Part 1

Guiding Principles



INTRODUCTION

Setting the frame

Land degradation, resulting from unsustainable land management practices, is a threat to the environment in Sub-Saharan Africa (SSA), as well as to livelihoods, where the majority of people directly depend on agricultural production. There is a potentially devastating downward spiral of overexploitation and degradation, enhanced by the negative impacts of climate change - leading in turn to reduced availability of natural resources and declining productivity: this jeopardises food security and increases poverty. Sustainable land management (SLM) is the antidote, helping to increase average productivity, reducing seasonal fluctuations in yields, and underpinning diversified production and improved incomes.

Sustainable land management is simply about people looking after the land – for the present and for the future. The main objective of SLM is thus to integrate people's coexistence with nature over the long-term, so that the provisioning, regulating, cultural and supporting services of ecosystems are ensured. In SSA, this means SLM has to focus on increasing productivity of agro-ecosystems while adapting to the socio-economic context, improving resilience to environmental variability, including climate change and at the same time preventing degradation of natural resources.

These guidelines provide important guidance to assist countries to design and implement SLM technologies and approaches to scale up sustainable land and water management, at either the national program level or at the level of projects on the ground. The guidelines are one of a suite of products that falls under the TerrAfrica Country Support Tool, which offers a customisable approach for task teams and clients to build land management programs, either within investment operations or as standalone technical assistance. The guidelines build up on the experiences of the book 'where the land is greener' and have drawn from the expertise within the global WOCAT programme. They have been financed by the World Bank's Development Grant Facility 2008 as part of the 2009-2010 TerrAfrica Work Programs and co-funded by the Swiss Agency for Development and Cooperation (SDC).

TerrAfrica involves many Sub-Saharan countries and is led by the Planning and Coordination Agency (NPCA) of the African Union's New Partnership for Africa's Development (AU-NEPAD). TerrAfrica is a global partnership to mainstream and upscale sustainable land management (SLM) in SSA by strengthening enabling environments for mainstreaming and financing effective nationally-driven SLM strategies (www.terrafrica.org). Learning from past experiences, it endorses the principles of partnership, knowledge management and harmonised, aligned and scaled-up investment at the country level. The guidelines were developed in coordination with another TerrAfrica resource guide publication on 'Using sustainable land management practices to adapt to and mitigate climate change in Sub-Saharan Africa' (Woodfine, 2009).

These guidelines do not pretend to be exhaustive in terms of data and information collection, or to cover all aspects of SLM. A deliberate and strategic choice was made to show the potential of SLM in the context of SSA. A further function of these guidelines is to act as a prototype for national and regional compilations of SLM practices: thus showing how field knowledge can be made available in a way that can be followed by future publications covering other aspects of SLM. The focus here is on SLM practices in SSA which draw directly on WOCAT's extensive database, and take into account the experience of TerrAfrica's partners: in a rapidly changing environment every effort has been made to review and assimilate the latest trends, threats and opportunities (Crepin, et al., 2008; Woodfine, 2009).

Aims and audience

The overall aim of these guidelines is to identify, describe, analyse, discuss, and present for dissemination SLM practices, both technologies and approaches that are appropriate to Sub-Saharan Africa – and based in solid science. Materials are drawn from experience and representative case studies; these focus in particular on those practices with rapid paybacks and profitability and / or other factors likely to drive adoption. The direct objectives thus are:

- Knowledge synthesis and dissemination of 'best' SLM practices;
- Alignment of stakeholders for improved decision support in SSA;
- Promotion of standardised documentation, evaluation, sharing and use of SLM knowledge for decision-making.

The target group of this document constitutes key stakeholders in SLM programmes and projects, involved at the design and implementation stages. These thus include policy-makers, planners, programme managers together with practitioners, international financial and technical institutions, as well as other donors. The guidelines are intended also to raise further awareness and understanding among a broader public interested in poverty alleviation, protection of the environment and mitigation of land degradation.

Structure and sources

These guidelines build on WOCAT's book 'where the land is greener' (WOCAT, 2007), and are divided into two main parts.

Part 1 highlights the main principles behind SLM, and what considerations are important for technologies and approaches to qualify as 'best practices' suitable for upscaling. Information is based on literature and WOCAT's expertise.

Part 2 presents twelve groups of SLM technologies and a section on SLM approaches, supported by specific case studies. This section is based on the WOCAT global database, the TerrAfrica Knowledge Base, a literature review (publications, papers, project documents and manuals) and interactive contact with SLM specialists in SSA. The compilation of SLM groups and case studies focuses first on SLM interventions in order to identify factors of success / failure, good practices and lessons learnt. It determines the effectiveness and cost-efficiency of the various SLM interventions used to-date with the aim of identifying the best practices for scaling-up.

The best practices that are presented:

- cover major land use systems;
- represent solutions to various degradation types in different agro-ecological zones;
- cover a broad variety of technologies and approaches;
- have potential for upscaling, in terms of both production and conservation;
- capture local innovation and recent developments as well as long-term project experience;
- strike a balance between prevention, mitigation and rehabilitation of land degradation.

All groups and case studies are presented according to the familiar and standardised WOCAT format for documenting and disseminating SLM.

Particular efforts were made to show impacts of SLM and their potential to address current global issues such as desertification, climate change, water scarcity, and food security. Key resource persons and experts on SLM in SSA were asked to review and assist in finalising the SLM groups on technologies and approaches, to provide figures on costs and benefits, and to describe specific case studies. This is thus a product that brings together all the available, important information about SLM in SSA: it strives to be a 'state of the art' product. Thus, the guidelines are founded on a body of solid practical experience - and underpin the benefits of investing in SLM and the potential for building on success.

Focus on Sub-Saharan Africa

Sub-Saharan Africa is particularly vulnerable to the twin threats of natural resource degradation and poverty owing to the following factors:

- High population growth and pressure;
- Dependency of livelihoods on agriculture, with 65-70% of the population depending directly on rainfed agriculture and natural resources. Industry and the service sector also depend heavily on land management (Eswaran et al., 1997);
- Agriculture is highly sensitive to variability and change in climate, and markets / prices;
- Multiple severe impacts are likely to result from climate change (IPCC, 2007; Stern, 2007): these include higher temperatures, water scarcity, unpredictable precipitation, higher rainfall intensities and environmental stresses;
- The phenomenon of El Niño Southern Oscillation (ENSO) exerting a strong influence on climate variability, particularly in Eastern and Southern Africa;
- Abundance of fragile natural resources and ecosystems including drylands, mountains, rainforests, and wetlands;
- High rates of land degradation (erosion and declining soil fertility, increasing water scarcity and loss of biodiversity) and sensitivity to climate variability and change;
- Low yields and high post-harvest losses due to poor land management and storage practices and limited availability of, and access to, inputs.

It is clear from the foregoing that Sustainable Land Management (SLM) is crucial for SSA, and that there are special circumstances that pose particular problems and challenges for the successful implementation of SLM.

Focus on Sustainable Land Management

Land degradation is simply defined, within the 'FAO-LADA Approach' as a decline in ecosystem goods and services from the land. Land degradation negatively affects the state and the management of the natural resources – water, soil, plants and animals - and hence reduces agricultural production. Assessments in SSA show the severity of land degradation and the urgency of improving natural resource use through sustainable land management (SLM). Land degradation occurs in different forms on various land use types:

- On cropland: soil erosion by water and wind; chemical degradation - mainly fertility decline - due to nutrient mining and salinisation; physical soil degradation due to compaction, sealing and crusting; biological degradation due to insufficient vegetation cover, decline of local crop varieties and mixed cropping systems; and water degradation mainly caused by increased surface runoff (polluting surface water) and changing water availability as well as high evaporation leading to aridification.
- On grazing land: biological degradation with loss of vegetation cover and valuable species; the increase of alien and 'undesirable' species. The consequences in terms of soil physical degradation, water runoff, erosion are widespread and severe. Low productivity and ecosystem services from degraded grazing lands are widespread and a major challenge to SLM.
- On forest land: biological degradation with deforestation; removal of valuable species through logging; replacement of natural forests with monocrop plantations or other land uses (which do not protect the land) and consequences for biodiversity, and soil and water degradation.

Land uses addressed

Cropland: Land used for cultivation of crops (annual and perennial) e.g. field crops, vegetables, fodder crops, orchards, etc.

Grazing land: Land used for animal production e.g. natural or semi-natural grasslands, open woodlands, improved or planted pastures.

Forests / woodlands: land used mainly for wood production, other forest products, recreation, protection e.g. natural forests, plantations, afforestations, etc. *(WOCAT, 2008)*

Concerted efforts to deal with land degradation through SLM must address water scarcity, soil fertility, organic matter and biodiversity. Improving the water productivity and water cycle, soil fertility and plant management are important in raising land productivity.

Land degradation is exacerbated by climate change and climate variability. Africa's climate has long been recognised as both varied and varying: varied because it ranges from humid equatorial regimes, through seasonally-arid tropical and hyper-arid regimes, to sub-tropical Mediterranean-type climates; and varying because all these climates exhibit differing degrees of temporal variability, particularly with regard to precipitation (Nkomo et al., 2006). The complexities of African climates are attributable to a number of factors, many of which are unique to the continent, including the size of the tropical land mass, the expanse of arid and semi-arid lands, diverse vegetation, complex hydrology, incidence of dust exported from land surface to the atmosphere – and highly varied terrain including snow-capped mountains on the Equator, extensive low-lying swamp lands, huge inland lakes, rift valleys and two major deserts in the northern and southern sub-tropics (Crepin, et al., 2008; Woodfine, 2009).

Climate change is a major concern for SSA bringing new challenges. However, there is huge potential for SLM in climate change mitigation and adaption.

SLM best practices and their upscaling in Sub-Saharan Africa is essential for a variety of reasons – but the most basic is to sustain and improve livelihoods while protecting the land's resources and ecosystem functions. SLM thus seeks to increase production including traditional and innovative systems and to improve resilience to food insecurity, land degradation, loss of biodiversity, drought and climate change.

Sustainable Land Management has been defined by TerrAfrica as:
'the adoption of land use systems that, through appropriate management practices, enables land users to maximise the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources'[1].
SLM includes management of soil, water, vegetation and animal resources.



Degradation of vegetation, soils and water along river banks (Hanspeter Liniger).

SLM also includes ecological, economic and socio-cultural dimensions (Hurni, 1997). These three are not separate: in reality they are interconnected (Figure 1). They are also referred to as the '3 Es' of sustainable development - Equality, Economy, and Ecology (UNESCO, 2006).

Ecologically, SLM technologies – in all their diversity – effectively combat land degradation. But a majority of agricultural land is still not sufficiently protected, and SLM needs to spread further.

Socially, SLM helps secure sustainable livelihoods by maintaining or increasing soil productivity, thus improving food security and reducing poverty, both at household and national levels.

Economically, SLM pays back investments made by land users, communities or governments. Agricultural production is safeguarded and enhanced for small-scale subsistence and large-scale commercial farmers alike, as well as for livestock keepers. Furthermore, the considerable off-site benefits from SLM can often be an economic justification in themselves.

[1]In TerrAfrica's Background Note 1 SLM's definition is more complex, it is 'the combination of technologies, policies and activities aimed at integrating socio-economic principles with environmental concerns so as to simultaneously maintain or enhance production, reduce the level of production risk, protect the potential of natural resources and prevent soil and water degradation, be economically viable and be sociable acceptable' which is drawn originally from Dirk Kloss, Michael Kirk and Max Kasparek. World Bank Africa Region SLM Portfolio Review, Draft 19 Jan 2004.

Best practices are basically the 'best' known to us at present: in the view of TerrAfrica 'best' implies those practices that increase production and are profitable, cost-efficient with primarily rapid, but also long-term payback, are easy to learn, socially and culturally accepted, effectively adopted and taken up, environmentally friendly and are appropriate for all stakeholders including socially marginalised groups (FAO, 2008a).

Scaling-up of SLM 'leads to more quality benefits to more people over a wider geographic area more quickly, more equitably and more lastingly' (ILEIA, 2001). Investments in scaling-up of best SLM practices in SSA are essential to have a significant impact. Too many best practices remain isolated in pockets. The challenge is to gain significant spread, not just to help an increased number of families, but to achieve ecosystem impacts that can only be realised on the large scale. In this context it is important to note that SLM covers all scales from the field to watersheds, landscapes and transboundary levels. Beyond field level, on-site and off-site as well as highland-lowland interactions need special attention. The simultaneous challenge and opportunity is to find best SLM practices which are win-win solutions leading to sustainability at the local, national and global scales.

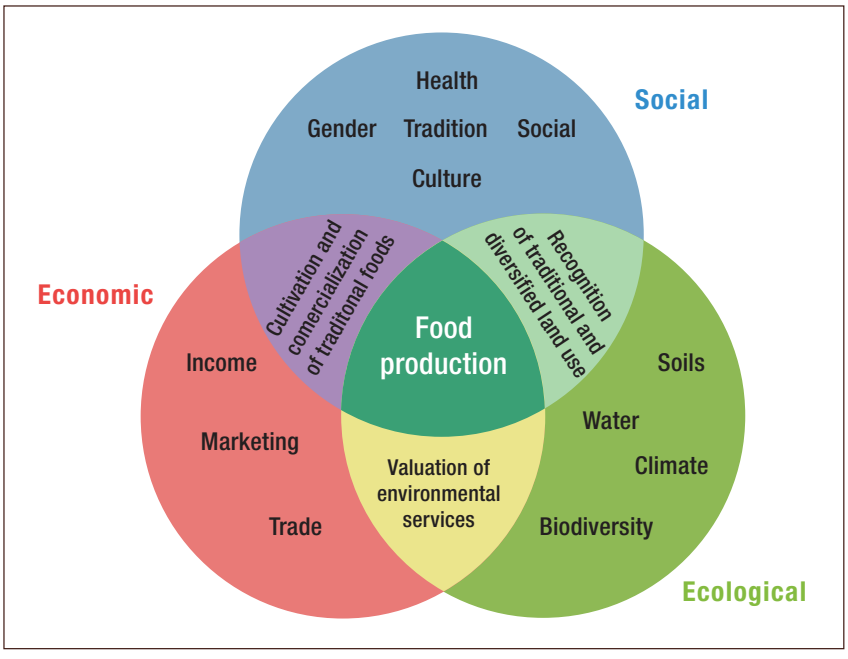


Figure 1: The 3 dimensions of sustainability. (Source: IAASTD, 2009a).



PRINCIPLES FOR BEST SLM PRACTICES

For all major land use systems in Sub-Saharan Africa (SSA) including cropland, grazing land, forest and mixed land, the focus of SLM is on increased land productivity and improved livelihoods and ecosystems.

Table 1: Land use in SSA (2000)

Land use	Percentage cover
Permanent pasture	35
Arable and permanent cropland	8
Forested	27
All other land	30
Total	100

(Source: WRI, 2005 and FAO, 2004)

Increased land productivity

African cereal yields, particularly in the Sudano-Sahelian region, are the world's lowest. For SSA, increasing agricultural productivity for food, fodder, fibre and fuel remains a priority given the fast growing demand, widespread hunger, poverty, and malnutrition.

The primary target of SLM for SSA is thus to increase land productivity, improve food security and also provide for other goods and services. There are three ways to achieve this: (1) expansion, (2) intensification and (3) diversification of land use.

Expansion: Since 1960, agricultural production in Sub-Saharan Africa has been increased mainly by expanding the area of land under farming (Figure 2). Limited access and affordability of fertilizers and other inputs (e.g. improved planting material) has forced African farmers to cultivate less fertile soils on more marginal lands; these in turn are generally more susceptible to degradation and have poor potential for production. There is very limited scope for further expansion in SSA without highly detrimental impacts on natural resources (e.g. deforestation).

Intensification: The last 50 years have witnessed major successes in global agriculture, largely as a result of the 'Green Revolution' which was based on improved crop varieties, synthetic fertilizers, pesticides, irrigation, and mechanisation. However, this has not been the case for SSA (Figure 2).

Diversification: This implies an enrichment of the production system related to species and varieties, land use types, and management practices. It includes an adjustment in farm enterprises in order to increase farm income or reduce income variability. This is achieved by exploiting new market opportunities and existing market niches, diversifying not only production, but also on-farm processing and other farm-based, income-generating activities (Dixon et al., 2001). Diversified farming systems (such as crop–livestock integration, agroforestry, intercropping, crop rotation etc.) enable farmers to broaden the base of agriculture, to reduce the risk of production failure, to attain a better balanced diet, to use labour more efficiently, to procure cash for purchasing farm inputs, and to add value to produce.

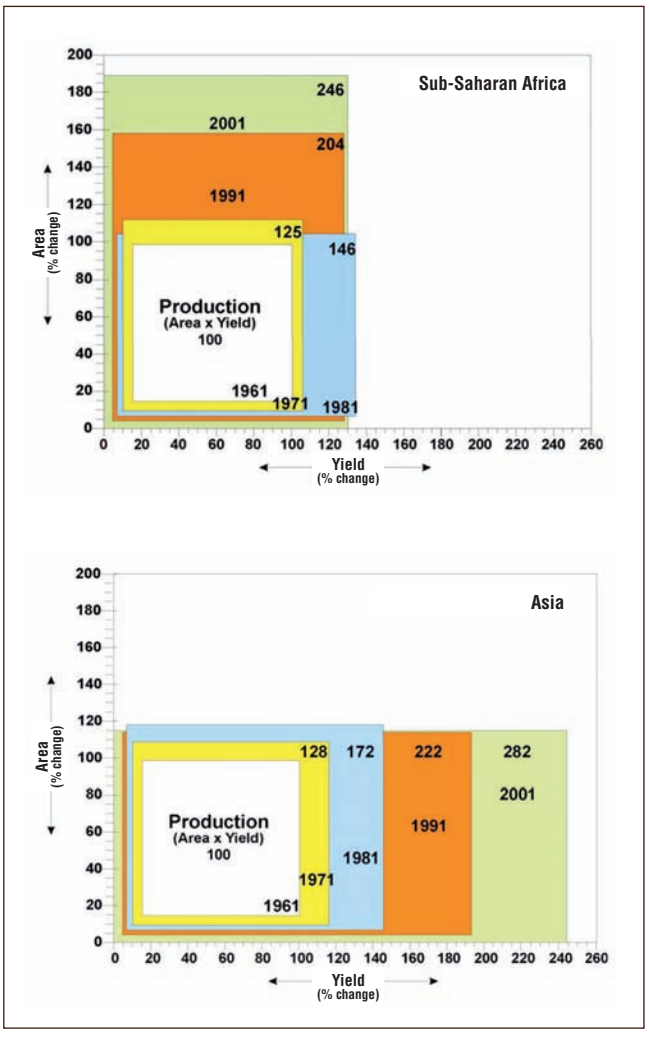


Figure 2: Comparison of changes in cereal production in SSA (above) due to changes in area and yield (1961=100) with those in Asia (below). (Source: Henao and Baanante, 2006)

Expansion, intensification and diversification to increase agricultural productivity imply:
– increasing water productivity (water use efficiency),
– enhancing soil organic matter and soil fertility (carbon and nutrient cycling),
– improving plant material (species and varieties), and
– producing more favourable micro-climates.

Agricultural production and food security in SSA today and in the future

– Population growth is 2.1% per annum: doubling of the population expected within 30-40 years.
– In 1997-99, 35% of the population had insufficient food to lead healthy and productive lives.
– Average cereal yields: of 1 tonne per hectare.
– Cereal availability per capita decreased from 136 kg/year in 1990 to 118 kg/year in 2000.
– 73% of the rural poor live on marginal land with low productivity.
– Approximately 66% of Africa is classified as desert or drylands; 45% of the population lives in drylands.
– In 2000, US$ 18.7 billion were spent in Africa for food imports and 2.8 million tonnes of food aid: this represents over a quarter of the world's total.
– 83% of people live in extreme poverty; the number of people and thus their demands on food, water and other resources are increasing.
– Energy needs and the demand for firewood and biofuel are growing even faster than food needs. This increases deforestation and pressure on vegetation, crop residues and on manure (which is often used as fuel). In many countries 70% of energy comes from fuelwood and charcoal.
– Climate change, with increased variability and extremes, puts an extra constraint on food security.
– Land is the source of employment for 70% of the population.
– Agriculture will remain the main engine of growth at least for the next few decades.
– Land degradation is severe and ongoing.
– Land productivity, food security, poverty reduction / human development and wellbeing are strongly linked

(Sources: Henao and Baanante, 2006; Castillo et al, 2007; FAO, 2007; IAASTD, 2009b TerrAfrica, 2009; WB, 2010)

Water use efficiency

Water use efficiency is defined as the yield produced per unit of water. Optimal water use efficiency is attained through minimising losses due to evaporation, runoff or

drainage. In irrigation schemes, conveyance and distribution efficiency addresses water losses from source to point of application in the field. Often the term water productivity is used: this means growing more food or gaining more benefits with less water. Commonly it is reduced to the economic value produced per amount of water consumed.

In the drylands of the world, water is – by definition - the most usual limiting factor to food production due to a mixture of scarcity, and extreme variability, long dry seasons, recurrent dry spells and droughts, and occasional floods. Water scarcity and insecure access to water for consumption and productive uses is a major constraint to enhancing livelihoods in rural areas of SSA (Castillo et al., 2007; FAO, 2008b). Hence, improving water use efficiency to minimise water losses is of top-most importance.

Under the principle of the water cycle, all water remains within the system. However, at local and regional level, water can follow very different pathways and losses may be high, depending on land (and water) management. In relation to agriculture, water is often referred to as being 'blue' or 'green'. Blue water is the proportion of rainfall that enters into streams and recharges groundwater – and is the conventional focus of water resource management. Green water is the proportion of rainfall that evaporates from the soil surface or is used productively for plant growth and transpiration (Falkenmark and Rockström, 2006; ISRIC, 2010).

Figure 3 illustrates three major sources of water loss in agricultural production, namely surface runoff, deep percolation and evaporation from the soil surface. Surface runoff can, however, sometimes qualify as a gain when it feeds rainwater harvesting systems. Similarly, deep percolation of water can be a gain for the recharge of groundwater or surface water. However, the main useful part ('productive green water') is the soil water taken up by plants and transpired back to the atmosphere.

Many land users in developing countries could raise water productivity and water use efficiency by adopting proven agronomic and water management practices. There is considerable potential especially under low yield conditions where a small increment in water translates into a significant increase in yield (Figure 4).



Expansion to steep slopes, intensification and diversification all combined in the Uluguru Mountains of Tanzania (Hanspeter Liniger).

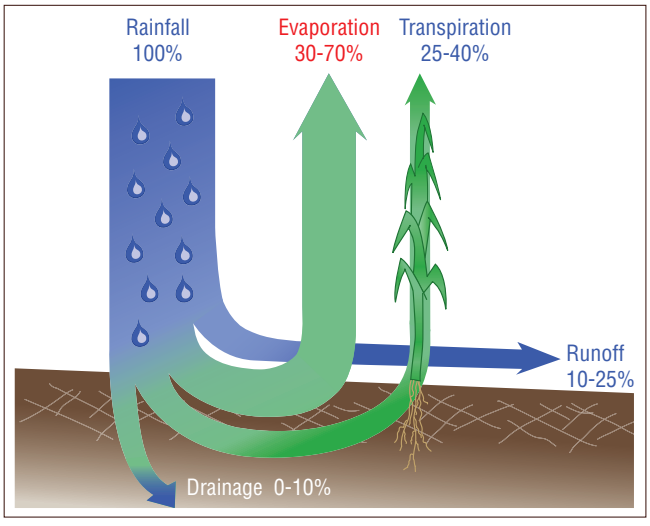


Figure 3: Productive water (transpiration) and water losses (evaporation and runoff) without water conserving measures in dry lands.

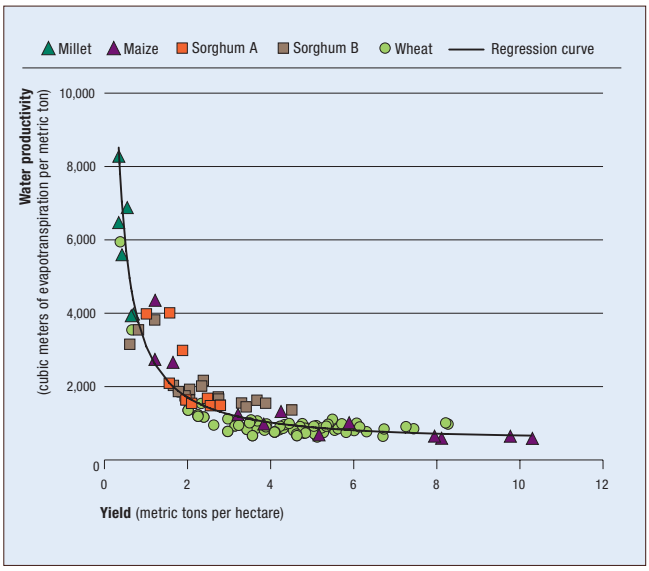


Figure 4: Water productivity and cereal yield under various management and climatic conditions: for cereal yields of less than 1 t/ha four to eight times more water is used per tonne compared to yields above 3 t/ha as the proportion used for grain (cf vegetative production is much less). (Source: Rockström et al., 2007)

Wastage of scare and precious water – the disturbed water cycle

- Depending on land management practices, between 30 and 70% of the rainfall on agricultural land in semi-arid areas is lost as non-productive evaporation from the soil surface or from intercepted rainfall.
- An additional 10-25% of that rainfall is lost as direct runoff without being harvested.
- As a result of these losses, only 15% to 30% of rainfall is used for plant growth.
- This low water use efficiency is closely linked to low or degraded soil cover, leaving soils exposed to solar radiation, wind and heavy rain storms and subsequent aridification and land degradation. Soil organic matter has major effects on water infiltration and nutrient availability.

(Sources: Liniger, 1995; Rockström, 2003; Molden et al., 2007; Gitonga, 2005)

Water use efficiency in rainfed agriculture: In Sub-Saharan Africa, some 93% of farmed land is rainfed (Rockström et al., 2007). The water challenge in these areas is to enhance low yields by improving water availability for plant growth: that is to maximise rainfall infiltration and the water-holding capacity of soils - simultaneously reducing surface erosion and other land degradation. Full response to water investments is only achievable if other production factors, such as soil fertility, crop varieties, pest and disease control, and tillage and weeding practices are improved at the same time (Figure 5).



Local practice combining deep tillage and ridging stops runoff but increases evaporation from the bare soil surface; under the plants the protected soil remains moist (Hanspeter Liniger).

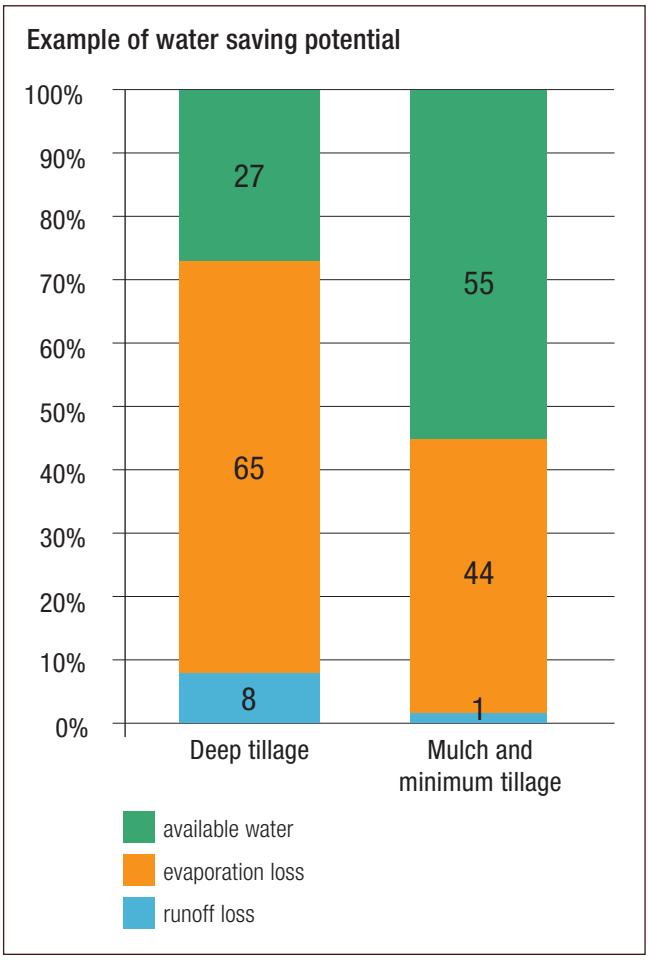


Figure 5: Water use efficiency in a semi-arid to subhumid environment comparing a local practice (deep tillage) with conservation agriculture comprising minimum tillage for weed control, mulching and intercropping of maize and beans. Under the local practice, total water loss was over 70%, with evaporation being the main contributor to this. Under mulch, the loss was reduced to 45%.The productive use of the water was doubled, and yields in some seasons even tripled (Gitonga, 2005).

Given the large water wastage through inappropriate land use practices there are significant opportunities to raise yields under rainfed agriculture and improve degraded ecosystems through better water management. All best practices in this regard fall under the five strategies listed in the box below. Management of rainwater is a main entry point into SLM.

Each of the best practices presented in Part 2 of these guidelines include improved water management and water use efficiency; some of them are particularly focused on coping with water scarcity - such as water harvesting in drylands or protection against evaporation loss and runoff, through conservation agriculture, agroforestry or improved grazing land management.

Different strategies for improved rainwater management

Divert / drain runoff & runon

Where there is excess water in humid environments, or at the height of the wet seasons in subhumid conditions, the soil and ground water can become saturated, or the soil's infiltration capacity can be exceeded. Thus safe discharge of surplus water is necessary. This helps avoid leaching of nutrients, soil erosion, or landslides. It can be achieved through the use of graded terraces, cut-off drains and diversion ditches etc.



Impede runoff (slow down runoff)

Uncontrolled runoff causes erosion - and represents a net loss of moisture to plants where rainfall limits. The strategy here is to slow runoff, allowing more time for the water to infiltrate into the soil and reducing the damaging impact of runoff through soil erosion. It is applicable to all climates. This can be accomplished through the use of vegetative strips, earth and stone bunds, terraces etc.



Retain runoff (avoid runoff)

In situations where rainfall limits plant growth, the strategy is to avoid any movement of water on the land in order to encourage rainfall infiltration. Thus water storage is improved within the rooting depth of plants, and groundwater tables are recharged. This is crucial in subhumid to semi-arid areas. The technologies involved are cross-slope barriers, mulching, vegetative cover, minimum / no tillage etc.



Trap runoff (harvest runoff)

Harvesting runoff water is appropriate where rainfall is insufficient and runoff needs to be concentrated to improve plant performance. Planting pits, half moons etc. can be used. This can also be applied in environments with excess water during wet seasons, followed by water shortage: dams and ponds can further be used for irrigation, flood control or even hydropower generation.



Reduce soil evaporation loss

Water loss from the soil surface can be reduced through soil cover by mulch and vegetation, windbreaks, shade etc. This is mainly appropriate in drier conditions where evaporation losses can be more than half of the rainfall.



Water use efficiency in irrigated agriculture: Irrigated agriculture consumes much more water than withdrawals for industrial and domestic purpose. The demand for irrigation water by far exceeds water availability. Due to water scarcity in SSA, the potential demand for irrigation water is unlimited and causes competition and sometimes conflicts. This is not just a question of drinking water supplies for people, livestock and wildlife but also environmental water requirements – which keep ecosystems healthy. Currently, only 4% of the agricultural land in SSA is irrigated - producing 9% of the crops (IAASTD, 2009b). Many irrigation schemes suffer from water wastage, and salinisation is also a common problem.

Irrigated Agriculture in SSA

– The agricultural sector is by far the biggest user of water resources worldwide; around 70% of annual water withdrawals globally are for agricultural purposes.
– In SSA, 87% of the total annual water withdrawals in 2000 were for agriculture, 4% for industry and 9% for domestic use.
– In SSA less than 4% of agricultural land is irrigated, compared to 37% in Asia and 15% in Latin America.
– The irrigated area in SSA is concentrated in South Africa (1.5 million ha), and Madagascar (1.1 million ha). Ten other countries (Ethiopia, Kenya, Mali, Niger, Nigeria, Senegal, Somalia, Tanzania, Zambia and Zimbabwe) each have more than 100,000 irrigated hectares.
– About half of the irrigated area comprises small-scale systems. In terms of value, irrigation is responsible for an estimated 9% of the crops produced in SSA.
– Inappropriate irrigation can result in soil salinisation. Tanzania for example has an estimated 1.7–2.9 million hectares of saline soils and 300,000–700,000 hectares of sodic soils, some of it now abandoned. This has not only detrimental effects on agriculture but also on water supply and quality.

(Sources: World Resources Institute (WRI), 2005; Falkenmark et al., 2007; Zhi You, 2008; IAASTD, 2009b)

Water use efficiency in irrigation systems needs to be disaggregated into conveyance, distribution and field application efficiency. Improved irrigation water management requires considering the efficiency of the whole system. Figure 6 illustrates the sequences of water losses, and Table 2 indicates the efficiency of different irrigation systems.

Table 2: Irrigation efficiency of different irrigation systems.

Irrigation System	Irrigation efficiency	Installation costs
Flooded fields (e.g. rice)	20–50%	low
Other surface irrigation (furrows etc.)	50–60% and higher	low
Sprinkler irrigation	50–70%	medium-high
Drip irrigation	80–90%	high

(Source: Studer, 2009)

Given water scarcity and widespread water wastage and poor management, best practices for irrigated agriculture include the following:

1. Increased water use efficiency: in conveying and distributing irrigation water as well as applying it in the field. Conveyance and distribution can be improved through well maintained, lined canals and piping systems – and above all avoiding leakages. In the field, reducing evaporation losses can be achieved by using low pressure sprinkler irrigation during the night or early morning, and avoiding irrigation when windy. Additionally, deep seepage of water beyond rooting depth needs to be avoided.

2. Spread of limited irrigation water over a larger area, thereby not fully satisfying the crop water requirements i.e. deficit irrigation. It allows achieving considerably higher total crop yields and water use efficiency compared to using water for full irrigation on a smaller area (Oweis and Hachum, 2001).

3. Supplementary irrigation by complementing rain during periods of water deficits, at water-stress sensitivity stages in plant growth. Supplementary irrigation is a key strategy, still underused, for unlocking rainfed yield potential and water productivity / water use efficiency.

Supplementary irrigation

– Yields of sorghum in Burkina Faso and maize in Kenya were increased from 0.5 to 1.5–2.0 metric tonnes per hectare with supplementary irrigation plus soil fertility management (Rockström et al., 2003; Molden et al., 2007).
– A cost-benefit study of maize-tomato cropping systems using supplementary irrigation found annual net profits of US$ 73 in Burkina Faso and US$ 390 in Kenya per hectare. In comparison traditional systems showed net income losses of US$ 165 and US$ 221, respectively (Fox et al., 2005).

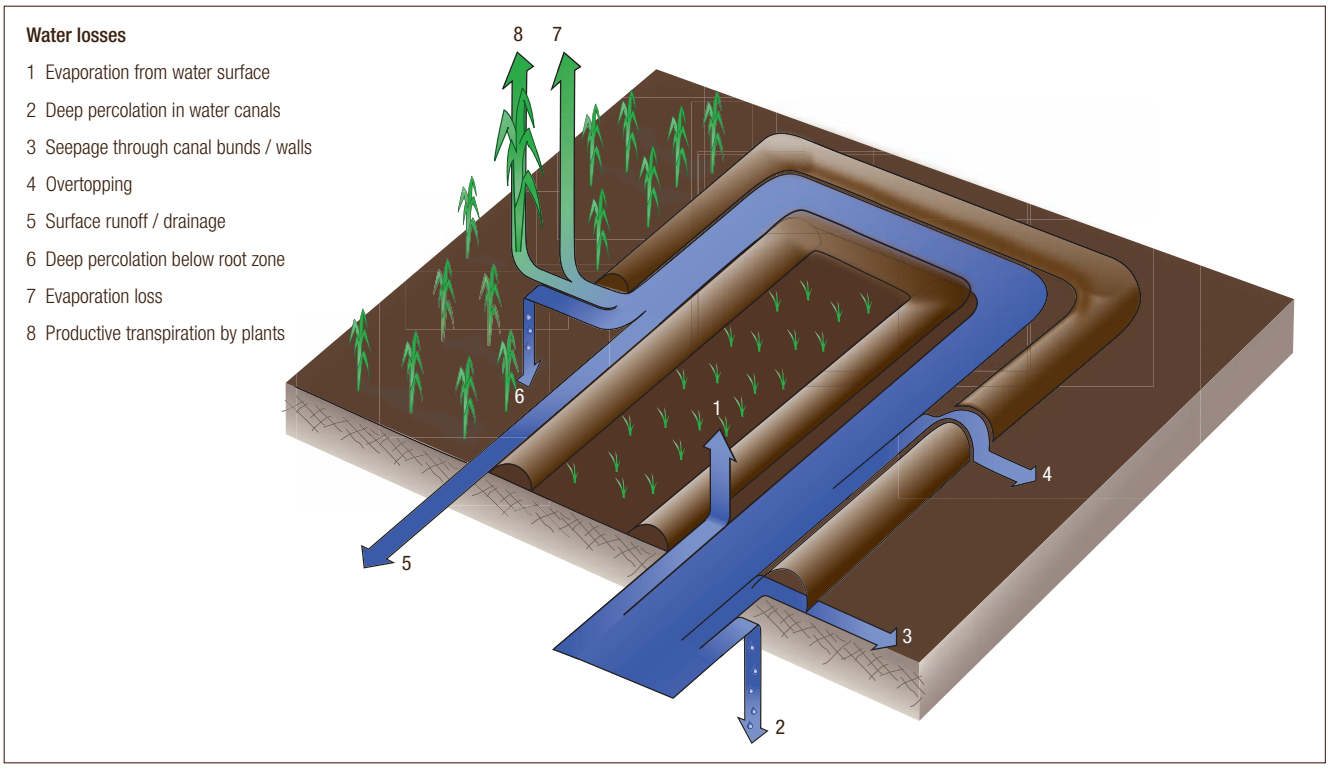


Figure 6: Water losses in irrigation systems: from source to plant illustrating the small fraction of water used productively for plant growth compared to the total water directed to irrigation systems (based on Studer, 2009).

4. Water harvesting and improved water storage for irrigation during times of surplus and using the water for (supplementary) irrigation during times of water stress. Small dams and other storage facilities as described in the SLM group of rainwater harvesting, which are combined with community level water management, need to be explored as alternatives to large-scale irrigation projects (IAASTD, 2009b).

5. Integrated irrigation management is a wider concept going beyond technical aspects and including all dimensions of sustainability. It embraces coordinated water management, maximised economic and social welfare, assured equitable access to water and water services, without compromising the sustainability of ecosystems (Studer, 2009).

Improving water productivity in rainfed and irrigated agriculture (Principles)

'More crop per drop' by:

– reducing water loss

– harvesting water

– maximising water storage

– managing excess water

Any efforts towards better water management must be combined with improved soil, nutrient, and crop management, and these synergies can more than double water productivity and yields in small-scale agriculture (Rockström et al, 2007).

There is need for a 'green water revolution' to explore the potential of increasing water use efficiency for improved land productivity. First, priority must be given to improved water use efficiency in rainfed agriculture; here is the greatest potential for improvements not only related to yields but also in optimising all round benefits. Practices that improve water availability relate to soil cover and soil organic matter improvement, measures to reduce surface runoff (see 'Cross-Slope Barriers') as well as to collect and harvest water.

For irrigated agriculture, conveyance and distribution efficiency are key additional water saving strategies. The emphasis should be on 'upgrading' rainfed agriculture with water efficient supplementary irrigation.

Soil fertility

Healthy and fertile soil is the foundation for land productivity. Plants obtain nutrients from two natural sources: organic matter and minerals. Reduced soil fertility undermines the production of food, fodder, fuel and fibre. Soil organic matter, nutrients and soil structure are the main factors influencing soil fertility. Many of Africa's soils are heavily depleted of nutrients, and soil organic matter is very low: below 1.0% or even 0.5% in the top soil (Bot and Benites, 2005).

Soil organic matter is a key to soil fertility. Organic matter includes any plant or animal material that returns to the soil and goes through the decomposition cycle. Soil organic matter (SOM) is a revolving nutrient fund: it contains all of the essential plant nutrients, and it helps to absorb and hold nutrients in an available form (Bot and Benites, 2005). Soil organic matter has multiple benefits; it is also fundamental for good soil structure through the binding of soil particles, for water holding capacity, and it provides a habitat for soil organisms.

Soil texture also influences soil fertility. The presence of clay particles influences the soil's ability to hold nutrients. Very sandy soils usually have a lower nutrient holding capacity than clay soils, and hence need particular attention in terms of soil fertility management.

Declining soil fertility: The reason for a decline in SOM and the closely linked nutrient content is simply that the biomass and nutrient cycle (Figure 7) is not sustained, meaning more material in the form of soil organic matter and / or nutrients (especially the macro-nutrients of nitrogen, phosphorous and potassium) leaves the system than is replenished. This results from various causes:

- removal of crop products and residues (plant biomass),
- loss through soil erosion,
- leaching of nutrients (below the rooting depth),
- volatisation of nutrients (e.g. nitrogen),
- accelerated mineralisation of SOM through tillage.

The gains or replenishments are derived from residues of plants grown or nutrient accumulation (e.g. nitrogen fixing), external input of organic matter, manure and fertilizer, and nutrients through the weathering and formation of the soil.

Nutrient deficit in SSA's soils

Nutrient depletion in African soils is serious:

– Soils on cropland have been depleted by about 22 kg nitrogen (N), 2.5 kg phosphorus (P), and 15 kg potassium (K) per hectare per year.
– Nutrient losses due to erosion range from of 10 to 45 kg of NPK/ha per year.
– 25% of soils are acidic with a deficiency in phosphorus, calcium and magnesium, and toxic levels of aluminium.
– Main contributing factors to nutrient depletion are soil erosion by wind and water, leaching and off-take of produce.

Low use of fertilizer:

– With an average annual application of 8-15 kg/ha, the use of fertilizer in Africa compares very poorly to an average global value of 90 kg/ha.
– Land users in Niger use manure on 30-50% of their fields at a rate of 1.2 tonnes/ha, which results in a production of only about 300 kg grain/ha.

Nutrient amount removed is higher than input:

– Negative nutrient balance in SSA's croplands - with at least 4 times more nutrients removed in harvested products compared with the nutrients returned in the form of manure and fertilizer.
– Current annual rates of nutrient losses are estimated to be 4.4 million tonnes of N, 0.5 million tonnes of P, and 3 million tonnes of K. These losses swamp nutrient additions from chemical fertilizer applications, which equal 0.8, 0.26, and 0.2 million tonnes of N, P, and K, respectively.
– Negative nutrient balance: 8 million tonnes of NPK/year.

(Sources: Sanchez et al., 1997; Sanchez, 2002; FAOSTAT, 2004; McCann, 2005; Henao and Baanante, 2006; Verchot, et al, 2007; Aune and Bationo, 2008; WB, 2010)

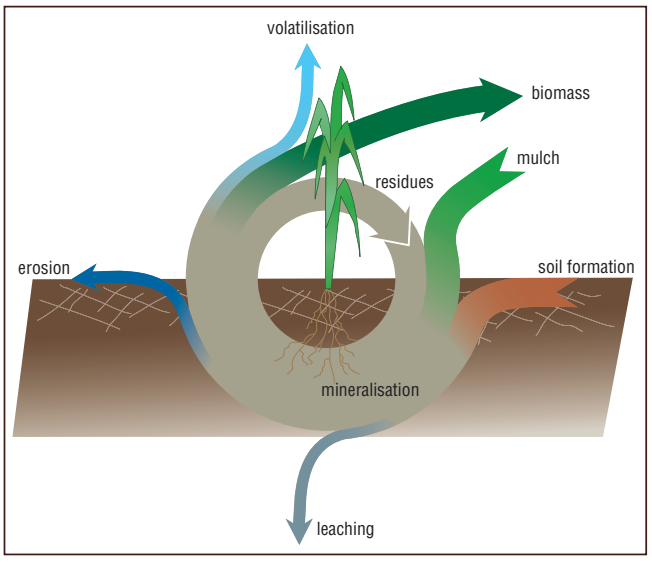


Figure 7: The nutrient and carbon cycle showing the main losses and gains / replenishments of soil organic matter, biomass and nutrients.

Enhancing and improving soil fertility through SLM: SLM practices should maintain or improve a balanced SOM–nutrient cycle, meaning that net losses should be eliminated and organic matter and / or nutrients added to stabilise or improve the soil fertility.

Replenishment of soil nutrients is a major challenge for SSA. As illustrated in the box on page 28, SSA soils have a significantly negative nutrient balance. Replenishment and reduced loss of soil nutrients can be achieved through the following options:

1. Improved fallow-systems: The deliberate planting of fast-growing species - usually leguminous - into a fallow for rapid replenishment of soil fertility. These can range from forest to bush, savannas, grass and legume fallows. The case study on 'Green Manuring with Tithonia' in Cameroon presented in Part 2 shows the importance of nutrient fixing plants planted either in sequence, intercropped or in rotation.

2. Residue management: A practice that ideally leaves 30% or more of the soil surface covered with crop residues after harvest. It requires residue from the previous crop as the main resource (thus burning is discouraged) – it also helps reducing erosion, improving water infiltration and therefore moisture conservation. There are positive impacts also on soil structure and surface water quality (see SLM group 'Conservation Agriculture').

3. Application of improved compost and manure: Compost (mainly from plant residues) and manure (from domestic livestock) help to close the nutrient cycle by ensuring that these do not become losses to the system. By building up SOM they help maintain soil structure and health, as well as fertility. Furthermore they are within the reach of the poorest farmers (see case studies on: 'Night Coralling' in Niger and 'Compost Production' in Burkina Faso).

4. Tapping nutrients: This takes place through the roots of trees and other perennial plants when mixed with annual crops (e.g. in agroforestry systems). Trees act as nutrient pumps: that is they take up nutrients from the deep subsoil below the rooting depth of annual crops and return them to the topsoil in the form of mulch and litter. This enhances the availability of nutrients for annual crops.



Composting, manuring and mulching in a banana plantation, Uganda. (William Critchley)

5. Application of inorganic fertilizer: Inorganic fertilizers are derived from synthetic chemicals and / or minerals. However there is a debate around the use of fertilizer in SSA. The mainstream view is that fertilizer use needs to be increased from the current annual average of about 9 kg/ha to at least 30 kg/ha. The other side points towards undesirable environmental impacts, such as soil acidification, water pollution and health problems (IAASTD, 2009b). However, without a combination of organic matter application and inorganic fertilizer, soil fertility is unlikely to meet production demands: thus the concept of 'Integrated Soil Fertility Management' should be supported. The examples of 'Microfertilization' in Mali and 'Precision Conservation Agriculture' in Zimbabwe presented in Part 2 show that it is possible to substantially increase millet and sorghum yields and profitability by using micro-doses of inorganic fertilizer in combination with techniques that conserve and concentrate soil moisture and organic matter.

6. Minimum soil disturbance: Tillage systems with minimum soil disturbance such as reduced or zero tillage systems leave more biological surface residues, provide environments for enhanced soil biotic activity, and maintain more intact and interconnected pores and better soil aggregates, which are able to withstand raindrop impact (and thus reduce splash erosion). Water can infiltrate more readily and rapidly into the soil with reduced tillage, and this also helps protect the soil from

erosion. In addition, organic matter decomposes less rapidly under these systems. Carbon dioxide emissions are thus reduced. No tillage, as described in the case studies on large and small scale conservation tillage in Kenya presented in Part 2, has proven especially useful for maintaining and increasing soil organic matter.

Improving soil fertility and the nutrient cycle (Principles)

– Reduce 'unproductive' nutrient losses: leaching, erosion, loss to atmosphere.
– Reduce mining of soil fertility: improve balance between removal and supply of nutrients - this is achieved through:
  – cover improvement (mulch and plant cover),
  – improvement of soil organic matter and soil structure,
  – crop rotation, fallow and intercropping,
  – application of animal and green manure, and compost (integrated crop-livestock systems),
  – appropriate supplementation with inorganic fertilizer,
  – trapping sediments and nutrients (e.g. through bunds; vegetative or structural barriers / traps).

These should be enhanced through improved water management and an improved micro-climate to reduce losses and maintain moisture.

Plants and their management

Improved agronomy is an essential supplement to good SLM practices. The Green Revolution in Asia made great advances in increasing agricultural production in the 1960s and 70s based on improved agronomic practices. As illustrated in figure 2, Africa has, over the last 50 years, increased its agricultural production mainly through expansion of agricultural land. The 'original' Green Revolution has largely failed in Africa (see next box) although achievements in crop breeding have been made and efforts are still ongoing to achieve the following:

- higher yielding varieties,
- early growth vigour to reduce evaporation loss,
- short growing period and drought resilience,
- better water use efficiency / water productivity in water scarce areas,
- tolerance to salinity, acidity and / or water logging,
- disease and pest resistance.

'Improved' varieties have potential advantages but their additional demands on applications of fertilizers, pesticides or herbicides need to be taken into account – as does costs and supply of seeds. They often create dependency on seed producers.

Organic agriculture and low external input agriculture have emerged in response to these concerns – but also because they relate more closely to the traditions and values of African agriculture. Organic agriculture improves production by optimising available resources, maximising nutrient recycling and water conservation. According to IFOAM (2009) organic agriculture is based on the principles of health, ecology, fairness and care. In Part 2 an example on 'Organic Cotton' in Burkina Faso is presented. All the strategies involved seek to make the best use of local resources.

Some advancements and drawbacks of the 'Green Revolution' in SSA

Cereal yields have remained largely stagnant at around 1 tonne/ha from the 1960s to 2000 in the SSA region. This is in stark contrast to the experience of the 'original' Green Revolution in Asia during the 1960s and 70s. Here, intensified production of cereals (especially wheat and rice) led to large production increases due to the introduction of new, high-yielding varieties. The new varieties however required irrigation and large amounts of chemical fertilizers and pesticides to produce their high yields. This then raised concerns about costs and potentially harmful environmental effects. It led to a loss of agro-biodiversity and the genetic pool through dependence on monocultures and replacement of land races (FAO, 2008a).

Agricultural intensification in SSA has largely failed because it has not addressed (1) depletion of organic matter through removal of crop residues for fodder and fuel, insufficient return of organic matter to the soil – causing low response to fertilizers; (2) degradation of soil structure through reduced organic matter combined with destructive tillage practices – leading to compaction, sealing, crusting, decreased infiltration and increased erosion; (3) adverse changes in the soil nutrient balance due to failure to replace essential nutrients removed from the soil and / or imbalanced fertilizer application – e.g. pushing production with nitrogen application but not replacing other essential nutrients, which become the limiting factor; (4) pollution of soil and water though inappropriate application of fertilizers, pesticides and herbicides.

(Source: IAASTD, 2009b)

A major limiting factor to plant productivity are weeds. Good SLM practices can reduce the weed infestation considerably by providing cover by crops, residues and mulch, and by minimum soil disturbance. On grazing land the control of undesirable species should be a key focus. In forests the problem of invasives is also a concern.

Adverse impacts of pest and diseases are various and a major threat to agricultural production. One way forward that resonates with SLM is to select more resistant species and varieties and follow the principles of integrated pest management (IPM) using biological and natural mechanisms as far as possible. IPM is an ecological approach with the main goal of significantly reducing or even eliminating the use of pesticides, through managing pest populations at an acceptable level as described in the case study 'Push-pull integrated pest and soil fertility management' from Kenya presented in Part 2.

However, improved agricultural production does not help if the post harvest management is lacking. Given the high rates of post harvest losses (reaching 30-100%), major efforts are needed to secure the harvest from damage.

A 'new' green revolution? The aim of a 'new' green revolution in SSA is to promote rapid and sustainable agricultural growth based on the smallholder farmer sector with minimal resources (and minimal government support), to ensure that smallholders have good seeds and healthy soils, access to markets, information, financing, storage and transport and last, but not least, policies that provide them with comprehensive support (TerrAfrica, 2009). In contrast to the 'original' green revolution in Asia, the 'new' green revolution intends to be both pro-poor and pro-environment.

Statement by Kofi A. Annan

Chair of the Board of the Alliance for a Green Revolution in Africa (AGRA)

'…..To feed the continent's 900 million people, Africa needs its own food security. This can only be achieved through an uniquely African Green Revolution. It must be a revolution that recognises that smallholder farmers are the key to increasing production, promotes change across the entire agricultural system, and puts fairness and the environment at its heart….. '

(AGRA, 2010)



Screening for drought tolerance of pigeon peas and lablab. (Hanspeter Liniger)

There is still huge potential to increase plant productivity through a 'new' green revolution. The major challenges are the following:

- Using breeding advances while increasing diversity: more productive and resilient varieties of crops, adapted to thrive in a variety of environmental conditions;
- Capitalising on the enormous plant genetic resources in SSA by including local land races and wild varieties into breeding schemes. Exchange of seeds among small-scale farmers is an efficient way to release and spread plant varieties. This includes not only crops but also improved fodder production on grassland / grazing land as well as fibre and fuel production in agroforestry systems and on forest land;
- Recognising that integrated soil fertility management and IPM are key;
- Developing more effective partnerships and networks for an interactive research system - making indigenous knowledge and local innovation available;
- Stressing the role of gender in agriculture: the recognition that the majority of smallholders in SSA are women must be brought into all supporting policy and practice;
- Marketing of produce (including value chain development) and procuring basic inputs are often critical constraints.

Improving planting materials and plant management (Principles)

Improve planting material and minimising impact of weeds, pest and diseases, and post-harvest losses

Through supporting:

– selection and experimentation with local germplasm and exchange of seed materials;
– nutrient and water management of improved plant species and varieties based on locally available inputs (such as manure, compost and micro-dosed application of fertilizers);
– optimising planting dates, planting geometry etc.;
– mixed plant systems to benefit from synergies between different plants (intercropping, relay planting, rotations etc);
– weed management;
– IPM (Integrated Pest Management);
– post harvest management.

Micro-climate

Micro-climate conditions can be substantially influenced by land management, particularly by practices reducing wind and improving shade. Ground cover, be it vegetative or through mulching, is the key factor in determining the micro-climate. Improved micro-climates have the following positive impacts:

1. Improve soil moisture and air humidity: Higher productivity per unit of water is achievable under humid rather than under dry air condition (Tanner and Sinclair, 1983). Evaporation (unproductive water loss from the soil surface) can be minimised by protecting the soil either with crops or mulch material. Practices including mulching, cover cropping, intercropping, agroforestry, shelterbelts, as well as no or minimum tillage protect the soil from excessive heating, exposure to wind and moisture loss, favour moist conditions around plants and improve performance and productivity.

2. Protect from mechanical damage: To protect plants from mechanical impact of heavy rain, storms and wind, dust and sand storms a 'protective' micro-climate can be created through the improvement of cover, for example establishing trees as shelterbelts and windbreaks.

3. Balancing temperature extremes and radiation: Excessive soil and air temperatures and radiation during hot seasons or spells can be reduced to favour plant (and animal) production through increased cover and shade. This is preferably achieved through increased vegetative cover as the evapotranspiration has a cooling effect, creating a favourable micro-climate. In highlands and mountains in SSA the constraint is high fluctuations with low minimum temperatures. This is particularly an issue in the highlands of Ethiopia, and in eastern and southern Africa where crops are grown over 3,000 m altitude. In southern Africa cold is an issue in winter. In these environments trees and cover can protect again cold winds - but the shading may slow down the warming up of the soil.

Creation of a favourable micro-climate (Principles)

In dry and warm areas:

– reduce strong winds and storms (avoid drying out and mechanical damage);
– protect against high temperature and radiation;
– keep conditions as moist as possible;

In humid areas:

– protect against storms (mechanical impact and soil degradation).

All of these improvements can be achieved through windbreaks, shelterbelts, agroforestry, multistorey cropping and good soil cover through vegetation or mulch.

In cold highlands and southern Africa with winter seasons land management may need to protect crops against cold winds or frost.

Improved livelihoods

There would be little importance attached to SLM - and its uptake - if the livelihoods of millions were not at stake. Increased and sustained agricultural production, the provision and securing of clean water and maintaining a healthy environment are essential for improved livelihoods in SSA. Despite the constraints and problems land users have, they are willing to adopt SLM practices that provide them with higher net returns, lower risks or a combination of both.

Costs and benefits

For improved livelihoods and for adoption and spreading of SLM, costs and benefits play a central role. Given the urgent needs in SSA, investments in SLM should aim at both short-term (rapid) and long-term (sustained) paybacks. Thus inputs for both initial establishment and continued maintenance afterwards need to be compared with benefits. Figure 8 illustrates the different positive paybacks from SLM interventions:

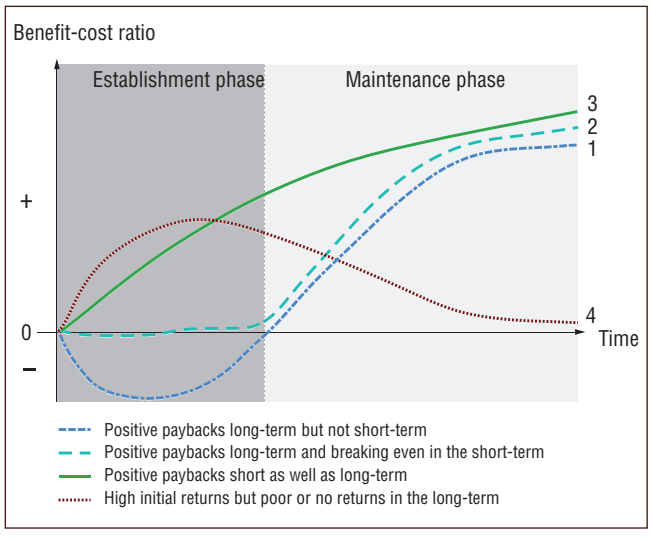


Figure 8: Benefits and costs of SLM over time, short-term establishment phase and long-term maintenance phase.

1 Long-term but not short-term: many land users in SSA might be constrained to make these long-term investments, thus might need a kick-start, where the establishment costs are partly funded by aid and external sources. The maintenance costs however would need to be covered by local sources and direct paybacks.

2 Long-term and breaking even in the short-term: thus increased benefits but also higher inputs. Depending on the wealth of the land users, the initial investments are not possible without external assistance (see scenario 1).

3 Short as well as long-term: This is the ideal case, where land users receive rewards right from the beginning. The question remains whether they need some initial support for investments (micro-credit, loans, access to inputs and markets etc). However, due to the rapid and continuous returns, land users have the possibility of paying back loans and credits quickly.

4 High initial returns but poor or no returns in the long-term: These options are tempting for land users but will lose attractiveness in the long-run as the returns are not sustained. This has occurred where high yielding varieties and inorganic fertilizers were applied but yield responses fell away after a few years (see box 'Green Revolution' page 30).

While establishment costs can be partly funded by aid and external sources, maintenance costs must be covered locally by land users to avoid the 'dependency syndrome' of continuous aid and to ensure self-initiative and ownership.

Experiences with implementation of SLM, show the need for accurate assessment of benefits and costs (in monetary and non-monetary terms) and short- and long-term gains. However, this is seldom done and data are few. Assessments of benefits and costs are very site specific and therefore pose a great challenge for the spread of SLM in SSA. Without proper assessments, land users and development agencies cannot make informed decisions about which technologies and approaches are the most viable options for a particular natural and human environment - and where incentives for land users are needed.

Inputs challenges for land users

Land users may require additional inputs to take up SLM practices. These are related to materials (machinery, seeds, fertilizers, equipment, etc.), labour, markets, and knowledge. Some of the SLM practices require few extra or different inputs and little change compared to current practices; others mean a complete change in machinery, inputs and management. Some considerations are:

- Small-scale land users in subsistence agriculture have fewer options and resources to invest than commercial or large-scale farmers with a high level of mechanisation.

- A clear distinction between initial investment for the establishment and the maintenance of SLM practices is essential. Initial investment constraints need to be overcome and may require external assistance especially when benefits mainly accrue in the long-term. Thus any material and financial support should build on currently available resources. Special attention needs to be given to poor and marginalised land users.



High labour costs for ridging and low returns (left) compared to less demanding mulching with high benefits (right). (Hanspeter Liniger)

- Labour availability is a major concern and depends on the health of people and competition with other income generating activities. Malaria, HIV-AIDS and water-borne diseases significantly affect labour productivity. Conflicts with off-farm work, including the seasonal migration of labour force (often men) can be a major constraint for SLM. Single (often female) headed rural households need practices with reduced labour inputs.

- Access to inputs and equipment such as machinery, seeds / seedlings, fertilizers, etc. is essential. Introduction of SLM is only possible if markets for inputs and products are secured.

- Access to knowledge related to SLM practices and their introduction is a prerequisite for all land users. Practices that are easy to learn, and build on existing experiences and knowledge, have the best chance of being taken up.

Apart from the costs, benefits, access to inputs, markets and knowledge, there are other elements related to improved livelihoods such as the need for practices to be:

- socially and culturally acceptable: aesthetics (a non-linear contour may be visually unacceptable for example) and beliefs (some areas are 'untouchable' because of spirits) norms and values;
- flexible enough to allow (and even encourage) local adaptation and innovation;
- clearly seen to add value to the land and to the quality of life.

Improving livelihoods (Principles)

– provision of short (rapid) and long-term (sustained) benefits
– assistance for establishment might be needed for small-scale subsistence land users if costs are beyond land users' means
– assistance for establishment if short-term benefits are not guaranteed
– maintenance costs need to be covered by the land users to ensure self-initiative

Changes towards SLM should build on – and be sensitive to - values and norms, allow flexibility, adaptation and innovation to improve the livelihoods of the land users.

Improved ecosystems: being environmentally friendly

The principles of increased production presented above, to be truly sustainable should also aim at improving ecosystem functions and services. Best practices must be environmentally friendly, reduce current land degradation, improve biodiversity and increase resilience to climate variation and change.

Prevent, mitigate and rehabilitate land degradation

Assessments in SSA show the severity of land degradation and the urgency to improve natural resources and their use through SLM (see box page 35).

Depending on what stage of land degradation has been reached, SLM interventions can be differentiated into prevention and mitigation of land degradation or rehabilitation of already degraded land (Figure 9) (WOCAT, 2007).

Prevention implies employment of SLM measures that maintain natural resources and their environmental and productive function on land that may be prone to degradation. The implication is that good land management practice is already in place: it is effectively the antithesis of human induced land degradation.

Mitigation is intervention intended to reduce ongoing degradation. This comes in at a stage when degradation has already begun. The main aim here is to halt further degradation and to start improving resources and their ecosys-

Land Degradation in Africa:
– 67% of Africa's land is already affected by land degradation. 4 - 7 % of SSA is severely degraded – the highest proportion of any region in the world.
– The cumulative loss of productivity is: 25% of cropland, 6.6% of pasture land.
– Soil degradation in Africa is attributable to: overgrazing (50%); poor agricultural management practices (24%); vegetation removal (14%); and overexploitation (13%).

Soil erosion by water and wind: mainly loss of topsoil / surface erosion, gully erosion and offsite degradation effects.
– Annual yield losses due to soil erosion estimated as averaging 6.2 %.
– Erosion by water: 46% of land area.
– Erosion by wind 38% of land area mainly in drylands.

Chemical soil degradation: mainly fertility decline and reduced organic matter content, salinisation.
– Four times the amount of nutrients removed in cropland compared to the amount returned with manure and fertilizer. Africa loses an equivalent of 4 billion USD per year due to soil nutrient mining.
– 30% of irrigated land lost due to salinisation: Kenya (30%), Namibia (17%), Nigeria (34%), Sudan (27%) and Tanzania (27%).
– Losses of irrigated land due to waterlogging: DR Congo (20%), Mauritania (50%) and Gambia (10%).

Physical soil degradation: compaction, sealing and crusting, waterlogging.

Biological degradation: reduction of vegetation cover, loss of habitats, quantity / biomass decline, detrimental effects of fires, quality and species composition / diversity decline, loss of soil life, increase of pests / diseases, loss of predators.
– Although the continent hosts only 17% of the world's forests, Africa accounted for over half of global deforestation during 1990-2000.
– In most parts of Africa, deforestation rates exceed planting rates by a factor of 30:1. The rate of 0.6 per year for the last 15 years is among the highest globally (largely in humid and sub-humid West Africa).
– 89% of deforestation is attributed to clearing for agriculture. Of these, 54% are attributed to subsistence agriculture and the other 35% to intensive agriculture.
– In South Africa and Lesotho, alien plants cover about 10 million ha (more than 8 percent of total land area), and are spreading at 5% per year

Water degradation: aridification, change in quantity of surface water, change in groundwater / aquifer level, decline of surface water quality, decline of groundwater quality, reduction of the buffering capacity of wetland areas.
– 70% of Africa's soils suffer from periodic moisture stress.
– Some 86% of African soils are under soil moisture stress.
– Water tables have dropped in many regions and many wells have dried up.
– More fluctuations in river, stream and spring flows, with more frequent flooding in the rainy season and longer periods of water shortage in the dry season.

Sources: Oldeman 1994 and 1998; Versveld et al, 1998; Reich et al. 2001; FAOSTAT, 2004; FAO, 2007; SARD, 2007; WOCAT, 2008a; WB, 2010)

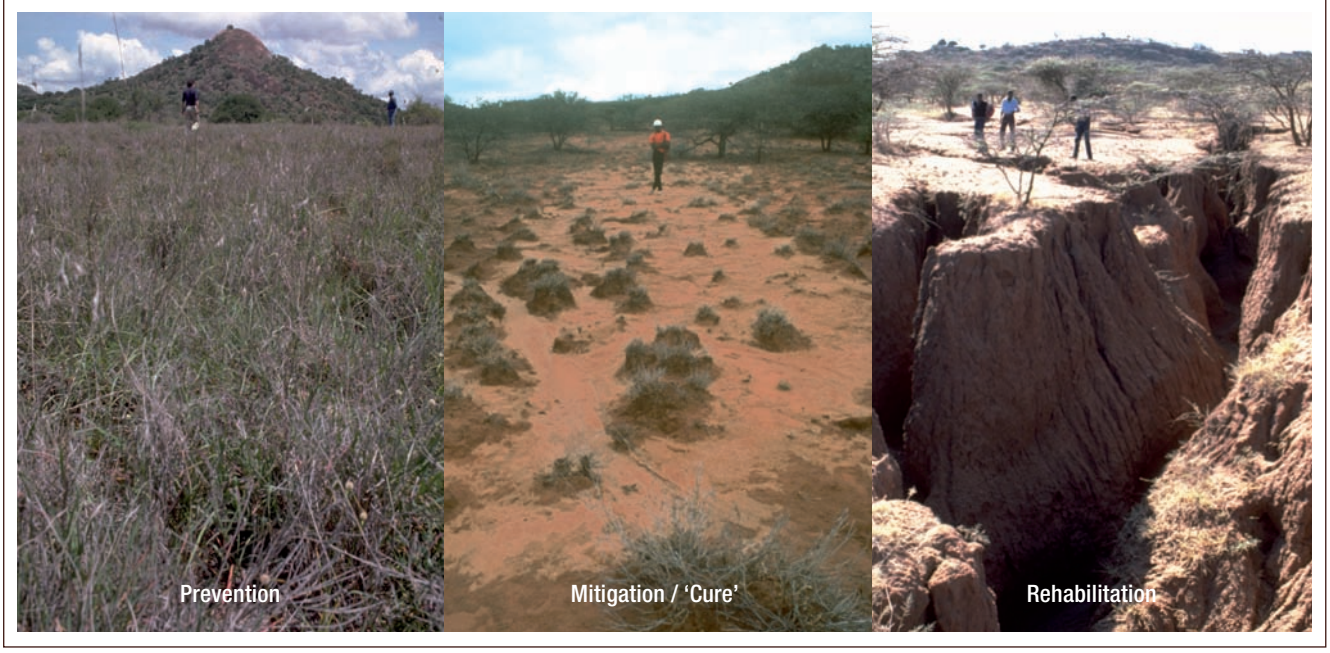


Figure 9: Prevention, mitigation and rehabilitation of land degradation less than half a kilometre apart. (Hanspeter Liniger)

tem functions. Mitigation impacts tend to be noticeable in the short to medium term: this then provides a strong incentive for further efforts.

Rehabilitation is required when the land is already degraded to such an extent that the original use is no longer possible, and land has become practically unproductive and the ecosystem seriously disturbed. Rehabilitation usually implies high investment costs with medium- to long-term benefits.

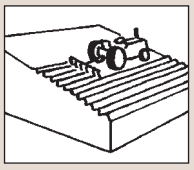
Major efforts and investments have been made in the implementation of structural measures. They are conspicuous in showing efforts made towards SLM. However they are input intensive and often could be substituted by less demanding agronomic, vegetative and management measures. As a rule of thumb priority should be given first to agronomic and / or vegetative measures with as little outside input as possible and only then apply structural measure if the 'cheaper' options are not adequate. In addition, structural measures should be combined as much as possible with vegetative or agronomic measures to protect the structures and make them directly productive (e.g. fodder grass on earth bunds). Frequently, measures can be implemented together, combining different functions and creating synergies. Combinations of measures that lead to integrated soil and water, crop-livestock, fertility and pest managements are promising as they increase both ecosystem - and livelihood - resilience.

Improve biodiversity

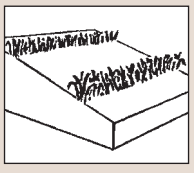
A key concern in sustainable land management and protecting ecosystem functions in SSA is conserving biodiversity. Sub-Saharan Africa has both remarkable richness and abundance of biological diversity. The world's second largest area of rainforest after South America's Amazon Basin is found in Central Africa. It shelters some of the greatest biological diversity of Africa in terms of vegetation and wildlife and plays a vital role in worldwide ecological services

Categories of SLM Measures

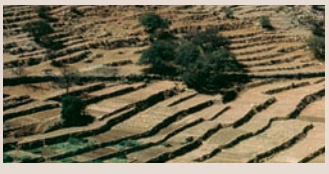
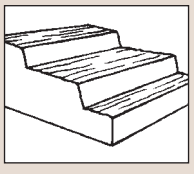
The measures for prevention, mitigation and rehabilitation of land degradation and restoration of ecosystems services can be classified into four categories (WOCAT, 2007):

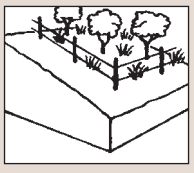
Agronomic measures: measures that improve soil cover (e.g. green cover, mulch); measures that enhance organic matter / soil fertility (e.g. manuring); soil surface treatment (e.g. conservation tillage); subsurface treatment (e.g. deep ripping).

Vegetative measures: plantation / reseeding of tree and shrub species (e.g. live fences; tree crows), grasses and perennial herbaceous plants (e.g. grass strips).

Structural measures: terraces (bench, forward / backward sloping); bunds banks / level, graded); dams, pans; ditches (level, graded); walls, barriers, palisades.

Management measures: change of land use type (e.g. area enclosure); change of management / intensity level (e.g. from grazing to cut-and-carry); major change in timing of activities; control / change of species composition.

Any **combinations** of the above measures are possible, e.g.: Terrace (structural) with grass strips and trees (vegetative) and contour ridges (agronomic).

(Owen, 2004). Furthermore, dryland biodiversity has distinguishable features that are often overlooked. These include heterogeneity, diversity of micro-organisms, presence of wild relatives of globally important domesticated species, and traditionally adapted land use systems (pastoralism, parklands, mixed farming, mixed seed cropping, etc.) (Bonkoungou, 2001; Mortimer, 2009). Sustainable management of natural forests, woodlands, wetlands, grasslands, savannas and deserts results in the protection of biodiversity and environmental quality and at the same time offers opportunities for food security and poverty alleviation. SSA has of the world's most attractive and rich national parks and reserves, which apart from their intrinsic value, offer employment and revenue from tourism.

Women are guardians of West Africa's crop diversity

Women play a dominant role in every part of West Africa's food systems. Often they are responsible for managing small parcels of land on the family farm or for growing food in small gardens around the home. At a time when diets are becoming increasingly simple, and nutritious traditional foods are being replaced by refined carbohydrates and fat, the role of women in promoting diversified diets rich in traditional crops is of vital importance (Smith, 2008).

Plant and animal biodiversity are central to human well-being, most notably in food production but also as a source of fibre for clothing, wood for implements, shelter, and fuel, and for natural medicines, as well as having strong cultural and spiritual significance. Agricultural biodiversity encompasses domesticated crop plants, livestock and fish (etc.), wild crop relatives, wild food sources, and 'associated' biodiversity that supports agricultural production through nutrient recycling, pest control and pollination. Agro-biodiversity is the result of the careful selection and inventive development of land users whose livelihood depends on the sustained management of this biodiversity. Land users value having agricultural biodiversity in their farming systems and small-scale farming is far less of a threat to biodiversity than large-scale mechanised systems (Mortimer, 2009). Promotion of crop genetic diversity is part of their coping strategies for mitigating weather unpredictability; it also spreads availability of food products over time (Bonkoungou, 2001).



Giraffes in the Amboseli Nationalpark, Kenya. (Hanspeter Liniger)

Sub-Saharan Africa is the cradle of vitally important international agro-biodiversity. It is the centre of origin of, for example sorghum (*Sorghum vulgare*) and both bulrush millet (*Pennesetum typhoides*) and finger millet (*Eleusine coracana*), as well as the cowpea (*Vigna unguiculata*) various yams, and coffee (Harrison et al., 1969,1985). There are important endemic species also, such as *rooibos* tea, which is restricted to South Africa. Because African farming depends, still, very largely on local landraces of a wide variety of crops, the wealth of its agro-biodiversity must not be underestimated. In the protection of agro-biodiversity the precautionary principle needs to be applied: maintain as many varieties of plants and domestic animals as possible for their future potential.

Climate change: a fresh challenge – a new opportunity?

Climate change is a major concern for SSA, bringing with it various new challenges. Without doubt, there is huge potential and opportunity for SLM in climate change mitigation and adaptation. Climate change science shows how important the land is, in terms of a carbon source and a carbon sink. SLM practices not only contribute to building up carbon in the land but can also give protection against climate variability. There is evidence of current



Afforestation around Mt. Kenya. (Hanspeter Liniger)

adaptations and innovation in SLM technologies and approaches, demonstrating response to climate change: this experience needs to be acknowledged, investigated and tapped (Woodfine, 2009).

The concept of dealing with environmental (including climate) change is not new to land users. Traditional SLM practices can serve as an entry point for efforts to enhance system resilience, but will not be enough on their own, in the medium to long-term, for coping with climate change (FAO, 2009b). Strong transdisciplinary research efforts are needed, and additional emphasis should be given to monitoring and assessment (M&A) of off-site impacts of land degradation and SLM. Increased occurrence of extreme climatic events leading to disasters such as floods, land slides, mud flows and droughts also have national, and global, impacts. The role of SLM to prevent and / or reduce disasters must be acknowledged and investigated.

Mitigation and adaptation are discussed in the following section. Mitigation in the context of climate change means reducing greenhouse gases and thus their impacts, while adaptation means amending practices to cope with the impacts of changing climate (FAO, 2009b). SLM is concerned with both. With respect to mitigation, SLM practices can help sequester carbon in the vegetation as well as in the soil; in terms of adaptation suitably versatile and 'climate proof' SLM technologies and approaches are key to maintaining productive land and ecosystem function. SLM is good for farmers: it is helpful in the challenges posed by climate change also. Climate change acts as a spur to encourage better SLM – and it provides new funding windows for the reasons set out above.

Mitigation of climate change: Land users in Sub-Saharan Africa can contribute to global efforts to mitigate climate change by adopting SLM technologies that sequester carbon both above and below ground and avoid emissions of greenhouse gases. Various SLM technologies presented in this document can make major contributions, and need to be acknowledged as such. While mitigation of climate change is not a priority for poor farmers, the same SLM practices that benefit them directly, can help sequester carbon and reduce emissions.

Sequestering carbon above and below ground can be achieved through:

- afforestation, reforestation and improved forest management practices;
- agroforestry and silvopastoral systems, integrated crop-livestock systems which combine crops, grazing lands and trees;
- improved management of pastures and grazing practices on natural grasslands, including optimising stock numbers and utilising rotational grazing to maintain ground cover and plant biodiversity;
- improved tillage practices – such as conservation agriculture – to increase soil organic carbon (SOC) content through permanent soil cover with crops and mulch, minimum soil disturbance, fallows, green manures, and crop rotations; and
- micro-dosing with fertilizer to increase biomass production, yields and SOC.

Reducing emissions of carbon dioxide through:

- reduced land degradation and deforestation, loss of biomass and OM;
- reduced use of fire in rangeland and forest management;
- reduced machine hours for agriculture by adoption of conservation tillage practices / conservation agriculture systems; and
- practices requiring lower doses of agrochemicals.

Climate change in Africa

Africa's climate ranges from humid equatorial regimes, through seasonally-arid tropical and hyper-arid regimes, to sub-tropical Mediterranean-type climates. All these climates demonstrate various degrees of variability, particularly with regard to precipitation. Africa is especially vulnerable to climate change because of its geographic exposure, low incomes, and greater reliance on climate sensitive sectors such as agriculture.

Climate change:

– Africa is considered at more risk from climate change than other regions.
– During the 20th century, most of Africa already experienced a warming of approximately 0.7°C and large portions of the Sahel experienced a rainfal decrease: East and Central Africa an increase in precipitation.
– Droughts and floods have increased in frequency and severity across Africa over the past 30 years, particularly in southern and eastern Africa (around the coast of the Indian Ocean e.g. Mozambique).
– Predictions regarding climate changes are uncertain but scenarios indicate additional temperature increase of 3-4°C and rise of sea level by 15-95 cm by 2100, and an increase in the frequency of extreme weather events – droughts, floods and storms. The length of growing period is likely to decrease in many parts of SSA.
– The general trend of currently marginal areas becoming more marginal is apparent. In aggregate, Africa will be left worse-off.

Climate change mitigation:

– Most African countries contribute little to the world's total greenhouse gas emissions.
– Land use change and deforestation in Africa account for 64% of its greenhouse gas emissions.
– 30-50% of savanna is burnt annually in Africa accelerating the release of GHG and the loss of organic matter. Carbon stocks in the soil are more than twice the carbon in living vegetation.
– Above ground carbon stock has been reduced through deforestation and replacement of land use systems with less permanent biomass. Afforestation and reduced deforestation in Africa have the potential to reduce global GHG emissions by about 6.5%.
– Soil organic carbon in most of SSA's drylands has been reduced in the topsoil - due to land degradation - to less than 1%, whereas SLM can increase SOC to a level of 2-3%.

Climate change adaptation:

– Adaptation to climate variability and extremes is not new to land users in SSA. Yet traditional coping strategies are not sufficient, additional and innovative efforts are required.
– Adaptation to high climate variability and more extreme events are a major concern in SSA especially on marginal agricultural prone to desertification.

Environmental impacts of climate change:

– physiological effects on crops, pasture, forests and livestock (quantity, quality)
– changes in land, soil and water resources (quantity, quality)
– changes in and shifts of vegetation
– increased weed and pest challenges
– sea level rise, changes to ocean salinity

Socio-economic impacts of climate change:

– decline in yields and production
– increased number of people at risk of hunger and food insecurity
– reduced marginal GDP from agriculture
– fluctuations in world market prices
– migration and civil unrest

(Sources: Desanker and Magadza, 2001; Desanker, 2002; Stern, 2007; FAO, 2009a; FAO, 2009b; Pender et al., 2009; Woodfine, 2009; WB, 2010)

Reducing emissions of methane and nitrous oxide through:

- improved nutrition for ruminant livestock;
- more efficient management of livestock waste (manure);
- more efficient management of irrigation water on rice paddies; and
- more efficient nitrogen management on cultivated fields, reducing volatile losses through better agronomic practices (rotations, fallows, manuring and micro-dosing).

To increase carbon stocks above ground, afforestation, reforestation and agroforestry systems are important, but additional attention must be given, and efforts made, to restore biomass and ground cover on grasslands (through improved grazing land management) as well as permanent cover on crop land (see SLM group on 'Conservation Agriculture'). Carbon markets for funding the spread need to be further explored and are emerging opportunities (refer to page 45) for land users to implement SLM.

Soil organic carbon (SOC) increase can be achieved by implementing SLM practices which add biomass to the soil, cause minimal soil disturbance, conserve soil and water, improve soil structure, enhance activity and species diversity of soil fauna – increasing 'biological tillage' and strengthen mechanisms of carbon and nutrient cycling (see SLM group on 'Integrated Soil Fertility Management') (FAO, 2009a).