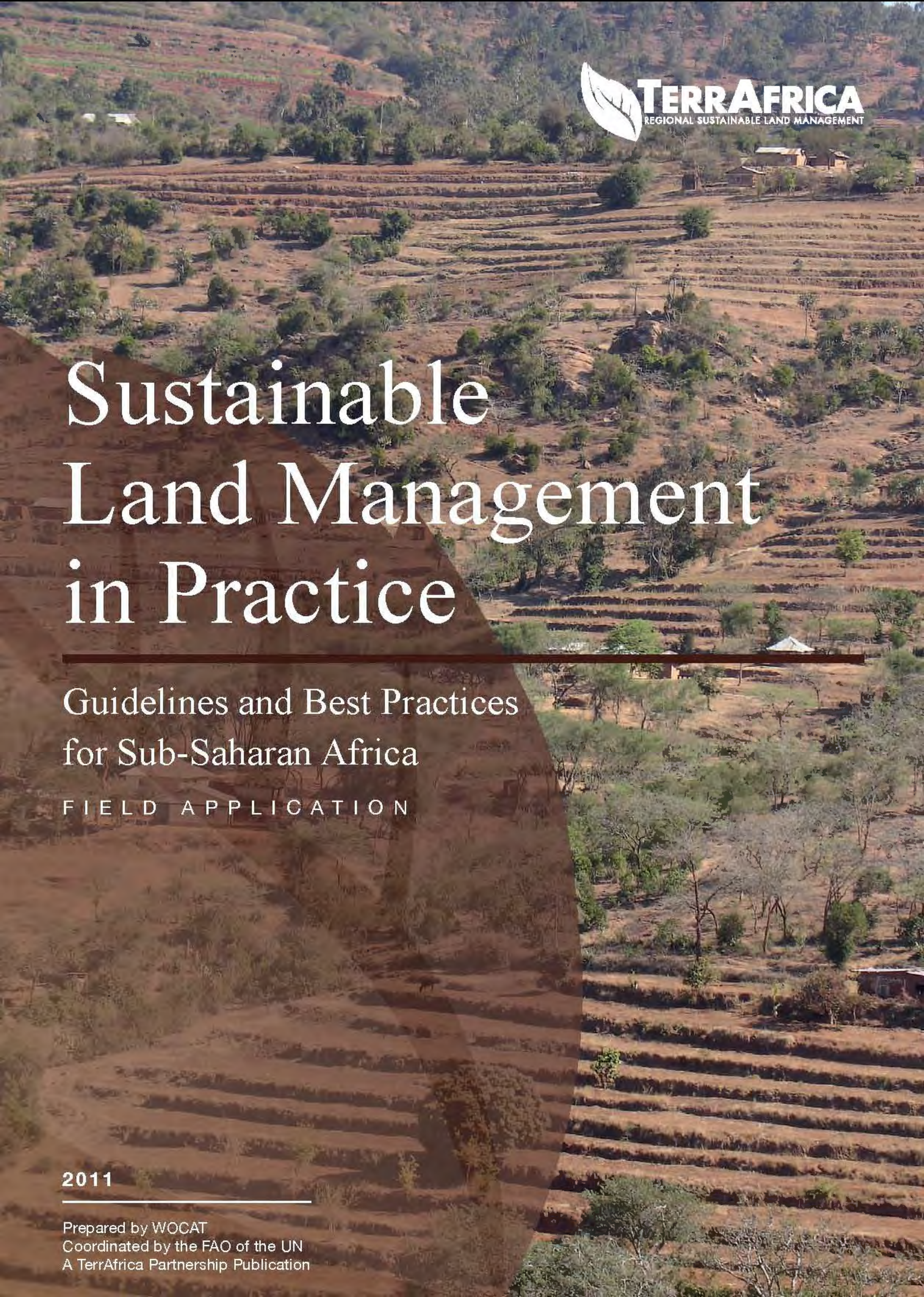


TERRAFRICA
REGIONAL SUSTAINABLE LAND MANAGEMENT

Sustainable Land Management in Practice

Guidelines and Best Practices for Sub-Saharan Africa

FIELD APPLICATION

2011

Prepared by WOCAT
Coordinated by the FAO of the UN
A TerrAfrica Partnership Publication

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views of FAO.

ISBN 978-92-5-000000-0

All rights reserved. FAO encourages reproduction and dissemination of material in this information product. Non-commercial uses will be authorized free of charge, upon request. Reproduction for resale or other commercial purposes, including educational purposes, may incur fees. Applications for permission to reproduce or disseminate FAO copyright materials, and all queries concerning rights and licences, should be addressed by e-mail to copyright@fao.org or to the Chief, Publishing Policy and Support Branch, Office of Knowledge Exchange, Research and Extension, FAO,
Viale delle Terme di Caracalla, 00153 Rome, Italy.

© FAO 2011

Sustainable Land Management in Practice

Guidelines and Best Practices for Sub-Saharan Africa

Authors:	Hanspeter Liniger, Rima Mekdaschi Studer, Christine Hauert, Mats Gurtner Under FAO coordination
Technical Editor:	William Critchley
Charts and Maps:	Ulla Gämperli, Simone Kummer, Chris Hergarten
Layout:	Simone Kummer
Citation:	Liniger, H.P., R. Mekdaschi Studer, C. Hauert and M. Gurtner. 2011. Sustainable Land Management in Practice – Guidelines and Best Practices for Sub-Saharan Africa. TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agriculture Organization of the United Nations (FAO)
Cover photo:	Sustainable Land Management practiced on small-scale farms in Machakos, Kenya: Protection of erosion-prone slopes through hand-dug terraces in combination with agroforestry (Hanspeter Liniger)

Table of Contents

Part 1: Guiding principles

Part 2: Best SLM practices for Sub-Saharan Africa

FOREWORD

Land is the true of wealth of Sub-Saharan Africa (SSA). The region is characterized by a very rich diversity of natural ecosystem resources, including soils, vegetation, water and genetic diversity. Together, these constitute the region's main natural capital. It is from these assets that the provision of food, water, wood, fibre and industrial products, and essential ecosystem services and functions are derived. And they must be maintained in order to support African populations into the future. Simultaneously, it is from the land that 60 percent of the people directly derive their livelihoods - from agriculture, freshwater fisheries, forestry and other natural resources (FAO 2004).

However, African land and water resources in some areas are seriously threatened through overuse although per capita availability is one of the highest in the world. This is a direct result of the increasing needs of a growing population, combined, often, with inappropriate land management practices. Thus, on the one hand, the African population is growing at over two percent a year (FAO 2008), requiring a doubling of food production by 2030 to keep pace with demand; on the other hand, productivity of natural resources is in general in decline. Additionally, the number of natural disasters has increased and climate change is already taking its toll.

A new system of management and governance of land resources is urgently needed; one that is able to respond in a systematic and integrated manner to this key development challenge. Sustainable land management (SLM) is a comprehensive approach, with the potential of making very significant and lasting differences in the near future, and over the long-term. But what is sustainable land management exactly? What are the principles, and above all, the practices that people can use? How can it make a real difference and provide concrete solutions for Africa? These are the key questions that this book wishes to address - and answers are provided through the case studies and analyses.

These guidelines have been developed based on FAO's and WOCAT's extensive experience. The book draws, in particular, on WOCAT's network and its database of SLM knowledge - as well as on WOCAT's first overview book entitled 'Where the land is greener'. These guidelines were implemented in the framework of the TerrAfrica partnership, whose main objective is to mainstream and upscale SLM in SSA, through the leveraging and harmonising of multisectoral investments at the local, country, subregional and regional levels.

This book is aimed at giving a strong boost to the adoption of SLM on the African continent. It is based on scientific and technical as well as practical and operational knowledge. It was written to provide clear guidance to countries, regional institutions and programmes, development partners and land users organizations that are ready and eager to change present investments towards a more sustainable direction.

The book presents 13 major groups of SLM technologies and approaches in a user-friendly manner, exemplified by 47 case studies from all over the region. It should be emphasized that, although comprehensive, these practices are not intended to be prescriptive or top-down, and in most cases can be improved and tailored to different situations. Users are therefore encouraged to adapt and modify them, based on specific conditions, integrating local knowledge and ingenuity.

Furthermore, the book addresses environmental issues that are the most pressing for SSA: thus not just combating land degradation, but also preserving ecosystem functions, ensuring food security, securing water resources within the land and confronting the climate change issues of adaptation and mitigation. Typical situations in SSA are addressed, and the potential for major contributions to improved livelihoods is emphasized.

It is expected that on-going major initiatives, such as country programmes and investment operations supported by TerrAfrica, national action plans and sector investment strategies, the Comprehensive Africa Agriculture Development Programme (CAADP) planning, as well as forest, water resources and climate change initiatives will facilitate operationalization and upscaling of these practices through multi-stakeholder partnerships. It is hoped that all stakeholders will benefit from the invaluable information contained in this guide and participate in the TerrAfrica partnership to expand and document the state of the knowledge.

Jacques Diouf
FAO Director-General

ACKNOWLEDGMENTS

This volume is a core knowledge product for the TerrAfrica platform, prepared under the Food and Agriculture Organisation's (FAO) leadership, and financed by the multi-donor TerrAfrica Leveraging Fund, the World Bank, FAO, Swiss Development Cooperation (SDC) and World Overview of Conservation Approaches and Technologies (WOCAT). These guidelines were prepared by Hanspeter Liniger, Rima Mekdaschi Studer, Christine Hauert and Mats Gurtner, initiated and coordinated by Dominique Lantieri of FAO, edited by William Critchley, CIS, VU-University Amsterdam and received support, technical contributions and reviews from Steve Danyo of the World Bank and Sally Bunning of FAO. The guidelines are based largely on an iterative process that tapped into the collected experiences of people and institutions both inside and outside Africa and could only be realised through the guidance, cooperation, and assistance of many contributors who champion SLM as a way to secure environmentally friendly and climate resilient livelihoods.

The SLM groups as they stand now could not have been realised without the review and technical inputs from the following resource persons: **Integrated Soil Fertility Management:** Jacqueline Gicheru, FAO; Stephen Twomlow, UNEP; Wairimu Mburathi, FAO; **Conservation Agriculture:** Amir Kassam, FAO; Josef Kienzle, FAO; Maimbo Malesu, ICRAF; Ric Coe, ICRAF; Theodor Friedrich, FAO; **Rainwater Harvesting:** Bancy Makanya Mati, ICRAF; Christoph Studer, Swiss College of Agriculture; Maimbo Malesu, ICRAF; Sally Bunning, FAO; **Smallholder Irrigation Management:** Bernard Keraita, IWMI; Chris Morger, Intercooperation; Pay Drechsel, IWMI; Sourakata Bangoura, FAO; Wairimu Mburathi, FAO; **Cross-Slope Barriers:** Hans Hurni, CDE; Jan De Graaff, WUR; Kithinji Mutunga, FAO; **Agroforestry:** Aichi Kityali, ICRAF; Chin Ong; Hubert de Foresta, Institute for Research and Development (IRD); Jeremias Mowo and Ric Coe, ICRAF; **Integrated Crop-Livestock Management:** Jonathan Davies, IUCN; **Pastoralism and Rangeland Management:** Eva Schlecht, University of Kassel; Jonathan Davies, IUCN; Pierre Hiernaux, CESBIO; **Sustainable Planted Forest Management:** Walter Kollert, FAO; **Sustainable Natural Forest Management in Drylands:** Anne Branthomme, FAO; Nora Berrahmouni, FAO; **Sustainable Rainforest Management:** Alain Billand, CIRAD; Carlos de Wasseige, projet FORAF, CIRAD; Nicolas Bayol, 'Forêt Ressources Management' (FRM); Richard Eba'a Atyi, projet FORAF; Robert Nasi, CIFOR; **Trends and new Opportunities:** William Critchley, CIS, VU-University Amsterdam; **SLM Approaches:** William Critchley, CIS, VU-University Amsterdam; Ernst Gabathuler, CDE

The authors are deeply indepted to the following persons who were either authors or contributed to the updating of the in the WOCAT database already existing case studies: Jens Aune, Norwegian University of Life Science, Norway; Sourakata Bangoura, FAO Central África; Jules Bayala, CORAF; Sally Bunning, FAO; Carolina Cenerini, FAO; William Critchley, CIS, VU-University Amsterdam; Daniel Danano, MoARD, Ethiopia; Etienne Jean Pascal De Pury, CEAS Neuchâtel, Switzerland; Toon Defoer, Agriculture R&D consultant, France; Friew Desta, Bureau of Agriculture, SNNPR, Ethiopia; Lopa Dosteus, CARE International, Tanzania; Deborah Duveskog, Regional FFS Advisor, FAO Kenya; Mawussi Gbenonchi, Université de Lomé, Togo; Paolo Groppo, FAO; Abraham Mehari Haile, UNESCO-IHE Institute for Water Education, The Netherlands; Andreas Hemp, University of Bayreuth, Germany; Claudia Hemp, University of Würzburg, Germany; Verina Ingram, CIFOR-Cameroon; Ceris Jones, Agronomica, UK; Franziska Kaguembèga, NGO newTree, Burkina Faso; Zeyaur R. Khan, ICIPE, Kenya; Frederick Kihara, Nanyuki, Kenya; Christian Kull, Monash University, Australia; Lehman Lindeque, Department of Agriculture, Forestry and Fisheries, South Africa; Maimbo Malesu, ICRAF; Joseph Mburu, MoA, Kenya; John Munene Mwaniki, Kenya; Kithinji Mutunga, FAO Kenya; James Njuki, MoA , Kenya; Adamou Oudou Noufou, Niger; Ahmed Oumarou, Ministry of Environment, Niger; Dov Pasternak, ICRISAT, Niger; Jimmy Pittchar, ICIPE, Kenya; Tony Rinaudo, World Vision, Australia; Eva Schlecht, University of Kassel, Germany; Abdoulaye Sambo Soumaila, GREAD, Niger; Déthié Soumaré Ndiaye, Centre de Suivi Ecologique, Senegal; Adjimon Souroudjaye, Volta Environmental Conservation Organization; Jacques Tavares, INIDA, Cape Verde; Donald Thomas, MoA, Kenya; Fabienne Thomas, Switzerland; Stephen Twomlow, UNEP; Larissa Varela, INIDA, Cape Verde; Flurina Wartmann, Biovision Foundation for ecological development, Switzerland; Marco Wopereis, Africa Rice Center, Benin; Lazare Yombi, Helvetas, Burkina Faso; Julie Zähringer, ETH Zürich, Switzerland; Iyob Zeremariam, MoA, Eritrea; Urs Scheidegger, Swiss College of Agriculture, SHL; Martin Dyer, Kisima Farm, Kenya; Bereket Tsehaye, Toker Integrated Communitiy Development, Eritrea

ABBREVIATIONS AND ACRONYMS

AfDB	African Development Bank
AU-NEPAD	African Union - New Partnership of African Development
CABI	Commonwealth Agricultural Bureaux International
CC	Climate Change
CDE	Centre for Development and Environment
CEAS	Centre écologique Albert Schweizer
CESBIO	Centre d'Etudes Spatiales de la BIOsphère
CGIAR	Consultative Group on International Agricultural Research
CIFOR	Centre for International Forestry Research
CIRAD	La recherche agronomique pour le développement; Agricultural Research for Development
CIS	Centre for International Cooperation (VU University Amsterdam)
CTA	Technical Centre for Agricultural and Rural Cooperation
FAO	Food & Agricultural Organization of the United Nations
FFS	Farmer Field School
FORAF	African Forest Observatory
GHG	Greenhouse gases
GREAD	Groupe de Recherche d'Etude et d'Action pour le Développement, Niger
ICIPE	International Centre for Insect Physiology and Ecology – African Insect Science for Food and Health
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
ILEIA	Centre for Learning on Sustainable Agriculture
INIDA	National Agrarian Development Institute, Cape Verde
ISRIC	World Soil Information
IUCN	International Union for Conservation of Nature
IWMI	International Water Management Institute
LADA	Land Degradation Assessment in drylands by FAO
M&A	Monitoring and Assessment
na	not applicable
NGO	Non Governmental Organisation
OECD	Organisation for Economic Co-operation and Development
PES	Payment for Ecosystem Services
PRA	Participatory Rural Appraisal
R&D	Research and Development
SDC	Swiss Development Cooperation
SLM	Sustainable Land Management
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa
SWC	Soil and Water Conservation
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN-REDD	United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degardation
USDA	United States Department of Agriculture
WB	World Bank
WOCAT	World Overview of Conservation Approaches and Technologies
WUR	Wageningen University & Research Centre

EXECUTIVE SUMMARY

PART 1: GUIDING PRINCIPLES

Introduction

Aims and structure

Production of guidelines for best sustainable land management (SLM) technologies and approaches in Sub-Saharan Africa (SSA) has been part of TerrAfrica's programme during 2009-2010. These guidelines and case studies are intended to help create a framework for investment related to SLM in SSA. The particular aim of these guidelines is to identify, analyse, discuss and disseminate promising SLM practices - including both technologies and approaches - in the light of the latest trends and new opportunities. The focus is, in particular, on those practices with rapid payback and profitability and / or other factors that drive adoption.

This document is targeted at key stakeholders in SLM programmes and projects at the design and implementation stages, including practitioners, managers, policy-makers, planners, together with, financial and technical institutions, and donors. The guidelines 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. Part 2 presents twelve groups of SLM technologies as well as a section on SLM approaches. These are supported by specific case studies. Key resource persons and experts on SLM in SSA were asked to assist in finalising the SLM groups and to describe specific case studies. This strives to be a 'state of the art' product.

Focus on Sustainable Land Management in Sub-Saharan Africa

Sub-Saharan Africa is particularly vulnerable to threats of natural resource degradation and poverty. This is due to various factors including a high population growth rate and increasing population pressure, reliance on agriculture that is vulnerable to environmental change, fragile natural resources and ecosystems, high rates of erosion and land degradation, and both low yields and high post-harvest yield losses. On top of this can be added sensitivity to climate variability and long-term climate change,

In SSA concerted efforts to deal with land degradation through SLM must address water scarcity, soil fertility, organic matter and biodiversity. SLM seeks to increase production through both traditional and innovative systems, and to improve resilience to the various environmental threats.

Principles for best SLM practices

Increased land productivity

In order to increase production from the land, water use efficiency and productivity need to be improved. This can be achieved by reducing high water loss through run-off and unperceived evaporation from unprotected soil, harvesting water, improving infiltration, maximising water storage - as well as by upgrading irrigation and managing surplus water. The first priority must be given to improving water use efficiency in rainfed agriculture; here lies the greatest potential for improved yields with all the associated benefits. For irrigated agriculture, conveyance and distribution efficiency are key water-saving strategies. 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.

Soil fertility decline due to unproductive nutrient losses (through leaching, erosion, loss to the atmosphere) and 'nutrient mining' is a major problem in SSA. An improvement to the current imbalance between removal and supply of nutrients can be achieved through various means. These include cover improvement, crop rotation, fallow and intercropping, application of animal and green manure, and compost through integrated crop-livestock systems, appropriate supplementation with inorganic fertilizer and trapping sediments and nutrients e.g. through

Integrated land use system with maize-bean intercropping and grass strips for fodder production in a high potential area (Hanspeter Liniger).

bunds, vegetative or structural barriers / traps. All these are part of an integrated soil fertility management leading to an improvement in soil organic matter and soil structure. Improved agronomy is an essential supplement to good SLM practices. Strategic choice of planting materials that are adapted to drought, pests, diseases, salinity and other constraints, together with effective management is a further opportunity.

Major potential to improve land productivity also lies in improving micro-climatic conditions. A favourable microclimate in dry and warm areas can be created by reducing winds through windbreaks and shelterbelts, protecting against high temperature and radiation (using agroforestry and multistorey cropping) and by keeping conditions as moist as possible. Mulch and plant cover are important in this context. In humid areas the emphasis is on protecting soils against intensive rainfall.

Thus to increase land productivity it is essential to follow and combine the principles of improving water use efficiency and water productivity, increasing soil fertility, managing vegetation and attending to the micro-climate. These synergies can more than double productivity and yields in small-scale agriculture. Further increases in productivity can also be achieved by intensification and / or diversification of production.

Improved livelihoods

Despite the constraints and problems land users have, they are willing to adopt SLM practices if they provide higher net returns, lower risks or a combination of both. Cost efficiency, including short and longterm benefits, is the key issue for adoption of SLM. Land users are more willing to adopt practices that provide rapid and sustained pay-back in terms of food or income. Assistance for establishment of certain measures may be needed for small-scale subsistence land users if costs are beyond their means and if quick benefits are not guaranteed. Maintenance costs need to be covered by the land users to ensure self-initiative. This implies an accurate assessment of costs and benefits in monetary and non-monetary terms: herein lies a significant challenge.

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. Labour and inputs are of concern, especially in areas affected by, for example, outmigration. In these cases especially, SLM practices such as conservation agriculture, with the advantages of reduced labour and inputs, will stand a better chance of being adopted. Changes towards SLM should build on – and be sensitive to - values and norms, allow flexibility, adaptation and innovation to improve livelihoods. Most appropriate is the promotion of SLM practices that are easy to learn and thus require minimal training and capacity building.

Improved ecosystems: being environmentally friendly

Practices, to be truly sustainable, must be environmentally friendly, reduce current land degradation, improve biodiversity and increase resilience to climate variation and change. Given the current state of land in SSA, SLM interventions are vital to prevent, mitigate and rehabilitate land degradation. The main efforts should address the problems of water scarcity, low soil fertility, organic matter and reduced biodiversity. Priority should be given to low-input agronomic and vegetative measures, and only then consider the application of more demanding structural measures. Combinations of measures that lead to integrated soil and water, crop-livestock, fertility and pest management are promising. Spreading of local successes in combating degradation leads to compound impacts – the whole being greater than the sum of the parts - at the watershed, landscape and global levels.

A key concern in SLM and protecting ecosystem function in SSA is conservation of biodiversity. Plant and animal biodiversity are central to human well-being, most notably in supporting food production, but also as a source of fibre, wood, and medicines. They also have cultural, recreational and spiritual significance. 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.

Of immediate importance to people across SSA are the opportunities that SLM practices offer to help adapt to and mitigate climate change (CC). Adaptation to climate change can be achieved by adopting more versatile and CC-resilient technologies – but also through approaches which enhance flexibility and responsiveness to change. Some practices increase the amount of rainfall that infiltrates the soil (e.g. mulching, improved plant cover) as well as improving its capacity to store water (e.g. increased soil organic matter content) - while simultaneously helping protect the soil from extremes of temperature and more intense rainfall. Thus the most appropriate SLM practices for SSA are characterised by tolerance to increased temperatures, to climate variability, and to extreme events. If the SLM principles of improved water, soil fertility and plant management, and micro-climate are considered, the result will be better protection against natural disasters and increased resilience to climate variability and change. Diversification of production is an additional way to increase resilience.

Land users in SSA can also contribute to global efforts in mitigation of climate change primarily by adopting SLM that sequesters atmospheric carbon in the soil and in perennial vegetation. These technologies include afforestation, agroforestry, reduced tillage, improved grazing land management. Greenhouse gas emissions can also be reduced by limiting deforestation, reducing the use of fire, better livestock management, and better agronomic practices. In summary, the principles of improved water use efficiency, soil fertility, plant management and micro-climate underpin the best land management practices and they constitute win-win-win solutions for SSA. The SLM practices presented in Part 2 are based on these principles and contribute to the improvement of land productivity, livelihood and ecosystems.

Adoption and decision support for upscaling best practices

Despite continuous efforts to spread SLM practices adoption is still alarmingly low. Successful adoption of SLM depends on a combination of factors. All must be addressed.

Adoption - uptake and spread

Setting up institutional and policy frameworks to create an enabling environment for the adoption of SLM involves the strengthening of institutional capacities as well as collaboration and networking. Rules, regulations and by-laws need to be established, but must be relevant to be accepted and followed. Resource use rights and access are key entry points that give people individual and / or collective security and motivation for investment. Access to markets, where prices can change quickly, require flexible and adaptable SLM practices, open to innovation. These practices also need to be responsive to new trends and opportunities such as ecotourism or payment for ecosystem services.

A key aspect in adoption and spread of SLM is to ensure genuine participation of land users and professionals during all stages of implementation to incorporate their views and ensure commitment. At the same time off-site (e.g. downstream) interests may restrict freedom at the local level, such as the free use of water for irrigation. But it may equally provide an opportunity for collaboration, resulting in win-win solutions upstream and downstream.

Extension services need to be based on appropriate training and capacity building. These activities should involve individual land users (e.g. through farmer field schools, farmer–to-farmer exchange, support of local promoters) and communities, and not just depend on government agents. Access to credit and financing schemes can be of vital help for rural people starting new SLM initiatives - but may also create dependency if incentives are not used judiciously. Financial support needs to be enhanced for institutions providing advice, plans and decision support to land users.

Monitoring and assessment of SLM practices and their impacts is needed to learn from the wealth of knowledge available. This embraces traditional, innovative, project and research experiences and lessons learnt – both successes and failures. Major efforts are required to fill knowledge gaps and shed light on where and how to invest in the future. While donors request more and better quality data related to spread, impacts and benefit-cost ratios of SLM, there are still too few efforts in assessment and harmonised knowledge management.

Decision support – upscaling SLM

Given the challenge of finding best SLM practices for diverse local conditions, it is essential to provide decision support for local land users and the specialists who advise them - as well as for planners and decision-makers. This requires sound procedures, tapping into existing knowledge and weighing criteria that are important at all levels of scale. A first step is to raise awareness of the importance of, and the need for, investments in knowledge management and decision support mechanisms.

The building up of a common and standardised pool of knowledge related to SLM technologies and approaches for implementation and dissemination provides the basis for successful upscaling. Making this information available, and providing tools for comparing, selecting and fine-tuning SLM practices for different environments, ecological, economic, social and cultural conditions is a further requirement. Proper mapping of SLM practices and their impacts, and comparison of these with areas of land degradation, provides the foundation for deciding where to locate SLM investments that are cost-efficient and have the highest on-site and off-site impacts. Given the limited resources for SLM, decisions must be aimed at maximising impact with the least input.

Future interventions need to promote the development of joint or 'hybrid' innovation that ensures making the best of local and scientific knowledge. However all developments must take into consideration markets, policies and institutional factors that can stimulate widespread smallholder investment.

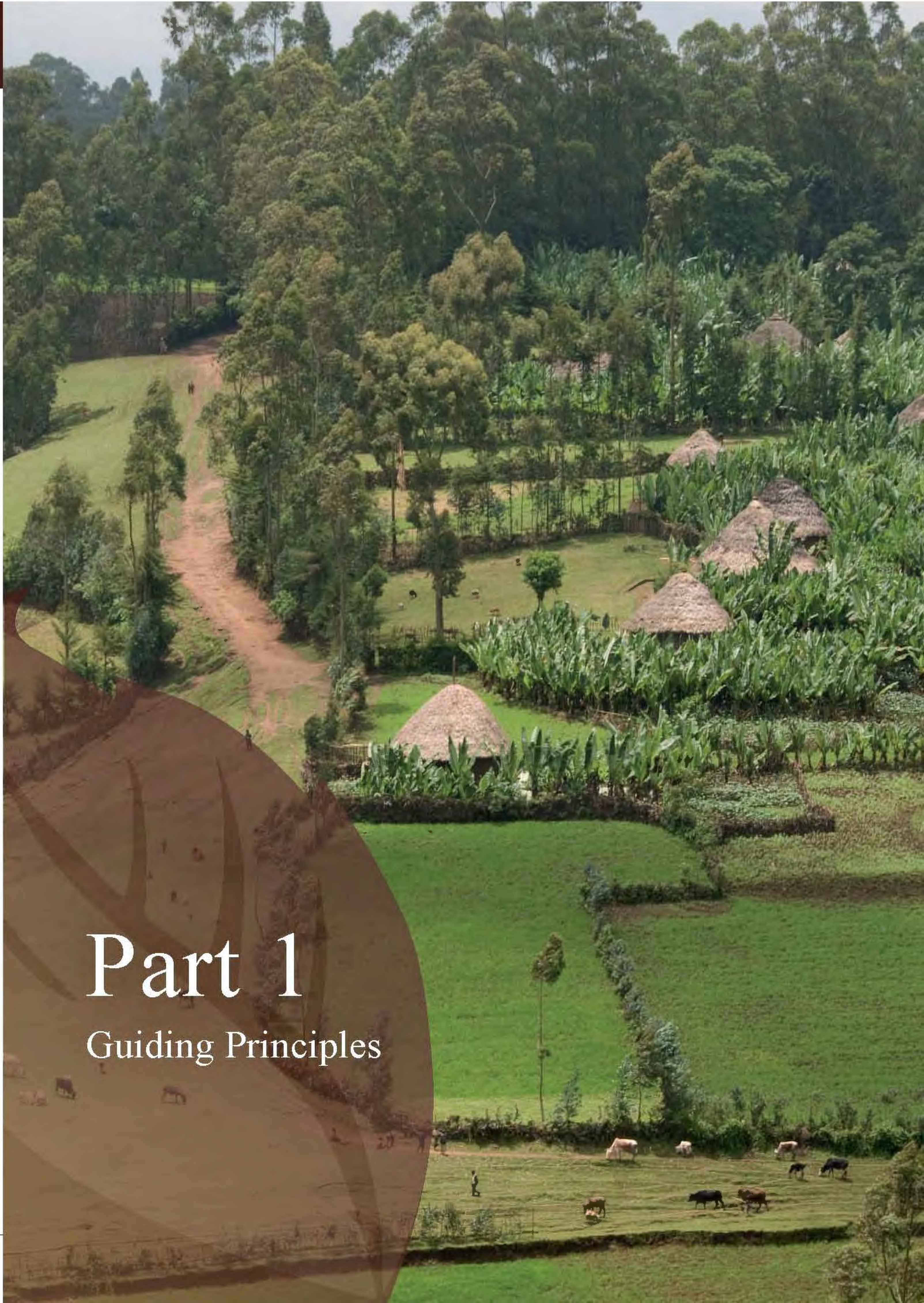
The way forward

Part 1 of the guidelines ends by acknowledging the complexity of sound natural resource management and clearly shows the need for major shifts in emphasis to overcome bottlenecks and barriers to the spread of SLM in SSA. These shifts concern various aspects, at different levels, including technologies and approaches, institutional, policy, governance, economy, knowledge management and capacity building.

Investments in spreading SLM practices in Sub-Saharan Africa have great scope and can provide multiple benefits not only locally, but also regionally nationally and globally. Consolidated action towards better use of valuable knowledge at all levels is needed and will be beneficial in the future, as it can be anticipated that change will be even more pronounced with respect to global markets, climate change, demands on ecosystem services, etc. In short, investment in SLM and a sound knowledge management pays now - and will continue to do in the future.

PART 2: BEST SLM PRACTICES FOR SUB-SAHARAN AFRICA

Twelve groups of SLM technologies backed up by 41 case studies and a section on SLM approaches, with 6 case studies, are presented in Part 2 of the guidelines. The SLM groups follow the principles of best practices: increasing productivity, improving livelihoods and improving ecosystems. The approaches illustrated were proven successful in implementing and spreading of SLM in SSA. All groups and case studies are presented according to the standardised WOCAT format for documenting and disseminating SLM. There is no one miracle solution ('silver bullet') to solve the problems which land users in SSA face. The choice of the most appropriate SLM practice will be determined by the local context and particular situation of local stakeholders.



Part 1

Guiding Principles

Hanspeter Liniger

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.

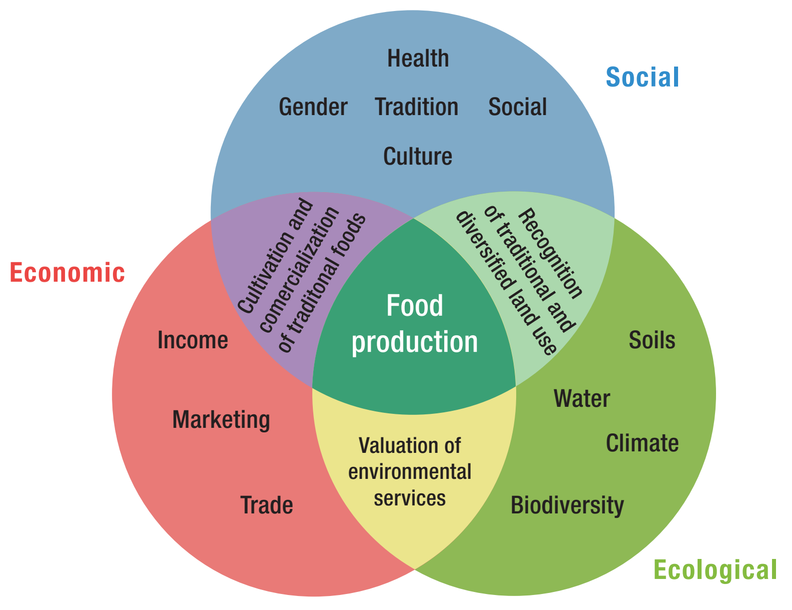


Figure 1: The 3 dimensions of sustainability. (Source: IAASTD, 2009a).


Hanspeter Liniger

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.

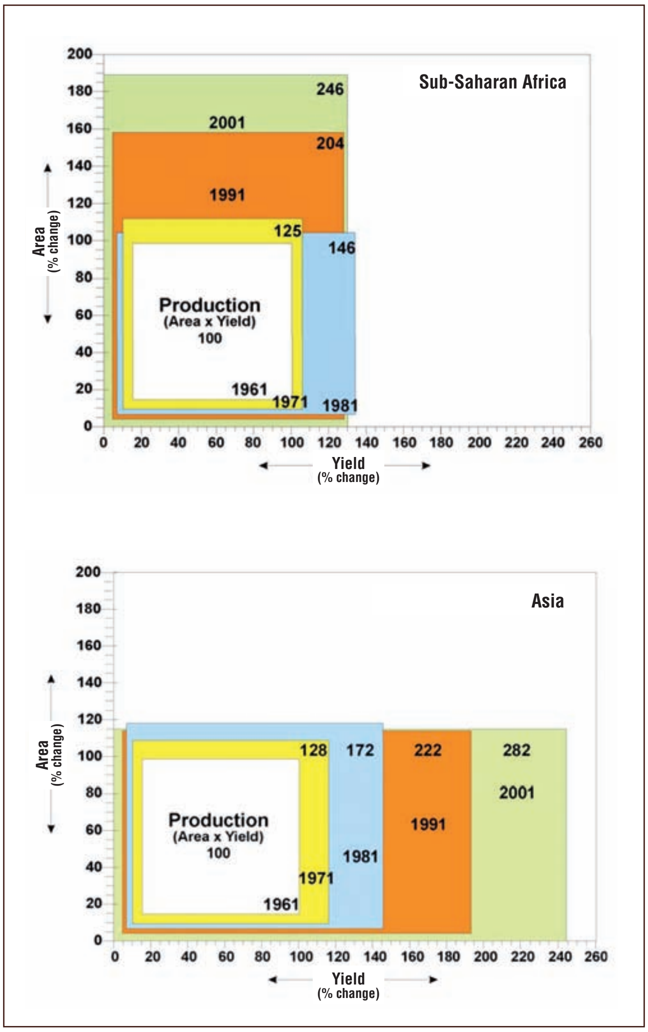


Figure 2: Comparison of changes in cereal production in SSA (above) due to changes in area and yield (1961=100) with those in Asia (below). (Source: Henao and Baanante, 2006)

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 Rockstöm, 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).

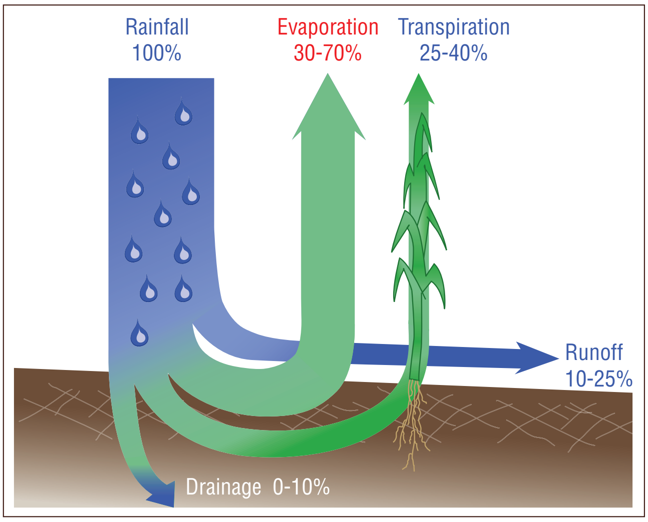


Figure 3: Productive water (transpiration) and water losses (evaporation and runoff) without water conserving measures in dry lands.

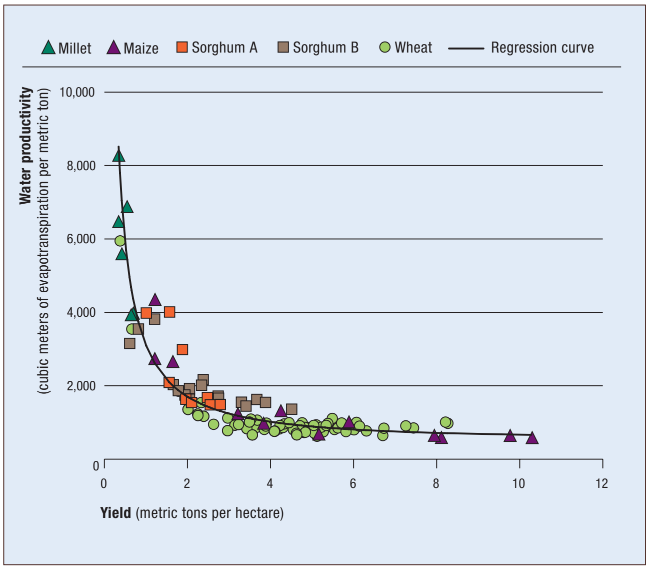


Figure 4: Water productivity and cereal yield under various management and climatic conditions: for cereal yields of less than 1 t/ha four to eight times more water is used per tonne compared to yields above 3 t/ha as the proportion used for grain (cf vegetative production is much less). (Source: Rockström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

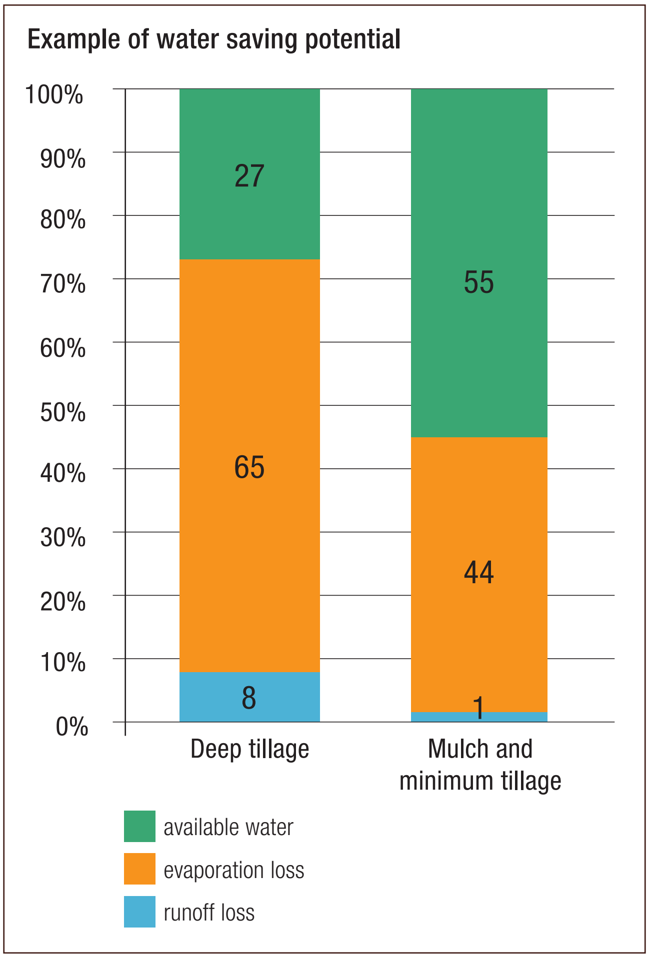


Figure 5: Water use efficiency in a semi-arid to subhumid environment comparing a local practice (deep tillage) with conservation agriculture comprising minimum tillage for weed control, mulching and intercropping of maize and beans. Under the local practice, total water loss was over 70%, with evaporation 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).

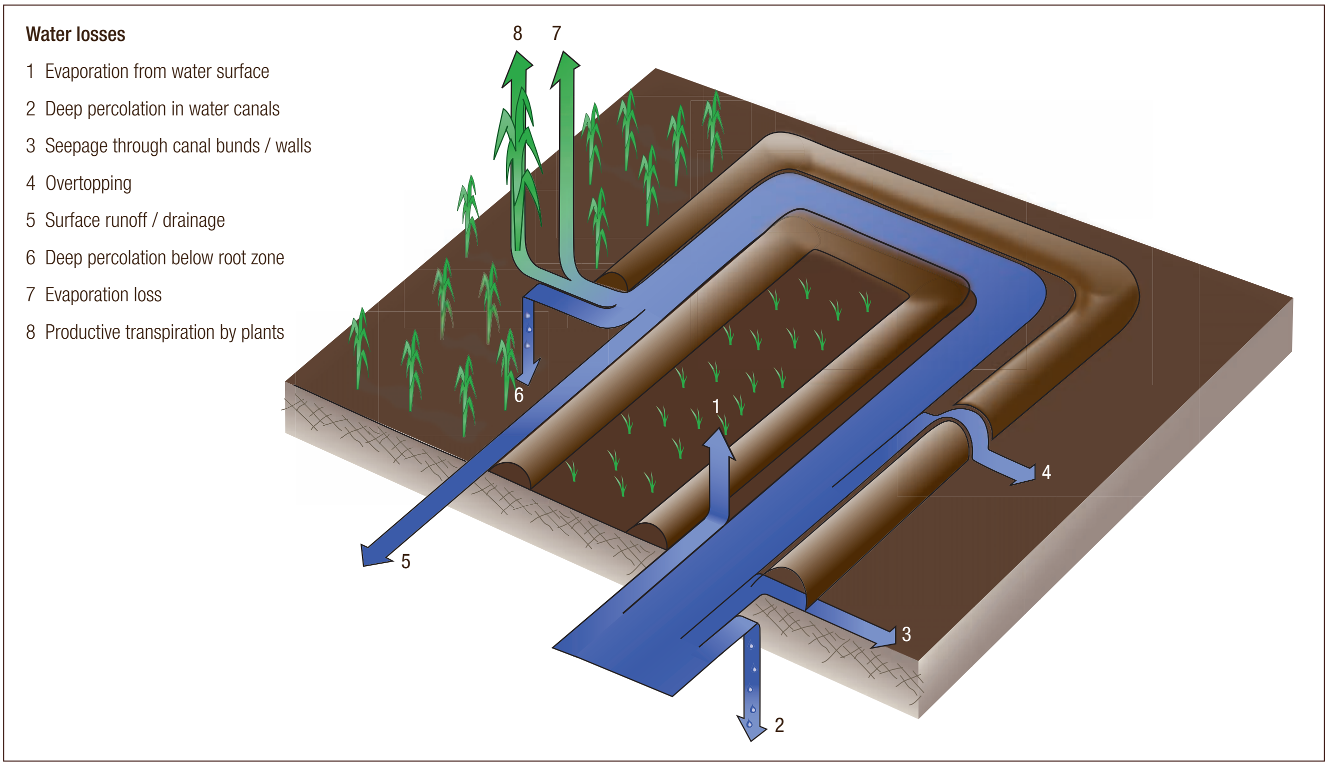


Figure 6: Water losses in irrigation systems: from source to plant illustrating the small fraction of water used productively for plant growth compared to the total water directed to irrigation systems (based on Studer, 2009).

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)

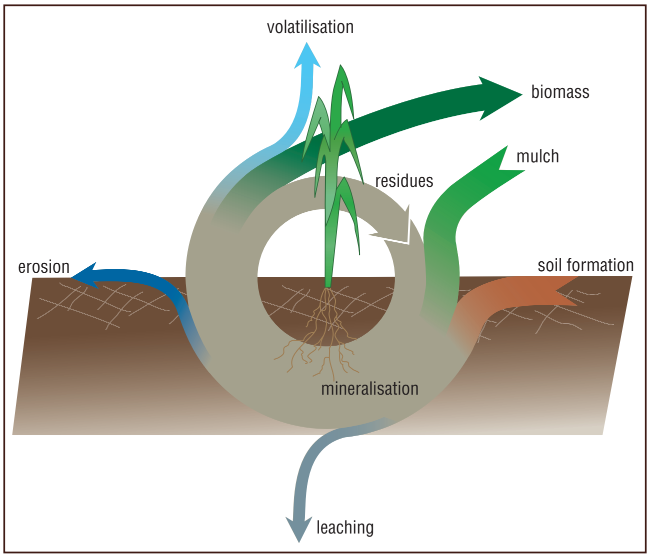


Figure 7: The nutrient and carbon cycle showing the main losses and gains / replenishments of soil organic matter, biomass and nutrients.

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:

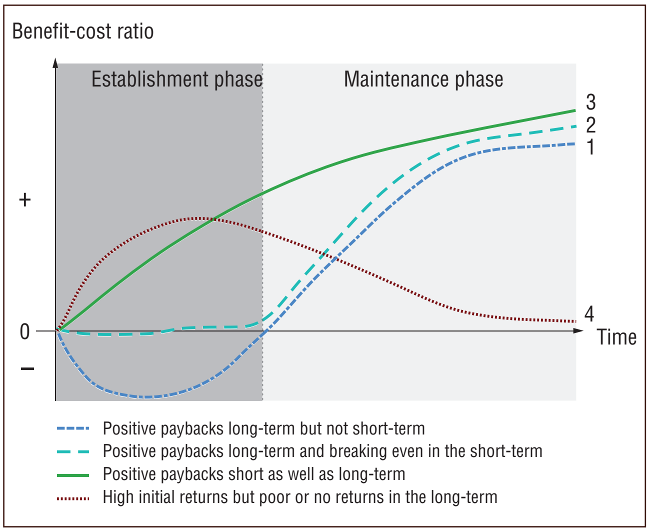


Figure 8: Benefits and costs of SLM over time, short-term establishment phase and long-term maintenance phase.

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.

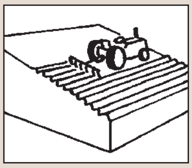
Major efforts and investments have been made in the implementation of structural measures. They are conspicuous in showing efforts made towards SLM. However they are input intensive and often could be substituted by less demanding agronomic, vegetative and management measures. As a rule of thumb priority 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

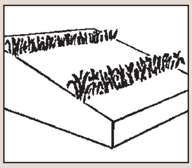
A key concern in sustainable land management and protecting ecosystem functions in SSA is conserving biodiversity. Sub-Saharan Africa has both remarkable richness and abundance of biological diversity. The world's second largest area of rainforest after South America's Amazon Basin is found in Central 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

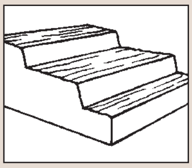
The measures for prevention, mitigation and rehabilitation of land degradation and restoration of ecosystems services can be classified into four categories (WOCAT, 2007):



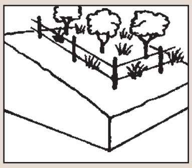
Agronomic measures: measures that improve soil cover (e.g. green cover, mulch); measures that enhance organic matter / soil fertility (e.g. manuring); soil surface treatment (e.g. conservation tillage); subsurface treatment (e.g. deep ripping).



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).

Adaptation to climate change: Adaptation to climate change means dealing with its impacts and this can be achieved by adopting more versatile and climate change resilient technologies – but also through approaches which involve flexibility and responsiveness to change. In this latter context land users need to be aware of alternative SLM practices.

Implementing SLM practices which increase soil organic matter will be beneficial in adapting to climate change. These will increase 'the resilience of the land', and thus 'climate proofing' through enhanced fertility, soil structure, water infiltration and retention, soil life and biomass production (Scherr and Sthapit, 2009).

Surface mulch or plant cover established under several SLM practices generally protect soil from wind, excess temperatures and evaporation losses, reduce crop water requirements and extend the growing period. This could prove critical in many areas of SSA affected by climate change. All practices improving water management increase resilience to climate change. This can be achieved through reducing water losses and harvesting of rainwater to improve water storage in the soil but also in reservoirs.

Practices diversifying incomes and reducing risks of production failure, for example integrated crop-livestock systems and improved or more appropriate plant varieties provide additional opportunities for adaptation.

Thus avoiding or reversing any form of land degradation, thereby improving the ecosystem health as well as improving the micro-climate, increases resilience to climate variability and change, and results in improved agricultural production. There is no one silver bullet solution to solve the problems which land users face due to climate change. However, the following generalisation can be made: Virtually all of the SLM practices identified in these guidelines contribute (in varying degrees) both to climate change mitigation and adaptation strategies.

Synergies between adaptation and mitigation: Synergies between reduced land degradation, conserved biodiversity, food security, poverty reduction and climate change mitigation and adaptation through SLM generate multiple benefits. A multifocal approach to SLM that takes into account all ecosystem services and human wellbeing is more likely to succeed than one focused exclusively on climate change mitigation and adaptation. SLM is not limited to smallholder land users; many SLM practices can make medium to large-scale commercial land use more sustainable and resilient to climate variability and can contribute to climate change mitigation.

Yet, some mitigation responses may conflict with food security – and vice-versa. For instance, plant production for biofuels leads to competition for land and water resources. Adaptation and mitigation synergies or antagonisms in agriculture, forestry, and fisheries at the global, regional, and local levels are poorly documented. Therefore further research and efforts related to knowledge management are needed to identify locations and conditions where food security adaptation and mitigation benefits intersect in a cost-effective way (FAO, 2009a; FAO, 2009b).

Climate change mitigation and adaptation (Principles)

Mitigation:

- Increase carbon stock above and below ground: improve plant cover, increased biomass, mulch, organic and green manure, minimum soil disturbance, water and soil conservation – e.g. through forestation, agroforestry, conservation agriculture, residue management.
- Reduce emissions of greenhouse gases: reduce vegetation and soil degradation, reduce fire, reduce machine hours, improve livestock and irrigation management, more efficient use of fertilizers and manure

Adaptation:

Identify and promote versatile and resilient technologies

- improve soil cover and microclimatic conditions: through mulch, crops, grass, trees
- improve soil fertility: through soil organic carbon, soil structure, nutrient cycling
- improve water harvesting, storage (in soils, reservoirs etc), and distribution
- reduce water losses: evaporation, uncontrolled runoff, leakage in irrigation systems

Encourage adaptation approaches and strategies

- give land users SLM options
- encourage local innovation

Triple-win solutions

For food security and overall development in SSA, increased land productivity for food, fodder, fibre and fuel is the urgent priority. This can be achieved by:

- Intensification of agricultural production: which still has great potential, yet there remain challenges in finding sustainable practices to continued improvements.
- Diversification of agricultural production: which can help strengthening resilience to changes (be it induced by climate, markets or policies).
- Expansion of the agricultural area: though this has very limited potential. In most regions good and suitable land has already been used.

For intensification, diversification, and / or expansion, four land productivity principles guide the way towards SLM in SSA, namely (Figure 10):

1. improved water productivity and water use efficiency on rainfed and irrigated land;
2. improved soil fertility;
3. improved plant management: plant material and control of weeds, pest and diseases;
4. improved micro-climate.

This underlines the fact that good cover conditions, improved soil organic matter, water saving or harvesting, nutrient recycling, and improved management of plants, livestock and control of pests and diseases are key entry points for best SLM practices. SLM practices are related to maximum soil cover, minimum soil disturbance, enhancement of biological activity, integrated plant nutrition management, development of integrated crop / livestock / agroforestry systems, flexible management of traditional pastoral systems and reduced use of burning (Woodfine, 2009).

Best land management practices are win-win-win solutions. All SLM practices presented in Part 2 aim at tripple win: improving productivity, livelihood and ecosystems. Figure 11 summarizes the issues related to productivity, ecosystem concerns, livelihood and human well-being. Table 3 lists principles, strategies and practices to improve land productivity and yields.

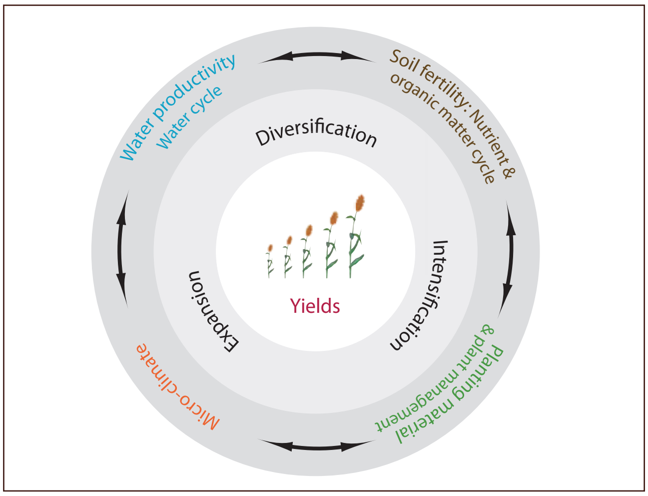


Figure 10: Key to improved land productivity and food security.

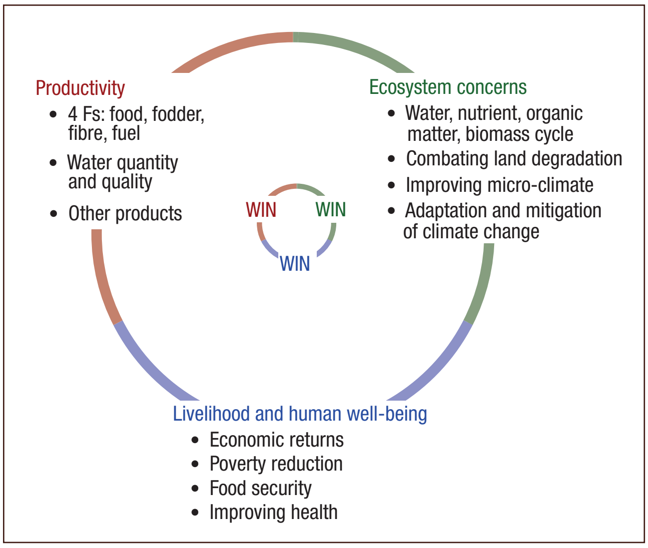


Figure 11: Win-win-win solutions for livelihood, ecosystem and productivity.

Table 3: Strategies and practices to improve land productivity and yields

Principles	Aim	Strategies	SLM practices (Case studies see Part 2)
Water use efficiency and productivity	**Increase plant water availability in rainfed agriculture**	minimise run-off; maximise rainfall infiltration and storage in the soil	soil cover, composting, contour cultivation, conservation agriculture, life barriers, soil / stone bunds, terracing, *fanya juu*, etc.
		reduce non-productive evaporation	good plant cover, intercropping, mulching, windbreaks, agroforestry, etc.
		harvest & concentrate rainfall through runoff to crop area or for other use	planting pits, semi-circular bunds, microbasins, contour bunds, stone lines, vegetative strips, trash lines, runoff and floodwater farming, small dams, etc.
	Increase plant water availability in irrigated agriculture	minimise water losses from irrigation system	lining of canals, deep and narrow instead of shallow and broad canals, good maintenance, pipes, etc.
		efficient and effective application of water	watering can irrigation, drip irrigation, micro sprinklers, low pressure irrigation system, improved furrow irrigation, supplemental irrigation, deficit irrigation, etc.
		recharge aquifer / groundwater; water collection to enable off-season irrigation	small dams, farm ponds, subsurface tanks, percolation dams and tanks, diversion and recharging structures, etc.
	Increase plant water uptake	increase productive transpiration	afforestation, agroforestry, optimum crop rotation, intercropping, improved crop varieties, planting date, etc.; vigorous plant and root development through soil fertility and organic matter management, disease and pest control, weed management, etc.
Soil fertility	**Improve nutrient availability and uptake**	reduce nutrient mining and losses	composting and manuring (e.g. corralling) integrated fertility management (organic combined with inorganic), microfertilization, green manuring, rotations including legumes, improved fallows with leguminous trees and bushes, enrichment planting of grazing land, rotational grazing, etc.
		improve soil nutrient holding capacity and plant nutrient uptake capacity	minimum to no till, improve soil biotic activity, increase soil organic matter, mulching, manage avoid burning (residue management), etc; adapted varieties, etc.
Plants & their management	**Maximise yields**	use best suited planting material and optimise management	choice of species, varieties, provenances, etc.; short season varieties, drought tolerant varieties, pest and disease resistant varieties, etc.; planting dates, plant geometry, fertility and water management, etc.
Micro-climate	**Create favourable growing conditions**	reduce evapotranspiration	windbreaks, agroforestry, hedges, living barriers, parklands, good soil cover, dense canopy, etc.
		optimise temperature and radiation	agroforestry, vegetative and non vegetative mulch, etc.
		reduce mechanical damage of plants	windbreaks, barriers, vegetative and non vegetative mulch, etc.

Hanspeter Liniger

ADOPTION AND DECISION SUPPORT FOR UPSCALING BEST PRACTICES

According to FAOSTAT 2008 it is estimated that less than 3% (5 million ha) of total cropland in SSA are under SLM using low-cost productivity enhancing land management practices (WB, 2010). This involves only about 6 million small-scale land users (Pender, 2008) and shows that adoption of SLM is alarmingly low, obviously excluding indigenous technologies.

Adoption - uptake and spread

Success in adoption of SLM depends on a number of factors. It depends primarily on the availability and suitability of best SLM practices that increase yields and at the same time reduce land degradation (as discussed in the chapter on 'increasing land productivity').

A study based on the WOCAT database showed that in SSA the single most important factor for adoption of SLM practices was increased short-term land productivity, followed by short establishment time, and practices that were 'easy to learn' (Stotz, 2009). An IWMI study analysing a number of technology information sheets underlines these findings (Drechsel et al., 2005). In that study, the most important adoption drivers for conservation, water harvesting and rangeland technologies in SSA were yield increase and accessibility to information, followed by secured land tenure. Additional important influential factors were improved nutrient availability on cropland and labour demand on rangeland.

When adapted to suit local contexts, there is potential for the best practices presented in Part 2 of the guidelines to be upscaled and replicated across SSA. However, this is not enough. For upscaling, an enabling environment is of paramount importance; this includes institutional, policy and legal framework, local participation as well as regional planning (landscape or watershed), capacity building, monitoring and evaluation, and research.

Institutional, policy and market bottlenecks in the context of SLM adoption

Institutional:

- Inappropriate national and local political agendas
- Lack of operational capacity
- Overlapping and unclear demarcation of responsibilities
- Ineffective decentralisation
- Lack of good governance

Policy / Legal framework:

- Often there are laws in favour of SLM, but they are not followed
- Enforcement is difficult, costly and can create adverse relationships between government and land users

Land tenure and user rights:

- Inappropriate land tenure policies and inequitable access to land and water
- Insecurity about private and communal rights
- Modern laws and regulations not considering traditional user rights, by-laws and social and cultural norms which may enhance conflicts and insecurity

Market and infrastructure:

- Insecure prices of agricultural products (crop, animal, timber, fuel / firewood, …)
- Increasing input prices and costs for the inputs (materials, equipment, labour, …)
- Access to markets for inputs and output

(Sources: TerrAfrica, 2007 and 2009; Drechsel et al., 2005)

Institutional and policy framework

While natural resources and climatic factors define the possible farming systems, national and international policies and institutional changes will continue to determine the socio-economic factors that underscore the continuation of land degradation or alternatively create an enabling environment for SLM to spread.

Policies in support of SLM are needed to promote and address the complexity of sustainable land use, in particular policies providing incentives for SLM investments at household, community, regional and national level (TerrAfrica, 2008). Policies must address the root causes of land degradation, low productivity and food insecurity and simultaneously establish socially acceptable mechanisms for encouragement or enforcement.

Improvement of national policy frameworks: There are clear opportunities to improve national policy frameworks in support of SLM and to overcome bottlenecks that hinder the spread of SLM (see also box left):

Creating an enabling institutional environment:
- strengthening institutional capacity
- clarifying roles and responsibilities
- furthering collaboration and networking between institutions involved in implementation as well as research
- enhancing collaboration with land users
- strengthening and integrating farmer-extension-research linkages
- securing finances (budgetary provision for extension)

Setting-up a conducive legal framework:
- creating acceptance of rules and regulations or setting up mechanisms of control and enforcement
- defining meaningful laws for local land users to support compensation mechanisms
- recognising customary rights in the local setting

Improving land tenure and users' rights is a key entry point:
- providing basic individual and collective security of resource use (mainly for small-scale land users)
- clarifying tenure and user rights to private and communal land, including locally negotiated tenure systems, regulations and land use. Protecting the rights of land under customary tenure
- looking for pragmatic and equitable solutions in cases where land tenure reforms are ongoing
- increasing land title registration and linking this to land use planning through a cadastral system
- promotion of women's land rights in land registration and customary land tenure systems

Improving access to markets for buying inputs and selling agricultural products and other outputs:
- developing and strengthening local informal markets
- securing accessibility by improving infrastructure (especially access roads)
- better understanding of the impact of macroeconomic, liberalisation and trade policies on prices
- facilitating markets for raw and processed products derived from SLM

- exploring and promoting access to regional, national as well as international markets, including niches for SLM products such as fair trade, organic, environmentally-friendly, certification of origin labels as well as ecotourism (see next paragraphs)
- develop favourable and fair international trade regulations

Land users and communities are likely to invest in improving the land and its natural resources given good institutional support, a conducive legal framework, access to markets, and clarity about land tenure and user rights (TerrAfrica 2008 and 2009).

Trends and new opportunities: To make SLM and its products, impacts and services more valuable or to connect SLM with emerging global environmental issues, emerging trends and opportunities need to be further explored. These may include:

- Processing of agricultural products: This can reduce post-harvest losses and produce higher value products where the market exists. It also generates additional income and job opportunities.

- Certified agricultural products: Look for opportunities under 'Fair Trade' with its focus on social criteria, equitable and just remuneration of producers; and 'Organic' with a focus on environmental health (production without chemical inputs, namely pesticides, herbicides, inorganic fertilizers). For forest products there exists a certification for sustainably managed forests (FSC – Forest Stewardship Council), with a growing global demand. For 'SLM-grown' produce a certification label could also be introduced (see case study on 'Organic Cotton').

- Market for bio-energy / fuel: Although heavily debated by the public and scientific communities due to the trade-off with food security and ecoystems, biofuels are gaining increased commercial attention. Driven by factors such as oil price spikes and the need for greater energy security, there are rapidly developing markets for bio-energy products.

- Payments for Ecosystem Services (PES): PES is the mechanism of offering incentives to farmers or land users in exchange for managing their land to provide ecological services. Through PES, those who benefit pay for the services and those who provide, get paid. This is a relatively new source of funding with considerable potential for expansion. New PES related markets for greenhouse gases, carbon, water and biodiversity are emerging globally (see case study on 'Equitable Payments for Watershed Services').

The most promising PES opportunities are:

- Carbon sequestration and GHG reductions: These offer payment possibilities for mitigating climate change. Many PES-projects ('carbon offsetting') have been started in SSA, paying for carbon storage in forest plantations. Forests-based transactions for the cost of emissions reductions can range between 1 to 15 US$ per tonne of carbon sequestered (Envirotrade, 2010).

- Payment for biodiversity and protection of natural resources: By environmental interest groups through international support for protection (e.g. establishment of parks, reserves) or through enhancing ecotourism, where local communities are the main beneficiaries. Ecotourism in preserved natural habitats is becoming increasingly popular in parts of SSA. Though agro-ecotourism is poorly developed as yet. Environmental interest groups can solicit considerable funds and goodwill for SLM, and there is a strong consumer demand for ecotourism. However, there can be no ecotourism business without sustainable managed ecosystems and biodiversity.

- Payment by downstream users, watershed management payments for protection and sustainable management of upper catchments resulting in clean water, reduced sedimentation of reservoirs, increased hydro-power generation, and reduced floods (ISRIC, 2010).

PES is not yet widely used in developing countries – and there are various constraints to its implementation, for example to establish fair and trustworthy distribution mechanisms down to the local level. However, it presents a promising and flexible approach to enhancing and recognising the role of land users in sustaining and improving the ecosystem.

New financing mechanisms - such as PES - are emerging especially in relation to sustainable forest management, restriction of deforestation and exploitation of natural forests. Today, almost one-fifth of global carbon emissions come from deforestation. Preventing forest loss is the cheapest method of limiting carbon dioxide emissions. However, since the market lacks a well-functioning system for compensating farmers, it is currently more economically beneficial for farmers to clear forests than to keep them. As far as the developing world is concerned, natural forests are, ironically, more valuable to the international community than to the local inhabitants.

The emergence of these financial mechanisms implies that regional / national and global community are beginning to take responsibility for protecting the world's forests, and are willing to pay / compensate the rural people for putting aside the axe. If there is no global shift in the readiness to pay for services including better climate, clean air, good water, greater biodiversity (etc.), we will continue to lose valuable ecosystems and their services. All possible efforts need to be made to quantify services and to show consequences on global human wellbeing. Local communities need to be recognised as - and renamed as - stewards and custodians of natural forests and their services.

The UN-REDD, a collaborative partnership between FAO, UNDP and UNEP, supports countries in developing capacity to Reduce Emissions from Deforestation and forest Degradation (REDD) and is a first step in taking these responsibilities (UN-REDD, 2009).

Participation and land use planning

SLM technologies need approaches that enable and empower people to implement, adopt, spread and adapt best practices. Over the last 50 years the involvement and role of local land users has changed, with a swing from top-down, to bottom-up, to a multilevel-multistakeholder (multi-dimensional) approach. In the top-down approaches there was little or no involvement of land users in planning and decision-making. They worked through payments or coercion during the implementation phase. In the 'farmer first', bottom-up approaches local land users were empowered, though this sometimes led to inequalities. This happened typically with river water abstraction where downstream users found themselves deprived of water. Empowerment must be for all, not just favoured groups. Furthermore gender-related aspects need to be taken into account while developing an approach to stimulate SLM.

Rural women have been involved in agricultural production since the invention of agriculture. Their work in 'smallholder agriculture' has become more visible over the last few decades. They continue to increase their involvement in two types of agricultural production, smallholder production and agro-export agriculture - a trend called 'feminisation of agriculture' (Lastarria-Cornhiel, 2006).

As presented in more detail in Part 2, current promising approaches underlie the following principles:

1. People-centred approaches: People and their actions are a central cause of land degradation, and thus need to be at the centre of SLM. There must be genuine involvement of land users throughout all phases.

2. Multi-stakeholder involvement: This includes all actors, with their various interests and needs, with respect to the same resources. It includes local, technical and scientific knowledge and mechanisms to create a negotiation platform.

3. Gender consideration: Gender roles and responsibilities need to be considered seriously, since in smallholder agriculture women are taking over more of the agricultural tasks once done only by men such as land preparation, and they are investing more work in cash crop production.

4. Multi-sectorial approaches: Successful SLM implementation brings together all the available knowledge in different disciplines, institutions and agencies including government, non-governmental and private sectors.

5. Multi-scale integration: This unifies local, community but also the landscape, watershed or transboundary level, and up to the national and international level also. It implies that not only are local on-site interests considered, but off-site concerns and benefits also. This means that the concept of 'freedom of local land users' might be narrowed down in the interest of a larger community. However, it also opens up possibilities for additional markets, as well as compensation or funding mechanisms. While local benefits from investments in SLM already might be a sufficient incentive for land users, off-site concerns and benefits need to be negotiated.

6. Integrated land use planning: This assesses and assigns the use of resources, taking into account demands from different users and uses, including all agricultural sectors - pastoral, crop and forests - as well as industry and other interested parties also.

Promotion and extension

In order to facilitate the adoption, adaptation and spread of SLM best practices, enhancing incentives are needed: these include awareness raising, promotion, training and financial or material support. In many countries in SSA existing extension and advisory services have been reduced or weakened over the last decades: these need reviving and revitalising due to their vital roles.

Capacity building and training: Many actors and stakeholders must be involved and work together towards successful planning, decision making and implementation of SLM. Extension of SLM practices has much to do with empowering land users. And they must be supported better through capacity building, knowledge management and training.

Two forms of extension and training especially need to be strengthened:

- Institutional capacity building: projects, extension services, research initiatives and community based grassroots organisations (e.g. user groups) to access better means for knowledge management, awareness raising and training, but also for advice and decision support towards land users and planners; increased investments in extension services for small-scale land users, with a clear focus on sustainable techniques.

- Land user capacity building and empowerment: people-centred learning and capacity building through training-the-trainers initiatives, Farmer Field Schools, farmer-based extension using local promoters and innovators, from farmer-to-farmer.

There has been a general move to more participation, devolution of powers and less authoritarianism. But empowerment requires enhanced capacity. Investment in training and building up of the capacity of land users and other local and national stakeholders must be a priority. Local innovation and farmer-to-farmer extension have proven to be widespread, effective and appropriate strategies, but they are not yet sufficiently recognised.


Training of farmers in the layout of contour barriers. (Hanspeter Liniger)

Recent developments in information and communication technologies (ICTs) and the media provide new opportunities in awareness-raising and knowledge dissemination. The use of local radio, TV, video, mobile phones and the internet, has increased the avenues for timely and wider delivery of useful information (AfDB, UNECA, and OECD, 2009) such as weather forecasts, farm inputs, market information and also development of SLM practices.

Financial and material support (incentives & subsidies)**:** Incentives for SLM should not exclusively be seen as financial or material support, but as the intangible stimulus (or ‘internal incentive’) that a land user experiences through higher production, or through saving time and money.

Judicious use of financial and material support implies various considerations:

- The possibilities of removing some of the root causes of land degradation such as an inappropriate land policy framework, land tenure security and market access, should be assessed (WOCAT, 2007).

Monitoring of river flow: Nanyuki River (Mount Kenya region) during the wet season (above) and during the dry season (below). The river started to dry up only as of the 1980s. (Hanspeter Liniger)

- There is often a need for material and financial support in the SLM sector in developing countries. Direct support to land users depends on the amount of investment needed for SLM interventions. In view of this, financial support is more likely to be justifiable in expensive rehabilitation exercises, or SLM requiring heavy initial investments. However support for maintenance should be avoided, as it creates dependency.

- Before considering the use of direct financial and material support for input-intensive measures, alternative approaches should be explored, such as adapting existing technologies, or choosing 'simple and cheap' technologies.

- If fertilizers, agro-chemicals, seed or seedlings are subsidised, the support should aim to be one element that helps build up a more integrated approach towards soil fertility, and pest and disease management.

The lower the degree of outside financial or material support, the greater the level of genuine land user self-initiative and participation, and thus the probability that the interventions are sustainable.

Access to credit and financing schemes can be vital help for rural people to start new SLM initiatives. Thus well-functioning financial services and mechanisms (such as micro-credit) need to be established, enabling land users to take the initiative for self-financing SLM interventions.

Financial support needs to be maintained or even enhanced for institutions providing advice, plans and decision support at all levels, to ensure sufficient and effective support to land users.

Monitoring, assessment and research

Monitoring and assessment – improve SLM and justify investments: Monitoring and assessment (M&A) of SLM practices and their impacts is needed to learn from the wealth of knowledge available including traditional, innovative, project and research experiences and lessons learnt – both successes and failures. M&A can lead to important changes and modifications in approaches and technologies (WOCAT, 2007). SLM is constantly evolving, which means M&A must be ongoing and responsive. Land users have to take an active role as key actors in M&A: their knowledge and judgement of the pros and cons of SLM interventions is crucial. More investment in training and capacity building is needed for M&A generally, and specifically to improve skills in knowledge management and decision support.

Although several countries and regions have prepared land degradation maps, mapping of SLM efforts and areas under SLM has been badly neglected. M&A through such mapping can contribute to raising awareness of what has been achieved, as well as justifying further investments and guiding future decision-making (Schwilch et al. 2009).

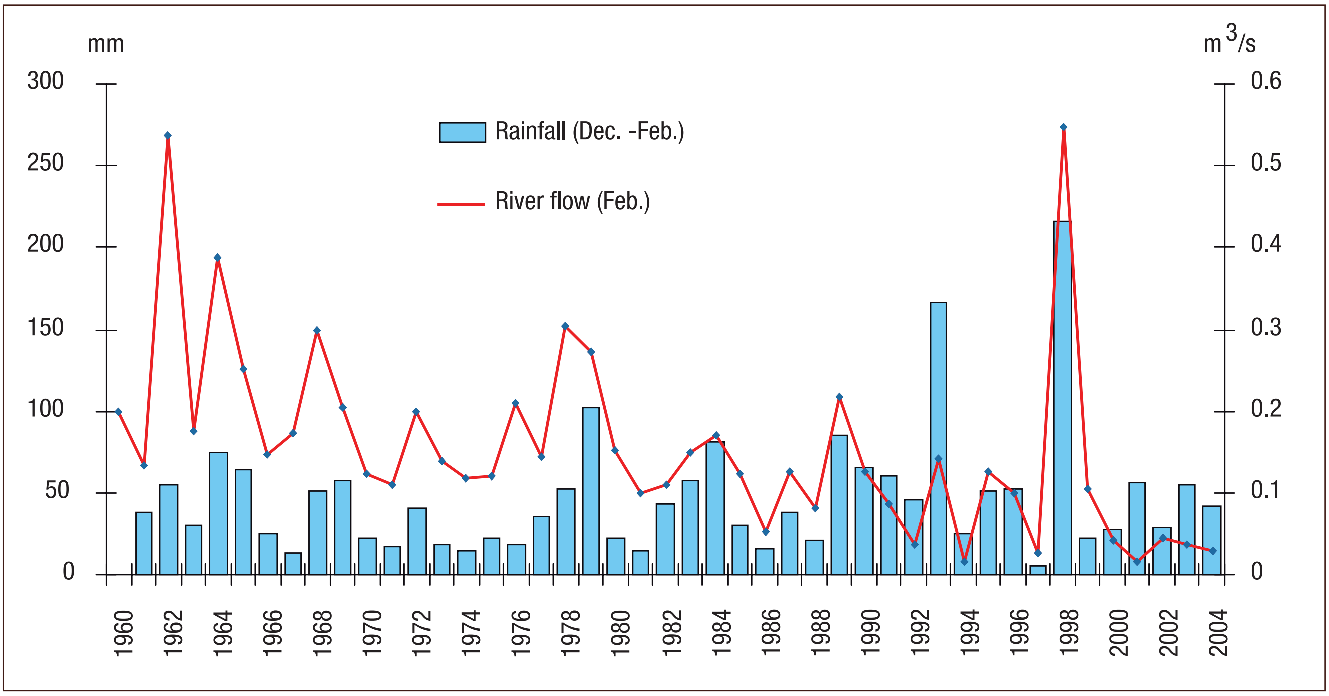


Figure 12: Monitoring of rainfall and river flow in February (dry season) document changes related to climate and impacts of land use. Timau River, Mount Kenya region (Liniger H.P., 2005)

Complexity and knowledge gaps – the role of research: The problems of land degradation are complex and so are the answers: there is a real danger of simplification. Blueprint solutions for the implementation of SLM do not take account of this complexity. Effective SLM depends on both suitable technologies and closely matched approaches for their promotion. They need to be flexible and responsive to changing complex ecological and socio-economic environments. An urgent and specific area for further investigations and research is quantification and valuation of the ecological (e.g. Figure 12), social and economic impacts of SLM, both on-site and off-site, including the development of methods for the valuation of ecosystem services. SLM research should seek to incorporate land users, scientists from different disciplines and decision-makers.

The major research challenges are:

- M&A of the local impacts of SLM and land degradation (ecological, economic and social);
- proper cost and benefit analysis of SLM intervention measures;
- M&A of regional impacts at watershed and landscape levels (including off-site and transboundary effects);
- mapping and monitoring of land degradation and the extent and effectiveness of SLM practices; and
- use of knowledge about SLM for improved decision-making at all levels (developing tools and methods for improved knowledge management and decision support).

The above challenges imply that further research and capacity building in SLM – as well as spreading and adapting SLM practices and innovations – are urgently needed. This also requires further development of decision support methods and tools for the local and national level (see following chapter).

Decision support - upscaling SLM

Land users, agricultural advisors and decision makers are faced with the challenge of finding the best land management practices for particular conditions. Thus they have the same questions to answer (see Figure 13):

- Which SLM technology and approach should be chosen?
- Where to apply them?
- How to apply them?
- Who plays what roles?
- What are the costs?
- What are the impacts?
- Do they improve food security, and alleviate poverty?
- Do they combat land degradation / desertification?
- How well are they matched to a changing climate?

Another fundamental question is where and when to invest: prevention before land degradation processes start, or rather mitigation / 'cure' after degradation has started - or rehabilitation when degradation is most severe? The costs vary considerably depending on the stage of SLM intervention (Figure 13).

Inputs and achievements depend very much on the stage of degradation at which SLM interventions are made. The best benefit-cost ratio will normally be achieved through measures for prevention, followed by mitigation, and then rehabilitation. In prevention, the 'benefit' of maintaining the high level land productivity and ecosystem services has to be measured compared to the potential loss without any intervention. While the impacts of (and measures involved in) rehabilitation efforts can be highly visible, the related achievements need to be critically considered in terms of the cost and associated benefits.

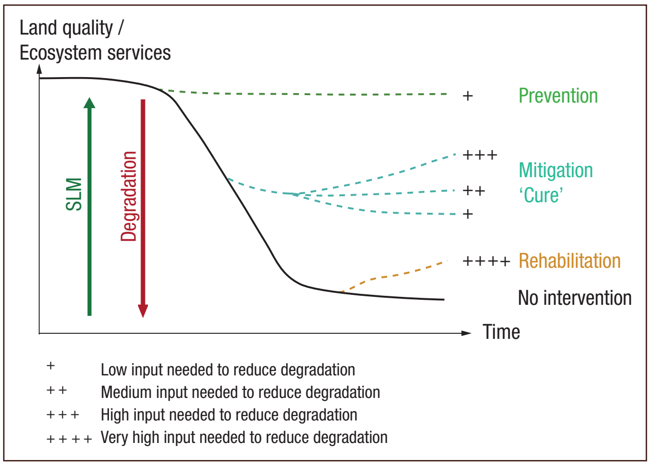


Figure 13: Stage of intervention and related costs.

Questions that need to be addressed for informed decision-making are: Where are the hot spots / priority areas for interventions? Where are the green spots? These require answers in order to make decisions on spreading best SLM practices. In the following, a 3-step decision support method is proposed to help answer these questions based on improved knowledge management and a selection mechanism involving relevant stakeholders at different levels (Schwilch et al. 2009).

Knowledge management: building the basis

Step 1 – Identification of SLM best practices involving all stakeholders: The first step for better decision support is the initial involvement of all stakeholders in SLM (e.g. through a stakeholder workshop). The aim is to identify existing prevention and mitigation strategies against land degradation and desertification. The methodology brings together scientific and local knowledge while simultaneously supporting a co-learning process oriented towards sustainable development. The objectives are: (1) to reflect on current and potential problems and solutions related to land degradation and desertification; (2) to create a common understanding of problems, potentials and opportunities; (3) to strengthen trust and collaboration among concerned stakeholders; (4) to identify existing and new SLM practices; and (5) to select a set of these identified strategies for further evaluation and documentation in the next step.

Step 2 – Documentation and assessment of existing SLM practices: There are many unrecognised SLM practices which constitute a wealth of untapped knowledge. Knowledge related to SLM often remains only a local, individual and institutional resource, unavailable to others. Therefore, existing SLM practices need to be documented and stored in a database using a standardised methodology - for example the WOCAT method and tools (Liniger and Critchley, 2008). The aim of standardised knowledge management is to accumulate, evaluate, share and disseminate experience; not just within countries but across the world. Several attempts to build up a global knowledge base on SLM have been made, but they use different formats which cannot be integrated nor compared, thus a globally accepted methodology is proposed. The main asset of this is to have a common and growing pool of SLM knowledge and with tools to share and access, and use the knowledge for better decision-making. In Part 2 of the guidelines a standardised format for documenting SLM practices is presented. It is a shortened version of the standardised WOCAT 4 page presentation of SLM Technologies and Approaches (WOCAT, 2007).

A standardised knowledge base allows thorough assessment and evaluation of the impacts and benefits of the various SLM practices. It also facilitates the comparison of different options.

Selection and fine tuning of SLM practices

Once documented, SLM experiences need to be made widely available and accessible in a form that allows all stakeholders to review existing practices, understanding their particular advantages and disadvantages – and thus to make appropriate decisions. New SLM efforts should first try to build on existing knowledge from within a location and region itself or, alternatively, from similar conditions and environments elsewhere.

Step 3 – Participatory decision-making for selection and implementation of SLM best practices: After documentation and assessment of existing SLM practices, the challenge is to decide on best practices and where to implement them. This again involves all stakeholders (e.g. in a second stakeholder workshop) and recently developed decision support tools to evaluate the best options and set priorities. These tools allow selection of SLM options, comparison and ranking of them, negotiation and finally a decision regarding which is (or are) the best-bets for specific conditions (Schwilch et al. 2009).

Whether such SLM practices are accepted or not depends on cost-effectiveness, severity of degradation, knowledge, enabling framework conditions (e.g. policies and subsidies) and on other socio-cultural and economic issues.
The key to success lies in a concerted effort by all, where special attention needs to be paid to the participatory process of selecting potential SLM interventions. Otherwise land users will neither accept nor properly implement the practice, and project success will be threatened. Stakeholder involvement is crucial at all stages.

Selection of priority areas for interventions

So far there are only few maps covering land degradation; but there are none covering SLM – nor the impacts either of land degradation or SLM. This makes sound decision-making very difficult, but likewise it is also impossible to demonstrate the needs and benefits of SLM interventions.

There is not only need to assess and monitor the different SLM practices but also the impacts of multiple SLM interventions at the larger scale. This would permit the assessment of off-site impacts and effects of upstream interventions on downstream areas. The design and the costs of downstream interventions can be reduced due to upstream investments. This does not only apply to impacts caused by the flow of water downstream, but also impacts from wind affecting off-site areas (e.g. dust storms). Showing benefits of linking upstream (on-site) with downstream (off-site) would help in setting priorities for intervention and investments.

A mapping methodology jointly developed by WOCAT and FAO-LADA generates information on degradation and SLM, and highlights where to focus investments. The mapping tool focuses on areas with land degradation ('red' spots) and on identifying where existing SLM practices ('green' spots) could be expanded. It further facilitates judgement of whether to rehabilitate, or to prevent land degradation and what the impacts on ecosystem services might be.

For different land use systems the type, extent and degree of land degradation and the causes are assessed. For areas covered with SLM practices, the extent and effectiveness is recorded and for both land degradation and SLM the impacts on ecosystem services are listed. The data is compiled through a participatory expert assessment involving local land users, supported by documents and surveys. Given this information from mapping degradation and conservation, land users, advisors and planners can set priorities for interventions, and judge where the benefits for investments made are likely to be highest or the most needed.

The combined assessment of SLM practices and mapping allows not only the expansion of SLM, but also points towards necessary adjustments and adaptations to local conditions.

Where to intervene and where to spread already well proven SLM technologies. (Hanspeter Liniger)

Conclusions for adoption and decision support

- All issues discussed under institutional and policy framework, have a strong influence on the implementation of SLM but are difficult / impossible to address at single project or local level. However, through the creation of coalitions of implementing programmes and investment frameworks (e.g. TerrAfrica) changes favourable for SLM can be induced.

- To make an impact SLM needs to be integrated within national and regional priorities through policies, strategies, and action plans (WOCAT, 2007). SLM policies must be mainstreamed into broader sectorial policy frameworks.

- Recognition that different approaches are needed in different contexts is important, and acknowledgement that not all land management problems can be solved by government intervention or donor investments. A greater engagement of civil society and empowering stakeholders at grassroots is required (TerrAfrica, 2008).

- Cutbacks in government extension services and farm credit, as a result of liberalisation policies, have deprived land users of important sources of knowledge and advice. Hence innovative extension and advisory services options need to be considered such as contracting extension services to NGOs and other third parties.

- Links need to be drawn between local and regional implications (e.g. off-site effects, highland /lowland, mountains).

- Regional / national and global communities must take responsibilities for protecting the world's forests and should be willing to pay / compensate local rural people, otherwise valuable ecosystems and services such as better climate, clean air, good water, and improved biodiversity will be lost. All possible efforts need to be made to quantify the valuable services and to show the consequences on global human wellbeing if we fail. Local communities need to be acknowledged as stewards and custodians of natural forests and their services.

- M&A and research is key for improved decision support and upscaling.

- Capacity building is needed at all levels for land users, extension workers, planners and decision-makers. Major efforts are needed for knowledge management and decision support for local selection and fine-tuning of best SLM practices but also for regional priority setting within a watershed or landscape.

Future interventions need to promote the development of joint or 'hybrid' innovation that ensures making the best of local and scientific knowledge. In this respect, current farmer experimentation – including the adaptation of traditional technologies – blended with scientific research offers real hope for the future. Local innovation has, after all, been the driving force behind the traditions that have shaped farming, and SLM, over the millennia (Critchley, 2007). However all developments must take into consideration markets, policies and institutional factors that can stimulate widespread smallholder investments.


Hanspeter Liniger

THE WAY FORWARD

Recognising the contribution of SLM to food security, improved livelihood, mitigation of widespread land degradation and climate change adaptation and mitigation, best SLM practices need to be scaled-up and SLM mainstreamed as a priority at all levels.

SLM experiences presented in this book clearly show the need for major shifts in emphasis to overcome bottlenecks and barriers for spreading SLM in SSA. These shifts concern various aspects at different levels including technologies and approaches, institutional, policy, governance, economy, knowledge management and capacity building.

General shifts	
From simplicity	**To** complexity (ecosystem)
From narrow and single sector views	**To** holistic, multi-level, multi-stakeholder views

Technology shifts	
From providing rigid 'blueprint' or 'silver bullet' technologies	**To** offering a basket of options of best practices, flexible to be adapted to local conditions and needs
From individual single measures	**To** integrated / combined measures
From focus on structural and expensive practices	**To** focus first on cheap and easy agronomic, vegetative and management measures
From introducing new 'exotic' SLM technologies	**To** identifying and building on existing practices and local innovations - if needed supplemented with new elements derived from experiences elsewhere with similar conditions
From high losses of water through runoff and evaporation	**To** improved water use efficiency in rainfed and irrigated agriculture and improved water harvesting
From 'old' green revolution	**To** 'new' green revolution: reduced reliance on external inputs (fertilizers and pesticides), pro-poor, women

Policy, Institutional, Governance shifts	
From looking at impacts of land degradation, treating symptoms	**To** looking at root causes of land degradation, curing
From focus on rehabilitation of degraded land	**To** focus on preventing and mitigating land degradation and enhancing ecosystem services
From isolated successful SLM technologies and approaches	**To** scaling-up best practices (technologies and approaches)
From local planning and interventions	**To** multi-stakeholder planning and treatment at landscape or watershed level
From top-down transfer of technology	**To** people-centered learning approach
From limited consideration for the concerns of women, youth and marginal groups	**To** adoption of approaches sensitive to cultural aspects, gender, youth and marginal groups
From contradictory or uncoordinated policies that address symptoms	**To** effective cross-sector policies that address cures
From insecure land and water user rights (hindering SLM investments)	**To** locally negotiated tenure systems, regulations, land use plans, and user rights
From inadequate laws, regulations and control mechanisms to implement SLM and land degradation control	**To** an incentive-oriented legislation which recognises ecological problems and opportunities, supports effective land and ecosystem management, and establishes socially acceptable mechanisms for their enforcement

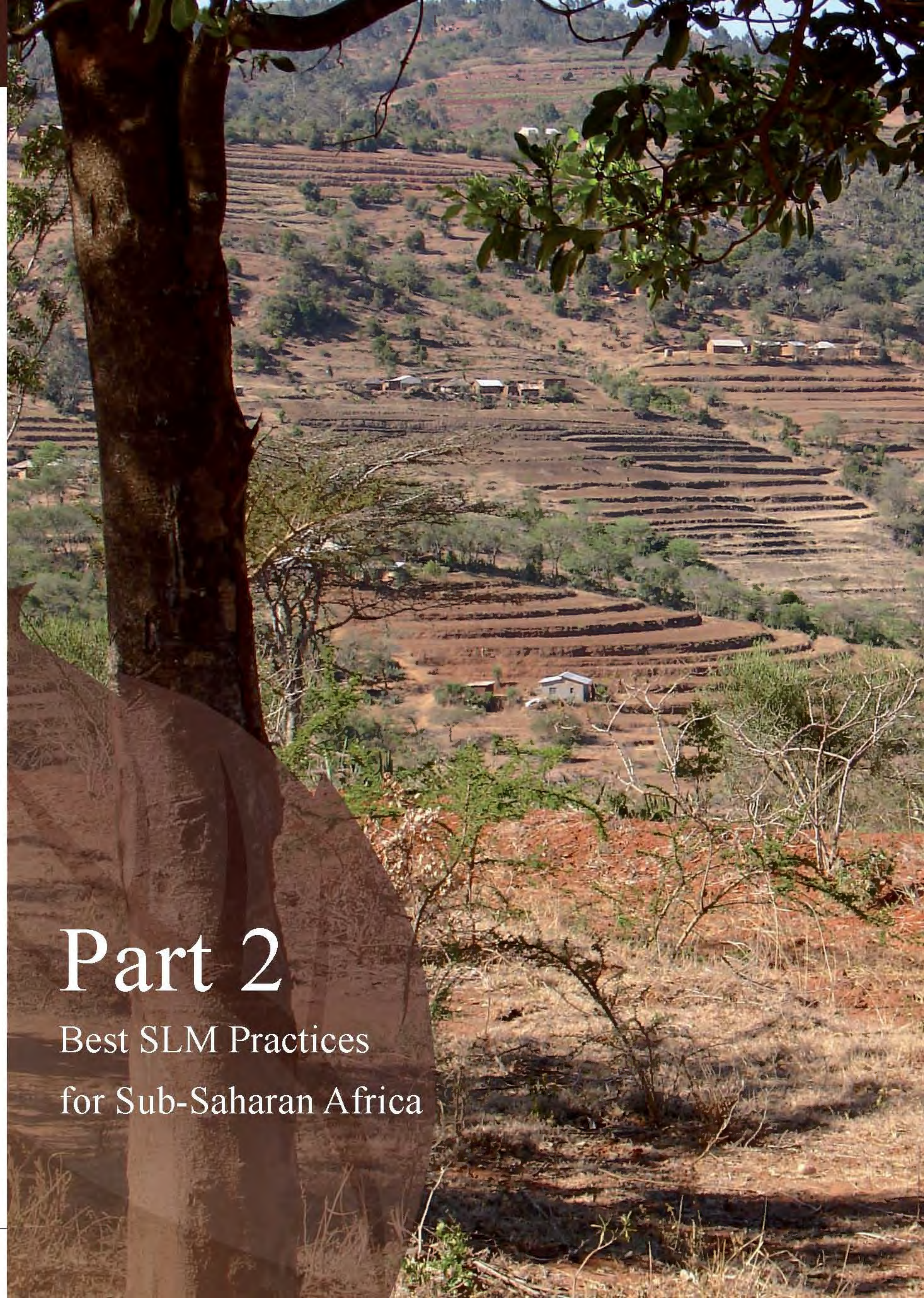
Knowledge management and capacity building shifts	
From focus on land degradation and desertification	**To** focus on SLM
From scattered and poorly documented SLM traditions and innovations as well as project experiences	**To** building common, easily accessible and standardised knowledge platforms to share and use information for decision-making
From poor knowledge on impacts of land management	**To** concerted action for monitoring and assessment of land degradation and SLM, and on-/offsite impacts on ecosystem services
From weakened advisory services	**To** major reinvestments in rebuilding rural advisory services
From poor awareness raising and capacity building related to SLM	**To** major efforts in awareness raising, training, education and capacity building
From poor use of SLM knowledge	**To** informed decision support at local and landscape / watershed level

Investment shifts	
From inadequate or contradictory economic and pricing policies that discourage investment in SLM	**To** the development of financial and market incentives that facilitate and encourage private investment in SLM
From inadequately monitored national and private sector budgets on SLM related issues	**To** traceable budgets on well defined SLM activities built within dedicated investment frameworks
From few / scattered project funding coming from poorly coordinated development partners	**To** specific budgets pooled around SLM programmes, according to Paris Declaration principles (budget support, basket funding etc.)

(Source: Elaborated by authors and based on TerrAfrica, 2009)

The final conclusions are that investment in spreading SLM practices in Sub-Saharan Africa has great scope and can deliver multiple benefits not only locally, but also regionally (e.g. in watersheds), nationally as well as globally. SLM concerns all, at all levels, and pays in many more ways than recognised. Many of the global issues such as food security, poverty, water scarcity, desertification, climate change mitigation and adaption, and biodiversity are closely related to SLM.

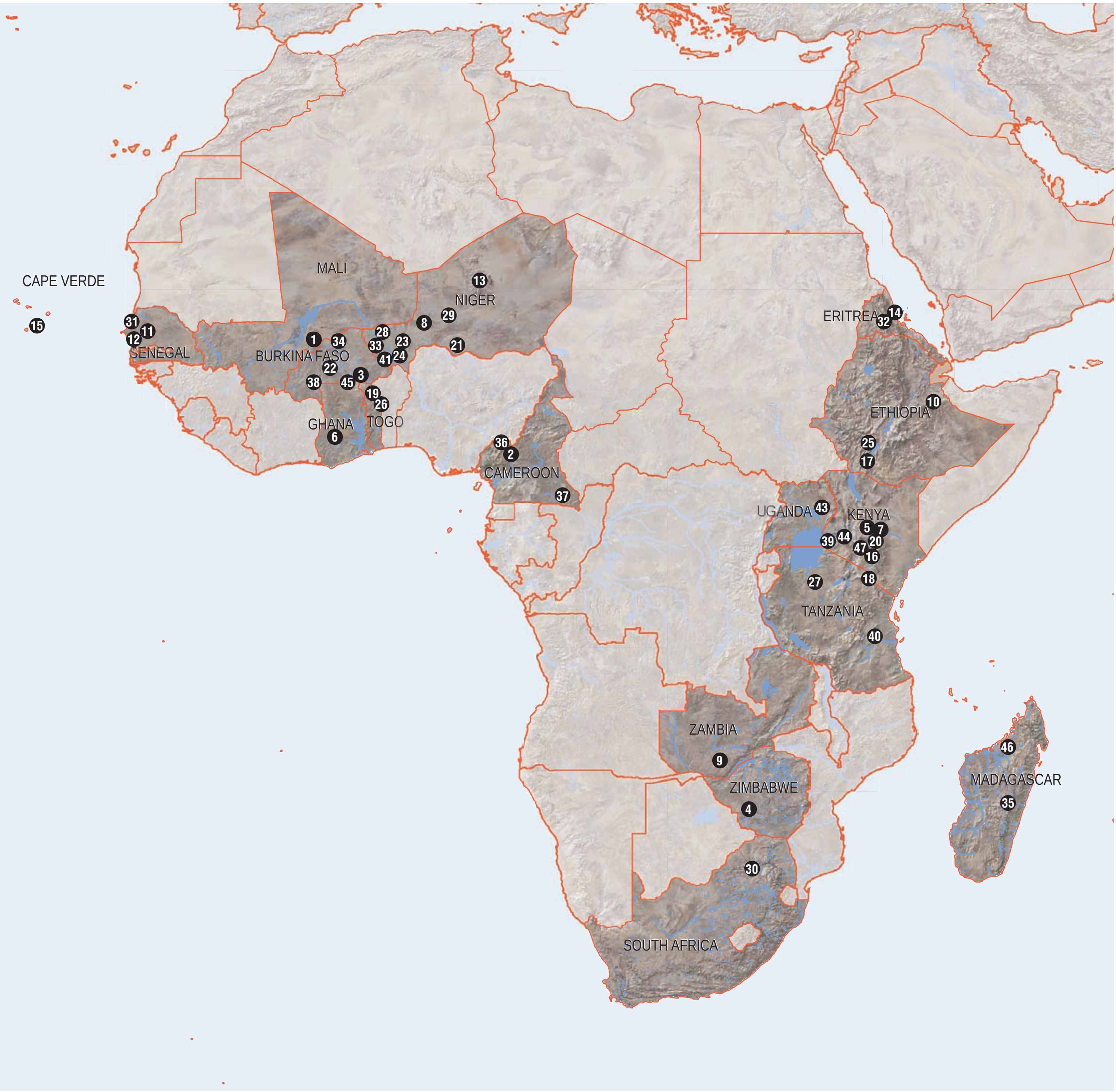
Additionally consolidated efforts are needed for knowledge management concerning SLM technologies and approaches and their spreading, not only to document and monitor valuable experiences for their own sake, but for dissemination and use in improved decision-making at the field and planning level. Given rapid changes, many adaptations and innovations concerning SLM will continue but will be untapped and unused. Consolidated action towards better use of valuable local, regional and global knowledge is needed and will be greatly beneficial in the future, as it can be anticipated that change will be even more pronounced (global markets, climate change, demands on ecosystem services, biofuel, etc.). Investment in SLM and knowledge management pays.



Part 2

Best SLM Practices for Sub-Saharan Africa

OVERVIEW OF BEST SLM PRACTICES



SLM Group and definition		Case studies	
Integrated Soil Fertility Management benefits from positive interaction and complementarities of a combined use of organic and inorganic plant nutrients in crop production.	p. 62	(1) Seed Priming and Microfertilization – Mali	p. 68
		(2) Green Manuring with Tithonia – Cameroon	p. 70
		(3) Compost Production – Burkina Faso	p. 72
		(4) Precision Conservation Agriculture – Zimbabwe	p. 74
Conservation Agriculture combines minimum soil disturbance (no-till), permanent soil cover, and crop rotation, and is very suitable for large- as well as small-scale farming.	p. 76	(5) Small-Scale Conservation Tillage – Kenya	p. 82
		(6) Minimum Tillage and Direct Planting – Ghana	p. 84
		(7) Conservation Tillage for Large-Scale Cereal Production – Kenya	p. 86
Rainwater Harvesting is the collection and concentration of rainfall to make it available for agricultural or domestic uses in dry areas where moisture deficit is the primary limiting factor.	p. 88	(8) *Tassa* Planting Pits – Niger	p. 94
		(9) Small Earth Dams – Zambia	p. 96
		(10) Runoff and Floodwater Farming – Ethiopia	p. 98
Smallholder Irrigation Management aims to achieve higher water use efficiency through more efficient water collection and abstraction, water storage, distribution and water application.	p. 100	(11) African Market Gardens – Senegal	p. 106
		(12) Low-Pressure Irrigation System 'Californian' – Senegal	p. 108
		(13) Irrigated Oasis Gardens – Niger	p. 110
		(14) Spate Irrigation – Eritrea	p. 112
Cross-slope barriers are measures on sloping lands in the form of earth or soil bunds, stone lines, or vegetative strips, etc. for reducing runoff velocity and soil erosion.	p. 114	(15) *Aloe Vera* Life Barriers – Cape Verde	p. 120
		(16) Grassed *Fanya Juu* Terraces – Kenya	p. 122
		(17) Konso Bench Terrace – Ethiopia	p. 124
Agroforestry integrates the use of woody perennials with agricultural crops and / or animals for a variety of benefits and services including better use of soil and water resources, multiple fuel, fodder and food products, habitat for associated species.	p. 126	(18) Chagga Homegardens – Tanzania	p. 132
		(19) Shelterbelts – Togo	p. 134
		(20) Grevillea Agroforestry System – Kenya	p. 136
		(21) Farmer Managed Natural Regeneration – Niger	p. 138
		(22) Parkland Agroforestry System – Burkina Faso	p. 140
Integrated Crop-Livestock Management optimises the uses of crop and livestock resources through interaction and the creation of synergies.	p. 142	(23) Night Corralling – Niger	p. 148
		(24) Rotational Fertilization – Niger	p. 150
		(25) Grazing Land Improvement – Ethiopia	p. 152
		(26) Smallstock Manure Production – Togo	p. 154
Pastoralism and rangeland management Grazing on natural or semi-natural grassland, grassland with trees and / or open woodlands. Animal owners may have a permanent residence while livestock is moved to distant grazing areas, according to the availability of resources.	p. 156	(27) Ngitili Dry-Season Fodder Reserves – Tanzania	p. 162
		(28) *Couloirs de Passage* – Niger	p. 164
		(29) Improved Well Distribution for Sustainable Pastoralism – Niger	p. 166
		(30) Rotational Grazing – South Africa	p. 168
Sustainable planted forest management The purpose of planted forests can be either commercial or for environmental / protective use or for rehabilitation of degraded areas. The sustainability of new planted forests depends on what they replace, e.g. the replacement of a natural forest will hardly be sustainable.	p. 170	(31) *Casuarina* Tree Belt for Sand Dune Fixation – Senegal	p. 176
		(32) Afforestation and Hillside Terracing – Eritrea	p. 178
		(33) Sand Dune Stabilisation – Niger	p. 180
Sustainable Forest Management in drylands encompasses administrative, legal, technical, economic, social and environmental aspects of the conservation and use of dryland forests.	p. 182	(34) Assisted Natural Regeneration of Degraded Land – Burkina Faso	p. 188
		(35) Indigenous Management of Tapia Woodlands – Madagascar	p. 190
Sustainable Rainforest Management encompasses administrative, legal, technical, economic, social and environmental aspects of the conservation and use of rainforests.	p. 192	(36) Forest Beekeeping – Cameroon	p. 198
		(37) Community Forests – Cameroon	p. 200
Trends and new opportunities SLM measures which have not yet widely spread and / or provide additional sources of income for land users, such as ecotourism, payments for ecosystem services, organic agriculture, etc.	p. 202	(38) Organic Cotton – Burkina Faso	p. 206
		(39) Push-Pull Integrated Pest and Soil Fertility Management – Kenya	p. 208
		(40) Equitable Payments for Watershed Services – Tanzania	p. 210
		(41) Conservation Approach for Kouré Giraffes – Niger	p. 212
SLM approaches A SLM approach defines the ways and means used to promote and implement a SLM Technology - be it project / programme initiated, an indigenous system, a local initiative / innovation - and to support it in achieving more sustainable land management.	p. 216	(42) *Stratégie Energie Domestique* – Niger	p. 222
		(43) Promoting Farmer Innovation – Kenya, Tanzania and Uganda	p. 224
		(44) Farmer Field Schools – Kenya	p. 226
		(45) Participatory Negotiated Territorial Development – Burkina Faso and Ghana	p. 228
		(46) Participatory Learning and Action Research approach to Integrated Rice Management PLAR-IRM – Madagascar	p. 230
		(47) 'Catchment' Approach – Kenya	p. 232

Hanspeter Liniger

SLM TECHNOLOGY GROUPS AND CASE STUDIES

There is no one miracle solution ('silver bullet') to solve the problems which land users in SSA face. The choice of the most appropriate SLM practice in a particular situation will be determined by local stakeholders, based on the local topographic, soil and vegetation conditions and socio-economic context, such as farm size and assets which may make certain practices ill-advised or not feasible.
The SLM groups presented in Part 2 follow the principles of best practices: increasing productivity, improving livelihoods and improving ecosystems.

Twelve groups of SLM technologies backed up by 41 case studies, are presented and these:
- Cover major land use systems;
- Represent degradation types and agro-ecological zones;
- Cover a broad variety of technologies;
- 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.

This selection of SLM groups and case studies does not claim to be complete or comprehensive:
- It does not cover or 'balance' all land use types, agro-ecological zones or regions;
- The selection shows the potential, and need for, further documenting of experiences to cover the broad spectrum better.

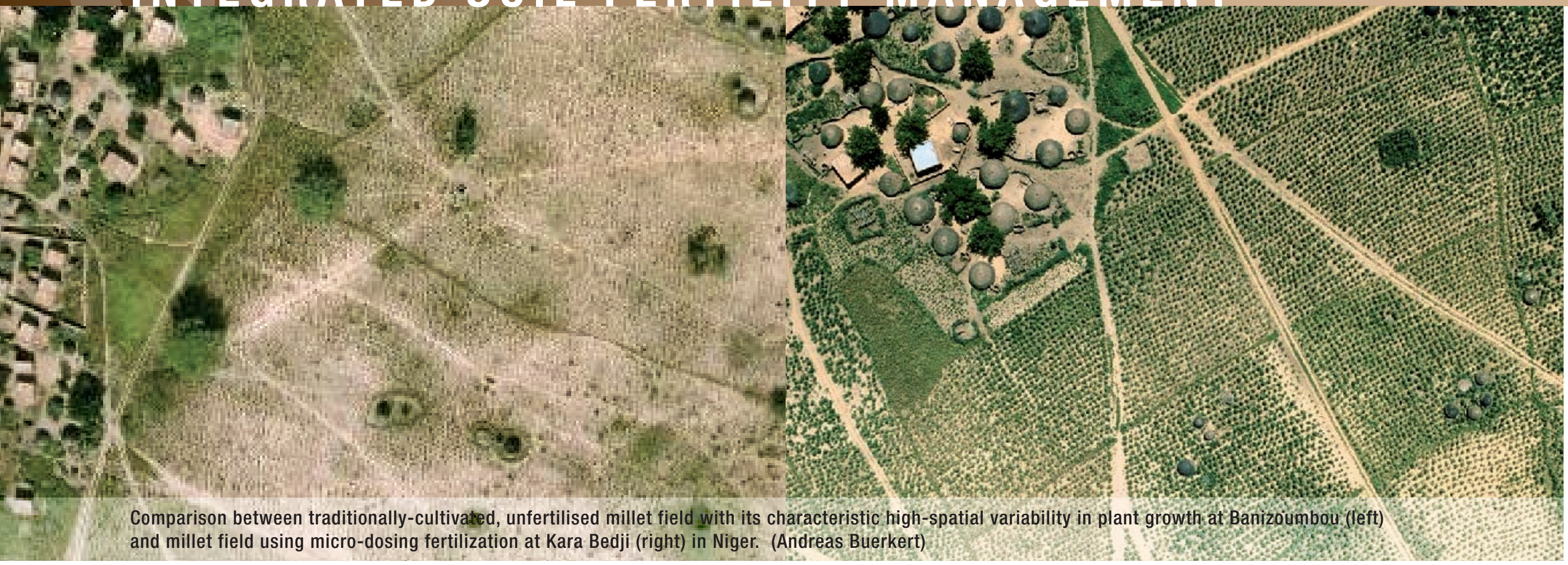
All groups and case studies are presented according to the familiar and standardised WOCAT format for documenting and disseminating SLM.

For the quantification of impacts the following categories are used in the presentation of SLM groups and case studies:

+++ = high impact
++ = moderate impact
+ = low impact
Na = not applicable

For the Benefit-cost ratio the meaning of the symbols «+» and «–» is slightly different (as indicated under the respective tables).

INTEGRATED SOIL FERTILITY MANAGEMENT



Comparison between traditionally-cultivated, unfertilised millet field with its characteristic high-spatial variability in plant growth at Banizoumbou (left) and millet field using micro-dosing fertilization at Kara Bedji (right) in Niger. (Andreas Buerkert)

In a nutshell

Definition: Integrated Soil Fertility Management (ISFM) aims at managing soil by combining different methods of soil fertility amendment together with soil and water conservation. It takes into account all farm resources and is based on 3 principles: (1) maximising the use of organic sources of fertilizer; (2) minimising the loss of nutrients; (3) judiciously using inorganic fertilizer according to needs and economic availability.

In Sub-Saharan Africa, soil fertility depletion is reaching a critical level, especially under small-scale land use. ISFM techniques can regenerate degraded soils and then maintain soil fertility by using available nutrient resources in an efficient and sustainable way. ISFM aims at making use of techniques without much additional cost to the farmer, such as organic fertilizer, crop residues and nitrogen-fixing crops, in combination with seed priming and water harvesting. A next step is the use of inorganic fertilizer, which requires financial input; however micro-fertilization can provide a cost-saving entry point.

Low cost ISFM techniques include: micro-dosing with inorganic fertilizers, manuring and composting, rock phosphate application, etc. SLM practices such as conservation agriculture or agroforestry include supplementary aspects of fertility management.

Applicability: ISFM is required in areas with low and rapidly declining soil fertility. Due to the wide variety of ISFM techniques, there is no specific climatic restriction for application apart from arid areas where water is constantly a limiting factor. ISFM is particularly applicable in mixed crop-livestock systems.

Resilience to climate variability: ISFM leads to an increase in soil organic matter (SOM) and biomass, and thus to soils with better water holding capacity that can support more drought-tolerant cropping systems.

Main benefits: Increased nutrient replenishment and soil fertility maintenance will enhance crop yields and thus increase food security, improve household income and hence improved livelihoods and well-being.

Adoption and upscaling: Land users' attitudes and rationale behind adoption of ISFM are influenced by the availability and access to inputs such as organic fertilizers (compost, manure) and the affordability of inorganic fertilizers. Access to financial services and micro-credit must be provided to land users to enable investment in fertility management. Awareness raising and capacity building on suitable options of ISFM techniques and appropriate application is needed.

Development issues addressed	
Preventing / reversing land degradation	++
Maintaining and improving food security	+++
Reducing rural poverty	++
Creating rural employment	+
Supporting gender equity / marginalised groups	++
Improving crop production	+++
Improving fodder production	+
Improving wood / fibre production	+
Improving non wood forest production	na
Preserving biodiversity	+
Improving soil resources (OM, nutrients)	+++
Improving of water resources	+
Improving water productivity	++
Natural disaster prevention / mitigation	+
Climate change mitigation / adaptation	++

Climate change mitigation	
Potential for C Sequestration (tonnes/ha/year)	no data
C Sequestration: above ground	+
C Sequestration: below ground	+

Climate change adaptation	
Resilience to extreme dry conditions	++
Resilience to variable rainfall	++
Resilience to extreme rain and wind storms	+
Resilience to rising temperatures and evaporation rates	+
Reducing risk of production failure	++

Origin and spread

Origin: Composting and manuring are traditional technologies, which are often reintroduced, in an improved form, through projects / programmes. The application of inorganic fertilizer is a relatively new technology, especially when applied on small-scale farms through micro-fertilization (or 'micro-dosing'). Micro-fertilization was developed through applied participatory research for use at small-scale level.

Mainly applied in: Integrated soil fertility management is applied in all parts of SSA, however the types of ISFM can differ depending on climate, soil, etc. Micro-fertilization has been the basis for reintroduction of fertilizer use in Mozambique, South Africa and Zimbabwe in Southern Africa; and Burkina Faso, Ghana, Mali, Niger and Senegal in West Africa.

Spread of micro-fertilization in SSA.

Principles and types

For optimized soil fertility management an integrated nutrient management system including both organic and inorganic inputs must be envisaged.

1. Organic inputs

Manuring and composting encompasses nutrient sources derived from plant or animal origin. Very often the availability of material is the main restriction, since it competes with feeding of animals and / or burning as fuel. Manure is a valuable, but often neglected resource in livestock and mixed farming systems because of its bulky nature and a lack of ox-carts and wheelbarrows for transportation around the smallholding. Including animals in farm production systems reduces the reliance on external inputs. Composting is the natural process of 'rotting' or decomposition of organic matter such as crop residues, farmyard manure and waste by micro-organisms under controlled conditions. It is an attractive proposition for turning on-farm organic waste into a farm resource and is gaining more importance among small-scale farmers in SSA.

The application of crop residues for mulching can also enhance soil fertility. Furthermore, seed priming can be used to reduce germination time. It ensures a more uniform plant establishment, and increases resistance to insects and fungus.

Integration of nitrogen fixing crops: Green manures or cover crops are leguminous plants that are intercropped or planted in rotation with other crops and used for nitrogen fixing in the soil. Very often green manure is incorporated into the soil, which is not the most effective way, due to the fast decomposition and release of nutrients: it is often better to slash and directly drill into the residue. The natural incorporation of cover crop and weed residues from the soil surface to deeper layers by soil micro- and macro-fauna is a slow process. Nutrients are released slowly and can provide the crop with nutrients over a longer period. Additionally, the soil is covered by the residues, protecting it against the impact of rain and sun.

2. Inorganic fertilizer

Crop yields can be dramatically improved (to a certain level) through the application of inorganic fertilizers at planting or as a top dressing after crop emergence. However, the application must be well targeted to reduce costs, to minimise GHG emissions and to avoid unhealthy plant growth, as well as an accelerated decomposition of soil organic matter. There is great pressure today to increase the availability and affordability of fertilizers for small-scale subsistence farmers in SSA. A low-cost method is micro-fertilization (or 'micro-dosing'). Small amounts of mineral fertilizer are applied to the planting hole at the time of sowing, and /or after emergence as a top dressing. Because soil fertility limits production, small and targeted doses of fertilizer can increase production significantly. To achieve long term soil fertility, micro-dosing should be combined with compost or manure because the small amounts of inorganic fertilizer used in micro-dosing are not sufficient to stop nutrient mining, nor do they directly build up the soil organic matter. Micro-fertilization can be the first step in lifting on-farm productivity and building the capacity of farmers to invest in manure or other organic or inorganic fertilizers.

Rock phosphate is said to have great potential, but it is yet underused because of the costs and limited availability in the local market, and the limited experience of farmers with applying it. A key issue is that the beneficial effects of rock phosphate become apparent only in the course of some years, compared to the immediate benefits of inorganic fertilizers.

Top: Compost pits with low containing walls, Ghana. (William Critchley)
Middle: *Tithonia diversifolia* as green manure in a cocoyam field, Cameroon. (Fabienne Thomas)
Bottom: One bottle cap of compound fertilizer for micro-dosing, Zimbabwe. (ICRISAT, Bulawayo)

Applicability

Land degradation addressed

Chemical soil deterioration: fertility decline through reduced soil organic matter content and nutrient loss
Physical soil deterioration: compaction, sealing and crusting
Water degradation: aridification
Soil erosion by water: loss of topsoil / soil surface

Land use

Mainly on annual cropland and mixed land (crop-livestock systems). Unsuitable for rangeland.

Ecological conditions

Climate: Compost making is most effective in subhumid to humid areas where water is available for watering. Here, above ground pits are better than the pits used in drier zones. Dry composting (covering the compost with soil and creating an anaerobic environment) is also applicable in arid areas.
Terrain and landscape: flat to hilly (transport is a heavy burden on very steep slopes)
Soils: ISFM is suitable for all types of soils, however it is difficult to increase the organic matter content of soils that are well aerated, such as coarse sands, and soils in warm-hot and arid regions because the added material decomposes rapidly. Soil organic matter levels can be maintained with less organic residue in fine textured soils in cold temperate and moist-wet regions with restricted aeration.

Socio-economic conditions

Farming system and level of mechanisation: Mainly manual labour for the making and spreading of compost and manure. Access to a wheelbarrow or an ox-cart aids movement of these bulky materials around the smallholding. The application of inorganic fertilizers can be undertaken manually in smallholder systems where small targeted applications are promoted. For large-scale commercial farming, fertilizer spreaders or combined seed and fertilizer drills are available. Crop rotation with nitrogen fixing crops can be integrated in either a manual or mechanised agricultural system.
Market orientation and infrastructure: Applicable for subsistence (self-supply), mixed (subsistence / commercial) farming and even commercial farming. The application of inorganic fertilizer (through micro-fertilization) is suitable for all types of crop production from subsistence to commercial.
Land ownership and land use / water rights: Individual land use rights or communal and individual not-titled land use rights influence the type and level of investment in soil fertility amendments and management.
Skill / knowledge requirements: Medium knowledge requirement regarding the careful application of inorganic fertiliser (N and P) to avoid loss, reduce GHG emissions and decomposition of soil organic matter, and appropriate use of crop rotations with nitrogen fixing legumes.
Labour requirements: Depending on the technology the level of labour required ranges considerably. Composting and manuring may require high labour inputs, depending on the distance of transport. Green cover crops involve a lower workload, since this can be integrated into the seasonal agricultural activities.
The application of inorganic fertilizer through a micro-dosing technique does not increase labour demand significantly since seeds and fertilizer are added simultaneously.

Land degradation

░ Erosion by water
□ Erosion by wind
■ Chemical degradation
▨ Physical degradation
□ Biological degradation
▨ Water degradation

■ High
▨ Moderate
░ Low
□ Insignificant

Land use

■ Cropland
□ Grazing land
□ Forests / woodlands
▨ Mixed land use
□ Other

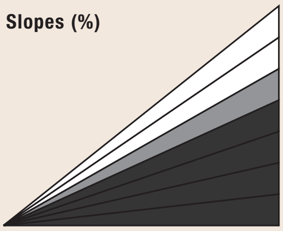
Climate

▨ Humid
■ Subhumid
■ Semi-arid
░ Arid

Average rainfall (mm)

□ > 3000
□ 2000-3000
▨ 1500-2000
■ 1000-1500
■ 750-1000
■ 500-750
▨ 250-500
□ < 250

Slopes (%)



□ very steep (>60)
□ steep (30-60)
▨ hilly (16-30)
■ rolling (8-16)
■ moderate (5-8)
■ gentle (2-5)
■ flat (0-2)

Farm size

■ Small scale
■ Medium scale
░ Large scale

Land ownership

□ State
□ Company
▨ Community
▨ Individual, not titled
■ Individual, titled

Mechanisation

■ Manual labour
░ Animal traction
░ Mechanised

Market orientation

■ Subsistence
■ Mixed
░ Commercial

Required labour

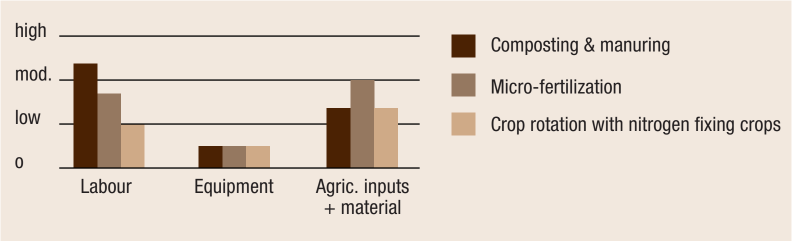
■ High
░ Medium
□ Low

Required know-how

□ High
■ Medium
□ Low

Economics

Maintenance costs



(Source: WOCAT, 2009)

Comment: Organic-based ISFM-techniques have lower cash requirements than the use of inorganic fertilizer; therefore they can more easily reach poorer households.
ISFM-techniques are agricultural measures / activities which have to be conducted every year / season, etc. The initial investment or establishment costs are negligible.

Production benefits

	Yield without SLM (kg/ha)	Yield with SLM (kg/ha)		Yield gain (%)	
Micro-fertilizing, (Mali) Sorghum Pearl millet	 500–800 200	 1100-1800[1] 300-370[1]	 900-1500[2] 400-500[2]	 30-50%[1] 48-70%[1]	 70-84%[2] 123-143%[2]
Zai+Micro-fertilizing, Sorghum (Burkina Faso) Sorghum (Ghana) Cowpea (Burkina Faso)	 552 290 590	 900-1200 400-650 950-1200		50-100%	
Tithonia - Green manure, (Cameroon) Beans	370	410-570		10-55%	

[1] application of 0.3 g fertilizer per hole; [2] application of 6 g fertilizer per hole.
(Sources: Aune, et al., 2007; WOCAT, 2009; ICRISAT))

Benefit-Cost ratio

	short term	long term	quantitative
Micro-fertilizing	+++	+++	Value-cost ratio, Mali: 3.5-12 (for 0.3 g), Sorghum 0.4-1.2 (for 6 g), Pearl Millet
Manuring & Fertilizer & 50% Crop Residues	+++	+++	Value-cost ratio, Nigeria: 20.8, Rice 5.9, Maize 3.5, Millet
Composting & Manuring	++	+++	
Green Manure	++	+++	
Overall	++	+++	

– – negative; – slightly negative; –/+ neutral; + slightly positive; ++ positive; +++ very positive
(Sources: Aune, et al., 2007; WOCAT, 2009 and IFPRI, 2010)

Comment: Micro-dosing shows an acceptable value-cost ratio (VCR) for land users. Even though the crop yield for the application of 6 g fertilizer is better than for 0.3 g fertilizer, the 0.3 g treatment appeals better to farmers because of the higher VCR and the better return on investment, low financial risk, low cash outlay and low workload required.

Example: Micro-fertilization, Mali

Aune et al. (2007) tested the agronomic, economic and social feasibility of micro-fertilizing in Mali. Two different amounts of fertilizer were applied to the holes, 6 g and 0.3 g. Both applications gave higher yields for pearl millet and sorghum in comparison to the control plot. Yields of sorghum increased by 34% and 52% compared with the control after applying 0.3 g of fertilizer per planting station for the years 2000 and 2001 respectively. For pearl millet, the corresponding yield increase was 48% and 67% for 2001 and 2003 respectively. Higher yield increases were observed when 6 g of fertilizer was applied per planting station than when 0.3 g of fertilizer was applied. The application of 0.3 g fertilizer has shown the better value-cost ratio (VCR), due to reduced workload and less inputs needed. The VCR varied from 3.4 to 12 in the 0.3 g treatment, and from 0.4 to 1.2 in the 6 g treatment. Application of 0.3 g of fertilizer appeals to farmers because of the good return on investment, low financial risk, low cash outlay and low workload required. Micro-dosing has been strongly promoted by ICRISAT. The amount of fertilizer recommended can be easily measured with a bottle cap which equates to approximately 6 g fertilizer. However, the study of Aune et al. has clearly shown that smaller amounts may have a better benefit / cost ratio. Nevertheless, for the long term sustainability micro-dosing should be combined with organic fertilization such as composting or manuring, otherwise nutrient mining cannot be stopped.

Example: Zimbabwe

Different studies have shown the high benefits of integrated soil fertility management compared to the application of single inorganic or organic fertilizers. The integration of manure and fertilizer on maize in Zimbabwe resulted in a return to labour of about US$ 1.35 per day, while the best single fertilizer or manure treatment yielded only US$ 0.25. Returns to integrated biomass transfer and rock phosphate systems on kale and tomatoes in Kenya showed returns to labour of between US$ 2.14 to US$ 2.68 as compared to a best return of US$ 1.68 when only one of the options was used. More economic analyses of farmer-managed ISFM systems are needed. However, existing evidence suggests that organic or ISFM systems may be remunerative where purchased fertilizer alone remains unattractive (Place et al., 2003).

Impacts

Benefits	Land users / community level	Watershed / landscape level	National / global level
Production	+++ increased crop yields ++ fodder production / quality increase + diversification of production	++ reduced risk and loss of production	+++ improved food and security
Economic	++ increased farm income ++ easy to maintain and to establish ++ simple technology using locally available material + reduced expenses on agricultural inputs (with manuring)	++ stimulation of economic growth + less damage to off-site infrastructure	+++ improved livelihood and well-being
Ecological	+++ increased organic matter and soil fertility ++ improved soil cover ++ reduced soil erosion by (water and wind) ++ improved excess water drainage ++ improved rainwater productivity ++ biodiversity enhancement + increased soil moisture + improved micro-climate	+ increased water availability + reduced degradation and sedimentation + intact ecosystem	++ reduced degradation and desertification incidence and intensity ++ increased resilience to climate change + enhanced biodiversity
Socio-cultural	++ improved conservation / erosion knowledge ++ ’is owned by the farmer’ + community institution strengthening + changing the traditional gender roles of men and women	+ increased awareness for environmental ‘health’ + attractive landscape	+ protecting national heritage

	Constraints	How to overcome
Production	• Need for water (for composting for optimal growth) • Availability of manure and compost and competition for materials (compost for animals or mulching; manure for house construction or fuel)	➜ furthering local market for organic fertilizers (manure and compost)
Economic	• Increased labour demands especially over using organic nutrient sources • Transportation of manure over too long distances not profitable • Affordability of inorganic fertilizers for small-scale land users – inflexible packaging in 50 kg bags • Lack of access to credit for investments (especially for inorganic fertiliser)	➜ purchase of inorganic fertilizer in a land user group and/ or provide small packages of fertilizers (e.g. 1-2 kg) ➜ ensure financial services and access of land users to small credits
Ecological	• It takes time to rejuvenate poor soils in SSA - the amount of organic material added is small relative to the mineral proportion of the soil • Waterlogging • Termites eating up trash; trash can harbour pests and diseases • Source of weeds; green manure could become a weed • Wrong application of inorganic fertilizer can lead to unhealthy plant grow and increased decomposition of soil organic matter • Inappropriate use of inorganic fertilizer and large applications of inorganic nitrogenous fertilisers can be a direct source of GHG emissions.	➜ needs integrated soil fertility management which encompasses organic and inorganic fertilizers in order to optimise the nutrient application ➜ control through weeding ➜ adequate training is necessary: better to use too little than too much fertilizer ➜ due to limited physical and economic access of smallholders to N-fertilizer, excessive use is not (yet) widespread in SSA. Appropriate and efficient use of N-fertiliser reduces the problem of GHG-emissions particularly if ammonium nitrate is used rather than urea
Socio-cultural	• Requires adequate knowledge especially for the right application of inorganic fertilizer • Some efforts do not have an immediate visible impact (e.g. rock phosphate, compost, etc.)	➜ effective and not too costly information provision and technical support ➜ appropriate awareness raising and information

Adoption and upscaling

Adoption rate

The use of animal manure and legume intercropping are well-established, whereas other practices like improved composting and micro-fertilization are relatively new and not yet widespread. So far, widespread adoption of ISFM practices has been hindered by high prices, and accessibility and availability of material and markets.

Upscaling

Profitability: The land user's decision is mainly influenced by perceived profitability of the system. Low-cost and resource-efficient methods should be promoted as a starting point for production intensification.

Access and availability of inputs must be ensured. Local markets for organic fertilizers such as manure or compost must be improved. Markets for green manure seeds do not yet exist to a significant degree. Inorganic fertilizers should be made available and methods promoted like micro-fertilization using only small amounts.

Access to financial services is needed and credit must be easily accessible by land users to facilitate investments in ISFM.

Access to markets and infrastructure: Functioning markets and market access is important for producing cash crops.

Awareness raising and promotion about the different options for better soil fertility management is needed.

Knowledge on ISFM: Capacity building on different and appropriate soil fertility techniques and educational programmes for the right application of inorganic fertilizers are needed (to reduce emissions of GHGs). Low adoption rates can be tackled by emphasising participatory learning and action-oriented research with stakeholders.

Incentives for adoption

In particular, there needs to be greater access to credit and economic rewards so that land users can make investments in soil fertility management. Users of inorganic fertilizer will need to develop a market-oriented approach. In many cases, small-scale land users cannot operate as individuals because that will make the purchase of fertilizer too expensive.

Enabling environment: key factors for adoption

Inputs, material incentives, credits	+++
Training and education	++
Land tenure, secure land use rights	++
Access to markets	++
Research	+
Infrastructure	+

Example: Kenya

Place et al. (2003) have compiled different rates of adoption for ISFM techniques. In Kenya, between 86% and 91% of farmers used manure in semi-arid and semi-humid zones east of Nairobi. Compost was adopted by about 40% of farmers in the more favourable parts of these zones, but by relatively few in the more arid sites. In the more humid western highlands, Place et al. (2002a) found that 70% of households used manure and 41% used compost. It was found that 49% of Rwandan farmers' plots received organic nutrient inputs, and Gambara et al. (2002) found legume rotations and green manure systems practiced in 48% and 23% respectively of focal extension areas in Zimbabwe. While the relative adoption rates between organic and mineral nutrients vary by location, the incidence of organic practices (especially natural fallowing and animal manure) often outpaces the use of mineral fertilizers (Place et al. 2003).

References and supporting information:

Aune J.B., A. Bationo. 2008. Agricultural Intensification in the Sahel – The ladder approach. Agricultural Systems 2008.

Aune J.B., D. Mamadou and A. Berthe. 2007. Microfertilizing sorghum and perl millet in Mali – Agronomic, economic and social feasibility. Outlook on Agriculture, Vol. 36. No. 3. pp 199-203.

Enyong L.A., S.K. Debrah, and A. Batiano. 1999. Farmers' perceptions and attitudes towards introduced soil-fertility enhancing technologies in western Africa. Nutrient Cycling in Agroecosystems 53: 177–187.

FAO. 2005. The importance of soil organic matter – Key to drought-resistant soil and sustained food and production. FAO Soils Bulletin 80.

ICRISAT. 2004. SATrends ISSUE 41, http://www.icrisat.org/satrends/apr2004.htm, accessed on 14 September 2009.

ICRISAT. 2008. International Crops Research Institute for the Semi-Arid Tropics - Eastern and Southern Africa Region. 2007 Highlights. PO Box 39063, Nairobi, Kenya: ICRISAT. 52pp.

Mati B. M. 2005. Overview of water and soil nutrient management under smallholder rainfed agriculture in East Africa. Working Paper 105. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Misra R.V., R.N. Roy, and H. Hiraoka. 2003. On-farm composting methods. FAO Land and Water Discussion Paper 2. Food and Agricultural Organization of the United Nations, Rome.

Osbahr H., Ch. Allan. 2003. Indigenous knowledge of soil fertility management in southwest Niger. Geoderma 111 (2003) 457–479.

Place F., Ch. B. Barrett, H.A. Freeman, J.J. Ramisch, B. Vanlauwe. 2003. Prospects for integrated soil fertility management using organic and inorganic inputs: evidence from smallholder African agricultural systems. Food Policy 28 (2003) 365–378.

Thomas F. 2005. Agroökologische Innovationen am Beispiel der Nutzung von Tithonia diversifolia (Mexican Sunflower) zur nachhaltigen Verbesserung der Nahrungsmittelsicherheit. Diplomarbeit, Departement der Geowissenschaften der Universität Freiburg, Einheit Geographie.

WOCAT. 2009. WOCAT databases on SLM technologies and SLM approaches. www.wocat.net, accessed on 15 September 2009

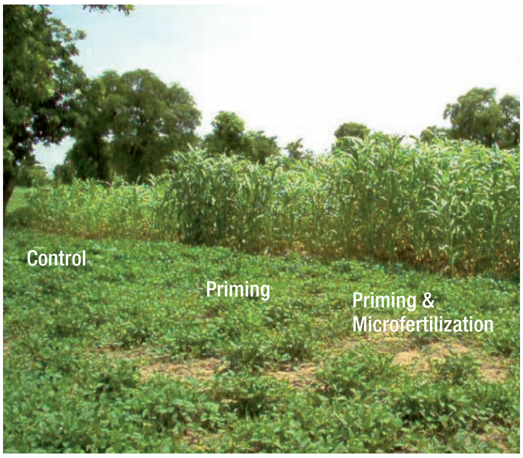
Woodfine, A. 2009. Using sustainable land management practices to adapt to and mitigate climate change in Sub-Saharan Africa: resource guide version 1.0. TerrAfrica. www.terrafrica.org

SEED PRIMING AND MICROFERTILIZATION - MALI

Seed priming and microfertilization have been found to be effective in increasing pearl millet and sorghum yields under dryland cropping systems. It is also applicable for cowpeas, groundnuts and sesame. Seed priming consists of soaking seeds for 8 hours prior to sowing and microfertilization is the application of small amounts of mineral fertilizer to the planting hole.

Seed priming should be carried out after a rain shower sufficient for sowing (15-20 mm) at the beginning of the rainy season. After soaking, the seeds should be air-dried for 1 hour prior to sowing (to reduce the stickiness of the seeds and to reduce risk of burning by fertilizer). Fertilizer (NPK 16-16-16; or Diammonium Phosphate) is applied at a micro-dose of 0.3 g per planting station, equivalent to 3-8 kg fertilizer/ha, dependent on plant population density. The air-dried seeds and the fertilizer can be applied simultaneously by first mixing the seeds and the fertilizer and thereafter taking a pinch of the mixture between thumb and forefinger.

Priming increases water use efficiency because seeds start germinating immediately after sowing. Results from Mali (Koro and Segou) show that yields can be increased by 50% if microfertilization is combined with seed priming. Other benefits are reduced labour constraints (thanks to simultaneous application) and risk reduction. Seed priming and microfertilization can be practiced independently from each other; however, the combination reduces the risk of crop failure and shows best results in terms of yield increase. Microfertilization has also been mechanised in Mali.



SLM measure	Agronomic
SLM group	Integrated Soil Fertility Management
Land use type	Annual cropping (pearl millet)
Degradation addressed	Soil fertility decline
Stage of intervention	Mitigation
Tolerance to climate change	Increased tolerance to droughts (particularly at beginning of growing season) due to better plant establishment

Establishment activities

Note: Seed priming and microfertilization are agronomic measures which are carried out repeatedly each cropping season. All activities are listed under maintenance / recurrent activities (below). There is no establishment phase (as defined by WOCAT).

Maintenance / recurrent activities

1. Soak seeds for 8 hours prior to sowing (onset of rainy season, late June).
2. Mix seeds and NPK fertilizer (16-16-16) or DAP at a ratio of 1:1 before sowing.
3. Sow seeds and fertilizer simultaneously and cover with soil.

Note: Seed priming can be started after sufficient rain for sowing has been received. If the method fails, it can be repeated again.

Option: If farmers have the resources to buy higher amount of fertilizer and if the season is promising, they can apply 2 g fertilizer per pocket at first weeding (20 days after sowing). This results in higher yields but also requires an additional operation for the farmer, tripling the labour inputs for fertilizer application. If this practice is adopted, it is not necessary to apply 0.3 g fertilizer at sowing.

All activities are carried out by manual labour; microfertilization has partly been mechanised, using an ox-drawn implement.

Labour requirements

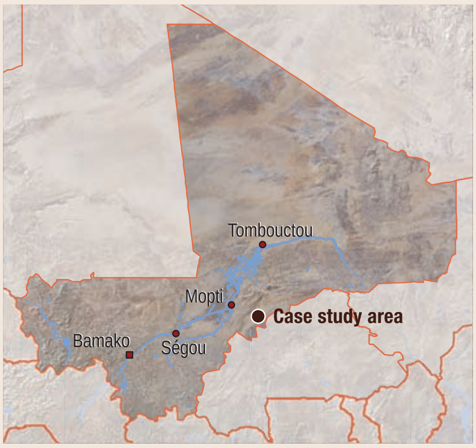
For establishment: na
For maintenance: low

Knowledge requirements

For advisors: low
For land users: low

Photo 1: Priming – soaking the seeds for 8 hours. (Adama Coulibaly)
Photo 2: Effect on yields of priming and of the combination microfertilization & priming compared to control plot. (Adama Coulibaly)
Photo 3: Farmers practicing microfertilization with animal traction. (Jens B. Aune)

Case study area: Koro, Mopti Region, Mali



Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour	0
Equipment	0
Agricultural inputs	0
TOTAL	**0**

No establishment costs.

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 6 person-days	1
Equipment / tools: planting stick / hoe	0
Agricultural inputs: 47 kg superphosphate fertilizer	2
TOTAL	**3**

Remarks: Sowing can alternatively be mechanised, which will cause establishment costs (purchase of the sowing machine).

Benefit-cost ratio

Inputs	short term	long term
Establishment	na	na
Maintenance	very positive	very positive

Remarks: The technology has a benefit-cost ratio of 10 (increased production value is 10 times higher than the costs for additional fertilizer). Compared to the 6 g microfertilization method (using bottle caps) cost-benefit ratio of 0.3 g treatment is 8-20 times higher.

Ecological conditions

- Climate: semi-arid; rainy season: late June – middle of October
- Average annual rainfall: 400-800 mm
- Soil parameters: low fertility and low soil organic matter
- Slope: mainly flat (0-2%), partly gentle (2-5%)
- Landform: plains
- Altitude: 260 m a.s.l.

Socio-economic conditions

- Size of land per household: 2-20 ha
- Type of land user: small-scale / large-scale; poor, average and rich land users
- Population density: no data
- Land ownership: community
- Land use rights: individual / communal
- Level of mechanisation: mainly manual / partly animal traction
- Market orientation: mixed (subsistence and commercial)

Production / economic benefits

+++ Increased crop yield: combined effect of seed priming and microfertilization 50%, seed priming alone 25%

+++ Increased production of straw / biomass

++ Decreased financial resources needed for purchasing fertilizer, makes the technology feasible for poor small-scale farmers

++ Risk minimisation: decreased risk of crop failure; and low financial risk in the case of crop failure; seed priming reduces the risk of fertilizer application

++ No additional labour inputs (the technology does not significantly increase sowing time due to simultaneous application of seeds and fertilizer)

++ Increased land productivity / clearance of new land is avoided

\+ Earlier harvest (food security)

Ecological benefits

+++ Reduced susceptibility to beginning-of-season droughts; less burning effect if drought after sowing

++ Reduced exposure of plants to droughts (compared to 6 g treatment)

++ Increased resistance to Striga (pest)

Socio-cultural benefits

\+ Can be mechanised

Off-site benefits

\+ Improved nutrition and both on-farm and off-farm employment

Weaknesses ➜ and how to overcome

- Dependence partly on availability of mineral fertilizer ➜ the technology should be combined with complementary methods for maintenance of soil fertility, such as increased recycling of crop residues as mulch and manure application.

Adoption

Trend for spontaneous adoption is high. Microfertilization has become a very popular technology in some area in Mali. Field officers from NGO's report that in some villages in the 'Dogon area' in the Mopti region more than 50% of the farmers are using the technology on their own initiative. NGOs working in the Mopti and Segou regions are currently actively promoting seed priming and microfertilization.

Main contributors: Jens B. Aune, Noragric/Department of International Environment and Development Studies; Norwegian University of Life Sciences; As, Norway; jens.aune@umb.no, http://www.umb.no

Key references: Aune JB, Doumbia M, Berthe A (2007): Microfertilizing sorghum and pearl millet in Mali - Agronomic, economic and social feasibility in Outlook on AGRICULTURE Vol 36, No 3, 2007, pp 199–203 ■ Aune JB, Doumbia M, Berthe A (2005): Integrated Plant Nutrient Management Report 1998-2004; Drylands Coordination Group Report 36, Norway ■ Aune JB, Bationo A (2008): Agricultural intensification in the Sahel. Agricultural Systems 98: 119-125; ■ Habima, D. 2008. Drylands ecofarming: An analysis of ecological farming prototypes in two Sahelian zones: Koro and Bankass. M.Sc Thesis, UMN, Ås, Norway

GREEN MANURING WITH TITHONIA - CAMEROON

Tithonia diversifolia hedges grow along roadsides or farm boundaries. The green leaf biomass is very suitable as green manure for annual crops, since the plant has a high content of nitrogen and phosphorus, and decomposes quickly after application to the soil: its nutrients are released within one growing season.

At an early stage of plant growth, fresh green leaves and stems are cut, chopped and applied on the cropland as green manure after the first pass of ridging. The fresh material is spread over the half-made ridges at a rate of 2 kg per m^2 and then covered with about 5-10 cm of soil to finish the ridges. Sowing of crop seeds is done only after a week or more, because of heat generation during the decomposition process of the leaves (which could damage the seeds).

Tithonia biomass enhances soil organic matter and soil fertility, resulting in higher crop yields. The treatment supplies the crop with nutrients at the early stage of the growing process, and thus improves the establishment of the crops through the early development of a good rooting system. The technology is especially beneficial for maize: yields in the study area increased by over 50%.

Tithonia can also be applied as mulch 6 to 8 weeks after planting the crop. Covering the mulch with a little soil facilitates nutrient release. Tithonia green manuring - before planting - and mulching can be combined, which is especially applicable to maize, beans and cabbage cultivation. Tithonia hedgerows have to be cut back regularly; otherwise it can spread fast and become a weed. Interplanting Tithonia in the field is not recommended due to root competition with crops.

SLM measure	Agronomic
SLM group	Integrated Soil Fertility Management
Land use type	Annual cropping
Degradation addressed	Soil fertility decline and reduced organic matter content
Stage of intervention	Mitigation and prevention
Tolerance to climatic change	No data

Establishment activities

1. Planting Tithonia along farm / field boundaries and along roadsides (if not growing naturally).

Maintenance / recurrent activities

1. Regular cutting of Tithonia plants: cutting back hedges in the dry season (Dec./Jan.) ensures that fresh material can be harvested from March to May.
2. Collect any organic material on the cropland and place it in the furrows of the previous cropping season (which will become the ridges of the new cropping season) in February.
3. Harvesting and chopping green leaves and stems of Tithonia (March-May).
4. Transport to farm and spread fresh Tithonia material on half-done ridges; and cover with earth.
5. Let decompose the green manure for at least 1 week before sowing the crops.
6. Apply a mulch layer of fresh Tithonia material (6-8 weeks after sowing; optional).

All activities carried out manually (using cutlasses and hoes). Cutting back is done annually, harvesting and spreading 1-2 times a year.

Labour requirements

For establishment: low
For maintenance: high

Knowledge requirements

For advisors: moderate
For land users: moderate

Photo 1: Effects of applying *Tithonia diversifolia*: cocoyam with green manure (left ridge) and cocoyam without green manure (right ridge).
Photo 2: Application of organic material to build ridges for the next cropping season.
Photo 3: Hedge of *Tithonia diversifolia*, known also as Mexican sunflower. (All photos by Fabienne Thomas)

Case study area: Akiri, North-West Province, Cameroon

Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour	–
Equipment	–
Agricultural Inputs	–
TOTAL	no data

Remarks: Costs for planting Tithonia along farm / field boundaries and along roadsides (if not growing naturally) are not known.

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 6 person-days	80
Equipment / tools: planting stick / hoe	30
Agricultural inputs: 47 kg superphosphate fertilizer	0
TOTAL	110
% of costs borne by land users	100%

Remarks: Labour costs are the main factor affecting the costs. Labour inputs depend a lot on transport distance between Tithonia hedge and cropland.

Benefit-cost ratio

Inputs	short term	long term
Establishment	na	na
Maintenance	positive	positive

Remarks: The closer to the field Tithonia is planted, the better is the benefit-cost ratio.

Ecological conditions

- Climate: subhumid
- Average annual rainfall: mainly 2,000-3,000 mm, partly 1,500-2,000 mm; rainy season mid March – mid October
- Soil parameters: medium fertility, medium soil organic matter, medium drainage
- Slope: mainly hilly (16-30%), partly mountain slopes (30-60%)
- Landform: hill and mountain slopes
- Altitude: 1,000-1,500 m a.s.l.

Socio-economic conditions

- Size of land per household: mainly 1-2 ha, partly 2-5 ha
- Type of land user: poor small-scale farmers
- Population density: 70-100 persons/km^2
- Land ownership: individual
- Land use rights: individual
- Market orientation: mainly subsistence, partly mixed (subsistence and commercial)
- Level of mechanisation: manual labour

Production / economic benefits

+++ Increased crop yield (over 50%, especially beneficial for maize)
\+ Increased farm income
\+ Cheap fertilizer

Ecological benefits

++ Increased soil fertility
\+ Increased soil moisture
\+ Improved soil cover
\+ Windbreak

Socio-cultural benefits

\+ Improved knowledge about green manure
\+ Health: Tithonia has also a medicinal use (anti-inflammatory effect)
\+ Life barrier: hedges avoid uncontrolled entering of cattle into cropland

Weaknesses ➜ and how to overcome

- Can spread as a weed on cropland (if planted close to fields) and also outside the area where it is used; some farmers consider the plant as poisonous ➜ advisory service is important, good information on proper management of Tithonia; regular cutting.
- Labour-intensive technology (harvest, transport, regular cutting, chopping and spreading) ➜ providing / subsidising transport equipment such as wheelbarrows would make transport more effective and time-saving.
- Might lead to conflicts if too many farmers want to use it ➜ clarify user rights; replant Tithonia plants and grow new hedges.

Adoption

There is a strong trend towards spontaneous adoption. In the villages where the technology has been implemented the interest of other farmers is big. All land users in the case study area have adopted the technology without any external support. Total area of land treated with the technology in the case study area is 0.3 km^2.

Main contributors: Fabienne Thomas; fabienne.thomas@volkart.ch ■ Urs Scheidegger, Swiss College of Agriculture SHL, Head International Agriculture, Switzerland; urs.scheidegger@bfh.ch.

Key references: WOCAT. 2004. WOCAT database on SLM Technologies, www.wocat.net ■ Thomas F. 2005. Agroökologische Innovationen am Beispiel der Nutzung von Tithonia diversifolia (Mexican Sunflower) zur nachhaltigen Verbesserung der Nahrungsmittelsicherheit. Diplomarbeit. Departement für Geowissenschaften – Geographie Universität Freiburg.

COMPOST PRODUCTION - BURKINA FASO

Compost is produced in shallow pits, approximately 20 cm deep and 1.5 m by 3 m wide. During the dry season after harvesting, layers of chopped crop residues, animal dung and ash are heaped, as they become available, up to 1.5 m high and watered. The pile is covered with straw and left to heat up and decompose. After 15–20 days the compost is turned over into a second pile and watered again. This is repeated up to three times – as long as water is available. Compost heaps are usually located close to the homestead. Alternatively, compost can be produced in pits up to 1 m deep. Organic material is filled to ground level. The pit captures rain water, which makes this method of composting a valuable option in dry areas.

The compost is either applied immediately to irrigated gardens, or kept in a dry shaded place for the next sorghum seeding. In the latter case one handful of compost is mixed with loose soil in each planting pit (*zai*). Compost in the pits conserves water and supplies nutrients. This enables the sorghum plants to establish better, grow faster and reach maturity before the rains finish. Vulnerability to droughts and risk of crop failure is reduced.

As compost is applied locally to the crop, not only is the positive effect maximised, but the weeds between the pits do not benefit either. It is the high water retaining capacity of the compost that makes the main difference, and is much more important than the additional nutrients, which only become available in subsequent years, and do not completely replace all the nutrients extracted by the crops. During the dry season, after harvest, fields are grazed by cattle of the nomadic pastoral *Peuhl*, who also herd the agriculturalists' livestock.

SLM measure	Agronomic
SLM group	Integrated Soil Fertility Management
Land use type	Mixed: agropastoral
Degradation addressed	Fertility decline; Erosion by water; Soil moisture problem; Compaction and crusting
Stage of intervention	Mitigation and rehabilitation
Tolerance to climate change	No data

Establishment activities

1. Dig two compost pits (3 m by 1.5 m and 20 cm deep) at the beginning of the dry season (November).
2. Cover the bottom of each pit with 3 cm clay layer.

Duration of establishment: 1 week

Maintenance / recurrent activities

1. Put 20 cm layer of chopped crop residues (cereal straw) into the compost pit and water with one bucket (November).
2. Add 5 cm layer of animal manure.
3. Add 1 cm layer of ash.
4. Repeat steps 1–3 until the compost pile is 1.0–1.5 m high.
5. Cover pile with straw to reduce evaporation, and leave to decompose. Check heating process within the heap by inserting a stick.
6. Turn compost after 15 days into the 2nd pit, then after another 15 days back into the 1st pit. Turning over is done up to 3 times (as long as water is available).
7. Water the pile after each turning with 3 buckets of water.
8. Store ready compost in dry shady place (January).
9. Transport compost to the fields by wheelbarrow or donkey-cart (before onset of rains) and apply a handful per planting pit before planting (after the first rains).

Labour requirements

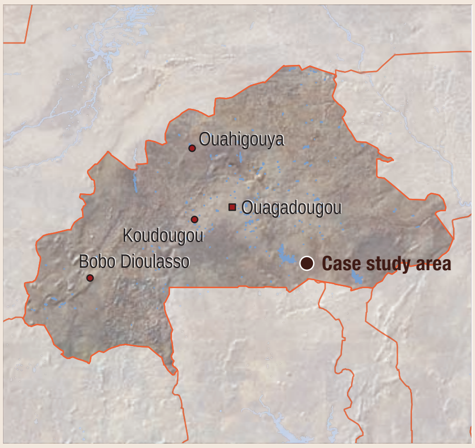
For establishment: low
For maintenance: medium

Knowledge requirements

For advisors: moderate
For land users: low

Photo 1: Application of one handful of compost in planting pits. (William Critchley)
Photo 2: Sorghum yields with and without compost application. (Reynold Chatelain)
Photo 3: Compost pits with low containing walls: Pit compost requires little or no additional water and is preferable in dry zones. (William Critchley)

Case study area: Boulgou Province, Burkina Faso



Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour: 2 person-days	2
Equipment: hoe, digging stick, bucket	10
Construction material: clay (0.5 m^3)	0
TOTAL	**12**
% of costs borne by land users	100%

Remarks: Establishment costs are for two pits which are needed to manure one hectare.

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 20 person-days	20
Equipment: wheelbarrow renting	6
Agricultural inputs: manure (100 kg)	2
Material: ash, straw	0
Compost transportation	2
TOTAL	**30**
% of costs borne by land users	100%

Remarks: Costs relate to production and application of 1 tonne of compost per ha (the product of one full compost pit). The compost is directly applied to planting pits at a rate of 7–10 t/ha (equal to actual rates applied in small irrigated gardens). If compost is produced in deep pits, production is cheaper because there is less work involved.

Benefit-cost ratio

Inputs	short term	long term
Establishment	very positive	very positive
Maintenance	very positive	very positive

Ecological conditions

- Climate: semi-arid
- Average annual rainfall: 750-1,000 mm (partly 500-750 mm)
- Soil parameters: fertility is mainly low, partly medium; depth is 50-80 cm; partly 20-50 cm; drainage is mainly poor, partly medium; organic matter content is low and further decreasing; soil texture is mainly clay, partly sandy (in depressions)
- Slope: mainly gentle (2-5%), partly moderate (5-8%)
- Landform: plains / plateaus
- Altitude: 100-500 m a.s.l.

Socio-economic conditions

- Size of land per household: < 1 ha or 1-2 ha
- Type of land user: small-scale; poor
- Population density: no data
- Land ownership: communal / village
- Land use rights: communal (organised)
- Level of mechanisation: manual labour
- Market orientation: mainly subsistence (self-supply), in good years mixed (subsistence and commercial)

Production / economic benefits

+++ Increased crop yield
+++ Increased farm income (by several times in dry years, compared to no compost use)
++ Increased fodder production and fodder quality

Ecological benefits

+++ Increased soil moisture
++ Increased soil fertility
++ Improved soil cover
++ Efficiency of excess water drainage
+ Reduced soil loss

Socio-cultural benefits

+ Community institution strengthening
++ Improved conservation/ erosion knowledge
++ Integration of agriculturalists and pastoralists

Weaknesses ➜ and how to overcome

- The modest quantity of compost applied is not enough to replace the nutrients extracted by the crops in the long term ➜ small amounts of nitrogen and phosphorous fertilizer need to be added and crop rotation practised.
- The short / medium term local benefits are not associated with a positive overall, long term ecological impact because there is a net transfer of organic matter (manure) to the fields from the surroundings ➜ improve management of the vegetation outside the cropland, avoiding overgrazing etc. to increase manure production.
- Needs considerable water and thus also extra-labour ➜ pit composting helps to reduce water requirement in drier areas and at the same time reduces labour input.

Adoption

Composting has been applied in Boulgou Province of Burkina Faso since 1988. 5,000 families adopted the technology (without external incentives), total area of manured fields is 200 km^2. Even some pastoralists use it in their gardens. There is a strong trend towards growing spontaneous adoption, with extension from farmer to farmer. The pastoral *Peuhl* have started to systematically collect the manure for sale, since the increased demand for manure in composting has led to doubling of the price.

Main contributors: Jean Pascal Etienne de Pury, CEAS Neuchâtel, Switzerland; www.ceas.ch
Key references: WOCAT. 2004. WOCAT database on SLM Technologies, www.wocat.net ■ Ouedraogo E. 1992. Influence d'un amendement de compost sur sol ferrugineux tropicaux en milieu paysan. Impact sur la production de sorgho à Zabré en 1992. Mémoire de diplôme. CEAS Neuchâtel, Switzerland ■ Zougmore R., Bonzi M., et Zida Z. 2000. Etalonnage des unités locales de mesures pour le compostage en fosse de type unique étanche durable. Fiche technique de quantification des matériaux de compostage, 4pp

PRECISION CONSERVATION AGRICULTURE - ZIMBABWE

Precision Conservation Agriculture (PCA) is a combined technology that encompasses four basic principles: (1) minimum tillage – use of small planting basins which enhance the capture of water from the first rains and allow efficient application of limited nutrient resources with limited labour input; (2) the precision application of small doses of nitrogen-based fertilizer (from organic and / or inorganic sources) to achieve higher nutrient efficiency; (3) combination of improved fertility with improved seed for higher productivity; and (4) use of available residues to create a mulch cover that reduces evaporation losses and weed growth.

Crop mixes are adapted to the local conditions and household resource constraints. Cereal / legume rotations are desirable. PCA spreads labour for land preparation over the dry season and encourages more timely planting, resulting in a reduction of peak labour loads at planting, higher productivity and incomes. Over four years these simple technologies have consistently increased average yields by 50 to 200%, depending on rainfall regime, soil types and fertility, and market access. More than 50,000 farm households apply the technology in Zimbabwe.

PCA strategies are promoted by ICRISAT, FAO and NGOs in Southern Africa focusing on low potential zones with the most resource-poor and vulnerable farm households.

SLM measure	Agronomic
SLM group	Combined: Integrated Soil Fertility Management and Conservation Agriculture
Land use type	Annual cropping (cereals)
Degradation addressed	Soil fertility decline and reduced organic matter; Soil erosion by water; Sealing and crusting
Stage of intervention	Prevention and mitigation
Tolerance to climate change	Increased resilience to droughts

Establishment activities

Note: PCA is based on agronomic measures which are carried out repeatedly each cropping season. All activities are listed under maintenance / recurrent activities (below). There is no establishment phase (as defined by WOCAT).

Maintenance / recurrent activities

1. Spreading residues (after harvesting).
2. Winter weeding.
3. Land preparation: mark out basins using planting lines and dig planting basins (dry season).
4. Application of available fertilizer: manure at a rate of a handful per planting basin (1,500-2,500 kg/ha) and micro-doses of basal fertilizer at a rate of 1 level beer bottle cap per pit (92.5 kg/ha); cover lightly with clod-free soil (soon after land preparation).
5. Planting at onset of rains; cover seed with clod-free soil.
6. First weeding when weeds appear.
7. Second Weeding (Dec.-Jan.; when cereals are at 5 to 6 leaf stage).
8. Apply micro-dose of top dress fertilizer (Ammonium Nitrate) at a rate of 1 level beer bottle cap per basin (83.5 kg/ha) (cereals at 5 to 6 leaf stage).
9. Third weeding.
10. Harvesting.

Hand hoes, planting lines marked at appropriate spacings.

Labour requirements

For establishment: high
For maintenance: medium to low

Knowledge requirements

For advisors: high
For land users: high

Photo 1: Excavation of planting pits (Dimensions: 15 cm by 15 cm by 15 cm; Spacing: varies between 60 – 90 cm, depending on average rainfall).
Photo 2: Mulch cover on planting pits.
Photo 3: Application of a micro-dose of basal fertilizer (a compound applied prior to planting in the bottom of the planting pit).
Photo 4: Application of a handful of organic manure.
Photo 5: Application of micro-dose of top dressing.
(All photos by ICRISAT)

Case study area: Bulawayo, Zimbabwe

Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour	0
Equipment	0
Agricultural inputs	0
TOTAL	**0**

No establishment costs.

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 124 person-days	108
Equipment: hand hoes	7
Agricultural inputs: fertilizer	69
TOTAL	**184**
% of costs borne by land users	no data

Remarks: Labour costs do not include harvesting (8 person-days/ha). Initially, fertilizers were partly subsidised by project, at a later stage farmers purchased more as they increased the area and became more self-reliant. Most households start applying chemical fertilizer from the 2nd year on (at least 1 bag).

Benefit-cost ratio

Inputs	short term	long term
Establishment	positive	very positive
Maintenance	positive	very positive

Remarks: Initial results suggest a cost-benefit ratio of US$ 3.5 per US$ invested. Returns to labor have been about two times higher than conventional practices.

Ecological conditions

- Climate: semi-arid
- Average annual rainfall: 450-950 mm
- Soil parameters: low fertility, medium depth, good drainage, low organic matter content
- Slope: average slope is 1-7%
- Landform: plains, footslopes
- Altitude: 500-1,500 m a.s.l.

Socio-economic conditions

- Size of land per household: 1-3 ha
- Type of land user: small-scale; poor / average level of wealth
- Population density: 10-50 persons/km^2
- Land ownership: communal (not titled)
- Land use rights: communal
- Market orientation: subsistence
- Level of mechanisation: manual labour / animal traction
- Opportunity to introduce commercial crops as part of the rotation if market access developed

Production / economic benefits

+++ Increased crop yield (400 kg/ha before, 1520 kg/ha after; increase varies between 50-200%)
+++ Increased fodder production (600 kg/ha before, 2200 kg/ha after)
+++ Increased farm income
+++ Increased product diversification
++ Reduced risk of production failure

Ecological benefits

++ Increased water quality
++ Increased soil moisture and reduced evaporation
++ Increased soil organic matter
++ Increased beneficial species
+ Weed control (timely weeding in combination with mulching)
+ Improved soil cover

Socio-cultural benefits

+++ Communities institution strengthening
+++ Improved situation of socially and economically disadvantaged groups (gender, age, status, ethnicity etc.)
+++ Improved food security / self-sufficiency (household meets food needs from less land)

Weaknesses ➜ and how to overcome

- Availability of residues and willingness to use as mulch ➜ long term demonstrations required.
- Access to basal and top dress fertilizers ➜ input market development and identification of enabling government policies. If the access to nitrogen fertilizer can be improved there is a great chance that households will move from a food insecure state to one of surplus.
- Lack of rotations and legumes poorly adopted ➜ increase access to quality legume seeds and develop output markets.

Adoption

5% of land users have applied the SLM technology. There is evidence of spontaneous adoption, with more than 50,000 households with at least 0.3 ha of basins in 2008. The average area per household increased from 1,500 m^2 in 2004 to more than 3,500 m^2 in 2008.

Main contributors: Steve Twomlow, UNEP, Nairobi, Kenya; stephen.twomlow@unep.org; www.unep.org

Key references: Hove L, Twomlow S. 2008. Is conservation agriculture an option for vulnerable households in Southern Africa? Paper presented at the Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas Workshop, United Nations Food and Agricultural Organization, 7-9 May, 2007. Damascus, Syria ■ Mazvimavi K., and S. Twomlow. 2009. Socioeconomic and institutional factors influencing adoption of conservation farming by vulnerable households in Zimbabwe. Agricultural Systems, 101 (1), p.20-29 ■ Pedzisa I., I. Minde, and S.Twomlow. 2010. An evaluation of the use of participatory processes in wide-scale dissemination of research in micro dosing and conservation agriculture in Zimbabwe. Research Evaluation, 19(2). ■ Twomlow S., J. Urolov, J.C. Oldrieve, B. Jenrich M. 2008. Lessons from the Field Zimbabwe's Conservation Agriculture Task Force. Journal of SAT Agricultural Research, 6.

CONSERVATION AGRICULTURE

Farmer explaining the difference between conventional tillage (left) and conservation tillage (right), Kenya. (Hanspeter Liniger)

In a nutshell

Definition: Conservation Agriculture (CA) is a farming system that conserves, improves, and makes more efficient use of natural resources through integrated management of soil, water and biological resources. It is a way to combine profitable agricultural production with environmental concerns and sustainability. The three fundamental principles behind the CA concept are: minimum soil disturbance, permanent soil cover, and crop rotation. Each of the principles can serve as an entry point to the technology; however, only the simultaneous application of all three results in full benefits. CA covers a wide range of agricultural practices based on no-till (also known as zero tillage) or reduced tillage (minimum tillage). These require direct drilling of crop seeds into cover crops or mulch. Weeds are suppressed by mulch and / or cover crops and need to be further controlled either through herbicide application or pulling by hand.

Applicability: CA has been proven to work in a variety of agro-ecological zones and farming systems: high or low rainfall areas; in degraded soils; multiple cropping systems; and in systems with labour shortages or low external-input agriculture. CA has good potential for spread in dry environments due to its water saving ability, though the major challenge here is to grow sufficient vegetation to provide soil cover.

Resilience to climate variability: CA increases tolerance to changes in temperature and rainfall including incidences of drought and flooding.

Main benefits: CA is considered a major component of a 'new green revolution' in SSA which will help to make intensive farming sustainable through increased crop yields / yield reliability and reduced labour requirements; will cut fossil fuel needs through reduced machine use; will decrease agrochemical contamination of the environment through reduced reliance on mineral fertilizers; and will reduce greenhouse gas emissions, minimise run-off and soil erosion, and improve fresh water supplies. CA can thus increase food security; reduce off-site damage; reduce foreign exchange required to purchase fuel and agrochemicals; and create employment by producing CA equipment locally. The potential to mitigate and to adapt to climate change is high.

Adoption and upscaling: Change of land user's mind-set, support for specific material inputs and good technical know-how increase the potential for adoption. A main aim is to phase out or minimise herbicide use - because of the potential risk to the environment. Alternative methods of weed control with minimum soil disturbance are needed. Pioneer farmers in regions of new adoption require support for access to no-till tools / equipment, cover crop seed and technical guidance. Critical constraints to adoption appear to be competing uses for crop residues (as mulch), increased labour demand for weeding, and lack of access to, and use of, external inputs.

Development issues addressed	
Preventing / reversing land degradation	++
Maintaining and improving food security	++
Reducing rural poverty	++
Creating rural employment	++
Supporting gender equity / marginalised groups	++
Improving crop production	++
Improving fodder production	+
Improving wood / fibre production	na
Improving non wood forest production	na
Preserving biodiversity	+
Improving soil resources (OM, nutrients)	++
Improving of water resources	++
Improving water productivity	+++
Natural disaster prevention / mitigation	++
Climate change mitigation / adaptation	++

Climate change mitigation	
Potential for C Sequestration (tonnes/ha/year)	0.57 ± 0.14*
C Sequestration: above ground	+
C Sequestration: below ground	++

Climate change adaptation	
Resilience to extreme dry conditions	++
Resilience to variable rainfall	++
Resilience to extreme rain and wind storms	+
Resilience to rising temperatures and evaporation rates	++
Reducing risk of production failure	+

** change from conventional tillage to no-till, carbon restored can be expected to peak after 5 to 10 years with SOC reaching a new equilibrium in 15 to 20 years (Source: West and Post, 2002 in Woodfine, 2009).*

Origin and spread

Origin: Through research activities and the development of herbicides and direct seeding equipment, no-till practices started spreading in the 1970s from the Americas and Australia to the rest of the world. In Sub-Saharan Africa, CA was introduced in the 1980s by research projects, and further developed and spread through the initiative of large-scale farmers. It must not be forgotten, however, that many traditional forms of farming in SSA (very shallow tillage with hand hoes for example) can be considered within the CA 'family'.

Mainly applied in: South Africa (2% of arable area), Zambia (0.8%), Kenya (0.3%), Mozambique (0.2%), Madagascar (0.1%)

Also applied in: Benin, Botswana, Burkina Faso, Cameroon, Ivory Coast, Ethiopia, Eritrea, Ghana, Lesotho, Malawi, Mali, Namibia, Niger, Nigeria, Sudan, Swaziland, Tanzania, Uganda and Zimbabwe

Spread of conservation agriculture in SSA.

Principles and types

Minimal soil disturbance: The main principle of conservation agriculture is minimal soil disturbance through reduced or no tillage. This favours soil life, and build up of soil organic matter (less exposure to oxygen and thus less soil organic matter mineralization). Compared to conventional tillage, CA increases the organic matter content of soils, increasing their porosity and hence improving their ability to absorb and retain water – and this has two positive effects: first, there is more water to support crop growth and the biological activity that is so important for productivity, and second, less water accumulates and thus doesn't flow across the surface, causing floods and erosion.

Seeding is done directly through the mulch (usually residues of previous crops), or cover crop (specially grown legumes). Although small-scale farmers can apply CA using a standard hoe or planting stick to open planting holes, appropriate machinery such as direct seed drills (large- or small-scale motorised or animal drawn) or jab-planters (hand tools) are normally required to penetrate the soil cover and to place the seed in a slot. Prior sub-soiling is often required to break-up existing hard pans resulting from ploughing or hoeing to a constant depth. Compacted soils may require initial ripping and sub-soiling to loosen the soil.

Permanent soil cover: Permanent soil cover with cover crops or mulch has multiple positive effects: increased availability of organic matter for incorporation by soil fauna, protection from raindrop splash, reduced soil crusting and surface evaporation, better micro-climate for plant germination and growth, reduced run-off and soil erosion, and suppression of weeds. In the initial years of CA, a large weed seed population requires management through use of herbicides or hand weeding to reduce the seed bank. Use of herbicides and weeding then falls to a minimum level after a few years, as the number of seeds is reduced and their growth hindered by crop cover.

Crop rotation: In order to reduce the risk of pests, diseases and weed infestation a system of rotational cropping is beneficial. Typical systems of rotation are cereals followed by legumes and cover / fodder crops. However, for small-scale farmers it is often difficult to become accustomed to growing crops in rotation, when this goes against tradition and dietary preference. One solution is inter-cropping which allows permanent cover and also replenishment of nutrients – when nitrogen-fixing legumes are included in the mixture.

For successful adaptation in SSA, CA needs to evolve to suit the biophysical and socio-economic conditions, in other words there need to be trade-offs. This implies being flexible regarding soil cover and crop rotation, and emphasizing the role of water harvesting in dry regions.

Top: Training on the use of a jab planter for direct seeding, Burkina Faso. (John Ashburner)
Middle: Direct seeding with special animal traction equipment, Zambia. (Josef Kienzle)
Bottom: A no-till seeder at work on a large-scale farm in Cameroon. (Josef Kienzle)

Applicability

Land degradation addressed

Physical soil deterioration: reduction in soil's capacity to absorb and hold water due to degradation of soil structure (sealing, crusting, compaction, pulverization) in drought-prone situations
Water degradation: aridification due to runoff and evaporation loss
Chemical soil deterioration and biological degradation: reduction in soil organic matter and fertility decline due to soil loss and nutrient mining, reduction of biodiversity and pest risk (in tropical and subtropical conditions)
Erosion by water and wind

Land use

Suitable for rainfed agriculture and irrigated systems (including those in semi-arid areas).
Mainly used for annual crops: cereals (maize, sorghum), with legume cover crops (mucuna, lablab, cowpea etc.), cotton; vegetables (e.g. onions) and some perennial / plantation crops and tree crops (e.g. coffee, orchard fruits, vineyards). Also used on mixed crop / livestock systems (but competition for plant residues reduces ground cover and organic matter restoration unless alternative fodder is grown).
Although CA is often not considered to be suitable for root crops, recent studies have shown that it can be used for crops such as beet and cassava since their roots grow more evenly and, due to the better structured soil, the soil sticking to the roots is reduced. CA can be also suitable for potatoes, if sufficient mulching material is provided to protect the potatoes from sunlight. Nevertheless harvest disturbs the soil in contrast to grain crops.

Ecological conditions

Climate: CA is suitable for all climates, although its specific benefits become more pronounced in unfavourable climates, such as semi-arid zones: it is most effective where low or uneven rainfall limits crop production. CA is also suitable for subhumid and humid climates: such as the moist savanna of West Africa and part of the East African highlands. The technology has specific challenges in arid climates, however, it still performs better than tillage-based alternatives, given adequate mulch.
Terrain and landscape: Suitable for flat to moderate slopes, mechanised systems are unsuitable for slopes steeper than 16%, but hand planters are suitable for steeper slopes. Mainly applied on plateaus and valley floors. Due to the reduced runoff and erosion it is particularly suitable for steeper slopes (under manual or animal traction), where crops are grown under these conditions.
Soils: Suitable for sandy loams to clay loams, but unsuitable for compacted hard soils or those at risk of waterlogging (poorly drained), shallow soils. Compaction due to previous tillage can be dealt with through sub-soiling.

Socio-economic conditions

Farming system and level of mechanisation: can be applied at all farm scales and implemented with different levels of mechanisation. Until recently there has been little emphasis on extending CA to the small-scale level.
Small-scale farms: hand or animal (oxen) draft implements such as animal (or sometimes tractor) drawn ripper, and ripper planter; hand jab planters for manual systems, etc.
Large-scale farms: direct seed drill, knife roller, sprayer, etc. with substantial reduction in time and energy use for tillage operations.
Market orientation: suitable for subsistence or commercial systems; access to markets is important to sell surplus and to purchase inputs.
Land ownership and land use / water rights: some communally-owned lands lack security of tenure and hence render land users reluctant to practise and invest in the shift to conservation agriculture.
Skill / knowledge requirements: medium to high for land users, extension agents and technical staff (rotations / crop sequence, planting dates, weed control / use of herbicides).
Labour requirements: significantly reduced (by 10% to more than 50%) compared to conventional tillage (reduced hired labour costs, family labour ➜ more time available for other activities).

Land degradation

■	Erosion by water
■	Erosion by wind
■	Chemical degradation
■	Physical degradation
░	Biological degradation
■	Water degradation

■	High
▓	Moderate
░	Low
□	Insignificant

Land use

■	Cropland
□	Grazing land
□	Forests / woodlands
▓	Mixed land use
□	Other

Climate

■	Humid
■	Subhumid
■	Semi-arid
□	Arid

Average rainfall (mm)

■	> 3000
■	2000-3000
■	1500-2000
■	1000-1500
■	750-1000
▓	500-750
░	250-500
□	< 250

Slopes (%)

░	very steep (>60)
░	steep (30-60)
▓	hilly (16-30)
■	rolling (8-16)
■	moderate (5-8)
■	gentle (2-5)
■	flat (0-2)

Farm size

■	Small scale
■	Medium scale
■	Large scale

Land ownership

░	State
■	Company
░	Community
▓	Individual, not titled
■	Individual, titled

Mechanisation

■	Manual labour
■	Animal traction
■	Mechanised

Market orientation

□	Subsistence
■	Mixed
■	Commercial

Required labour

□	High
▓	Medium
■	Low

Required know-how

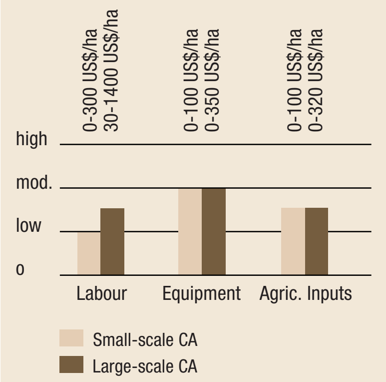
■	High
□	Medium
□	Low

Economics

Establishment and maintenance costs

Establishment costs: CA requires substantial initial investment. Initial costs are mainly related to the acquisition of new machinery and tools. The range of the costs can be very wide – from nothing (in case of the hand-based planting pit method) to high (in case of specific no-till seeders); input levels depend on the production intensity and can be low to high, but decrease over time.

Maintenance costs: On small-scale farms the labour requirements for maintenance are usually higher at the beginning due to the burden of weeding. Compared to conventional practices, the overall workload significantly decreases - by up to 50%. Agricultural input requirements are mainly cover crop seeds and (where appropriate) herbicides for controlling weeds. On large-scale farms the maintenance costs of the machines and tractor(s) significantly decrease by eliminating farming operations like ploughing, harrowing and by reducing weeding.



(Source: WOCAT, 2009)

Production benefits

	Yield without SLM (t/ha)	Yield with SLM (t/ha)	Yield gain (%)
Ghana: Maize	0.75-1.8 (Slash-and-burn)	2.7-3.0 (Minimum tillage, direct planting)	150-400%
Kenya: Wheat Maize	 1.3-1.8 1.3-2.2	 3.3-3.6 3.3-4.5	 100-150% 100-150%
Tanzania: Maize Sunflower	 1.13-1.5 0.63-0.75	 2.25-2.9 1.5-2.7	 93-100% 140-360%

(Source: Kaumbutho and Kienzle, 2007; Boahen et al., 2007; Shetto and Owenya, 2007)

Comment: Yield increase can vary widely – mostly an initial yield increase of 10-20% is observed if all other conditions remain the same; if CA introduction comes with ripping / sub-soiling and fertilizer use, a 100% increase can eventually be observed. Only after 4-5 years of continued application of CA can a significant increase in crop yield be recorded. The ecosystem requires a number of years to adjust.

Benefit-Cost ratio

	short term	long term	quantitative
Minimum tillage and direct planting	+(+)	+++	Labour returns (Ghana): 9.2 US$/ work hour (*under conventional tillage: 5.4 US$/ work hour*)
Conservation agriculture	+(+)	+++	Profit range (Kenya): 432-528 US$/ ha (for wheat) (*under conventional tillage: 158-264 US$/ ha*)

– – negative; – slightly negative; –/+ neutral; + slightly positive; ++ positive; +++ very positive

(Source: WOCAT, 2009; Kaumbutho and Kienzle, 2007; Boahen et al., 2007).

Comment: The short term benefit-cost ratio is mainly affected by the initial cost of purchasing new machinery and tools.

Example: Ghana

A study conducted on the impact of no-till in Ghana has shown a significant reduction of labour. No-till reduced labour requirements for land preparation and planting by 22%. Labour for weed control fell by 51%, from an average of 8.8 person days/ha to 4.3 person days/ha. There was, however, a slight increase in labour for harvest from 7.6 person days/ha to 8.6 person days/ha. This was largely a consequence of higher yields obtained. Ninety-nine percent of no-till users reported that it was less physically demanding than the traditional technology and that labour requirements at critical moments were reduced, thus simplifying labour management (Ekboir et al., 2002).

Example: Tanzania

Likamba, Tanzania suffered from a severe drought in 2004. Even though adequate soil cover was not attained, farmers who had ripped their land and planted lablab with maize were able to harvest at least 2-3 bags (90 kg) of maize per hectare, while conventional farmers harvested nothing, or less than half a bag, per hectare. This experience showed conservation agriculture was able to ensure an adequate harvest even under drought conditions (FAO, 2007).

Example: Tanzania and Kenya

The CA project under Sustainable Agriculture and Rural Development (SARD) introduced the concept of conservation agriculture in rural areas of northern Tanzania and in western and central regions of Kenya. Through participatory assessments it was found that the net financial benefits could be higher under CA than under conventional tillage, mainly due to reduced workload / time, smaller amount and cost of fertilizer required to maintain yields, and reduced energy fuel costs for tillage and spraying operations (FAO, 2008).

Impacts

Benefits	Land users / community level	Watershed / landscape level	National / global level
Production	+++ increased yield stability (mainly rainfed areas and in dry years) ++ increased crop yields + production diversification	++ reduced damage to neighbouring fields ++ reduced risk and loss of production + access to clean drinking water	+++ improved food and water security
Economic	+++ increased farm income / profitability (mainly long term) +(+) savings in labour / time (small-scale: only over the long term) +(+) lower farm inputs (fuel, machinery cost and repairs, fertilizer)	++ economic growth stimulation ++ diversification and rural employment creation (e.g. small manufacturing units) ++ less damage to off-site infrastructure	+++ improved livelihood and well-being
Ecological	+++ improved soil cover +++ improved water availability / soil moisture +++ improved soil structure (long term) ++ improved micro-climate / reduced evaporation ++ reduced soil erosion (by water / wind) ++ reduced surface runoff ++ increased organic matter / soil fertility ++ enhanced biodiversity / biotic activity (long term)	++ reduced degradation and sedimentation in rivers, dams and irrigation systems ++ improved recharge of aquifers, more regular water flow in rivers / streams + enhanced water availability + enhanced water quality + intact ecosystem	++ reduced desertification incidence and intensity ++ increased resilience to climate change ++ increased C sequestration + reduced C emissions + enhanced biodiversity
Socio-cultural	++ improved SLM / conservation / erosion knowledge + changing the traditional gender roles of men and women +/- changed cultural and traditional norms (e.g. no more burning of crop residues)	+ increased awareness for environmental 'health' + attractive landscape	+ protecting national heritage

	Constraints	How to overcome
Production	• Low biomass production (for cover) in low precipitation areas and short growing seasons • Scarcity of particular plant nutrients in humid areas due to high and fast decomposition rate (especially P)	➜ 'African adapted' CA: reduce the mulch requirement, focus on no-tillage methods (including traditional low-till systems such as *zaï* planting pits), promote efficient use of organic fertilizers, better water management, e.g. planting basins ➜ relieve deficiency by use of inorganic / organic (higher biological activity) fertilization
Economic	• Needs initial capital investment for adapted machinery and small scale equipment • External input constraints: fertilizers, cover crop seeds, herbicides, etc. (availability, access and costs) • Availability and access to equipment on local markets • Low capacity of local manufacturers of hand / animal-driven CA equipment • Labour constraints for hand weeding (availability and costs in first years)	➜ introduce and allow access (availability and costs) to appropriate conservation equipment (tested and adapted); ability to hire or share equipment and services ➜ in some countries small clusters for production and distribution of CA equipment already exists ➜ need further support and investment ➜ change weeding practice to 'shallow weeding' or chopping and the positive long term benefits of adoption CA needs to be recognised
Ecological	• Competition between soil cover and livestock feed (how to integrate livestock and mixed cropping smallholdings) • Weed control in the early years of adoption • Crop residues on the surface may favour disease and pests (micro-climate) • Compacted soils require prior sub-soiling	➜ stall-feeding, unpalatable cover crops, link CA with intensive live-stock production ➜ flatten cover crop using e.g. knife roller, machete or grass-whip or spray with a herbicide ➜ shallow manual weed control, use of herbicides, keep soils covered by mulch to suppress weeds ➜ adapt and improve crop rotations, pest management
Socio-cultural	• Uncertain land use rights • Lack of laws and regulations for communal grazing • Lack of supporting policies and implementing institutions • Poorly developed infrastructure / restricted access to markets, • Requires information, locally specific knowledge, technical skills and innovation to find the most suitable system • Difficult to introduce crop rotations on small portions of land (half a hectare or less) • 'Project' approach to piloting CA (short time frames, availability of support, limited lead-time for institutionalising CA into existing institutions and policies	➜ secure access to land ➜ enclosures, controlled grazing and residue-friendly management; communal by-laws on grazing ➜ well informed advisory service is necessary to provide training and share knowledge; the technology is flexible and allows multiple options

Adoption and upscaling

Adoption rate

Despite good quality and lengthy research only slow adoption of CA in SSA, but with an increasing trend in recent years (in South Africa, from 0% in 1988 to about 2% in 2007 of which the large majority in commercial lands). Farmers often adopt only certain components of CA (i.e. 'African-style CA').

Upscaling

Secure land use rights are a prerequisite for small-scale land users to invest in CA.

Immediate benefits must be seen by the land users to take the investment risk.

Training and capacity building: Good technical support to all stakeholders is needed. Training should include practical training, introduction of appropriate equipment and its maintenance, education on animal health and care.

Successful and innovative participatory learning approaches are needed such as Farmer Field Schools and the formation of common interest groups for strengthening knowledge about CA principles.

Farm inputs for CA such as adequate machinery, tools and herbicides need to be available and accessible to small-scale farmers for adoption of the system. Effective market systems and supply chains must be developed for producing CA equipment and other inputs for smallholders.

Disseminate knowledge: Agricultural machinery producers and agricultural, as well as political, advisors are heavily involved in developing and disseminating knowledge, advising farmers, providing relevant services or shaping local or national policies.

Incentives for adoption

Very often external support for small-scale farmers is needed in the form of credit / loans mainly for purchase of equipment, food-for-work (in emergencies), direct payments by project or government e.g. for inputs (agricultural seeds, fertilizers, etc.).

Enabling environment: key factors for adoption	
Inputs, material incentives, credits	++
Training and education	++
Land tenure, secure land use rights	++
Access to markets	++
Research	++

Example: FAO's Emergency Programmes, Swaziland

The FAO's Emergency Programme in Swaziland has trained about 800 land users, plus advisory and other staff over six years. There is now a demand for farmers in Shewala for expansion of CA as they recognize it as 'the most sustainable way to produce food'. Important requirements for successful implementation in Swaziland are among others: a) an agreed plan to implement CA involving all stakeholders i.e. land users, extension staff, etc., b) field research comparing CA to conventional tillage, c) policy support, d) sustained and practical training for extension and research staff and for land users, e) common understanding with livestock owners, f) supply of quality seeds, g) supply of CA tools and equipment, and h) need for good farm management including timely planting, weeding, etc. (FAO, 2008).

References and supporting information:

Baudeon F., H.M. Mwanza, B. Triomphe, M. Bwalya. 2007. Conservation agriculture in Zambia: a case study of Southern Province. Nairobi. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations.

Baudron F., H.M. Mwanza, B. Triomphe, M. Bwalya and D. Gumbo. 2006. Challenges for the adoption of Conservation Agriculture by smallholders in semi-arid Zambia. Online: www.relma.org.

Boahen P, B.A. Dartey, G.D. Dogbe, E. A. Boadi, B. Triomphe, S. Daamgard-Larsen, J. Ashburner. 2007. Conservation agriculture as practised in Ghana. Nairobi. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations.

Bwalya, M. and M. Owenya. 2005. Soil and water Conservation to Conservation Agriculture Practices: experiences and lessons from the efforts Eotulelo Farmer Field School – a community based organisation. (http://www.sustainet.org/download/sustainet_publication_eafrica_part2.pdf).

Derpsch, R. 2008. No-Tillage and Conservation Agriculture: A Progress Report. In: No-Till Farming systems. 2008. Edited by Tom Goddard, Michael A. Zoebisch, Yantai Gan, Wyn Ellis, Alex Watson and Samran Sombatpanit, WASWC, 544 pp.

Ekboir, J., K. Boa and A.A. Dankyi. 2002. Impacts of No-Till Technologies in Ghana. Mexico D.F. CIMMYT.

FAO Aquastat. http://www.fao.org/nr/water/aquastat/data/query/results.html

FAO, 2002. Conservation Agriculture: Case studies in Latin America and Africa. Soils Bulletin 78.

FAO, 2005. Conservation Agriculture in Africa, A. Calegari, J. Ashburner, R. Fowler, Accra, Ghana

FAO. 2008. Investing in Sustainable Agricultural Intensification, the role of Conservation Agriculture. Part III – a framework for action. An international technical workshop investing in sustainable crop intensification: The case for improving soil health, FAO, Rome: 22-24 July 2008. Integrated Crop Management Vol. 6-2008.

Giller, K.E., E. Witter, M. Corbeels and P.Tittonell. 2009. Conservation agriculture and smallholder farming in Africa: The heretic's view. Field Crops Research.

GTZ Sustainet. 2006. Sustainable agriculture: A pathway out of poverty for East Africa's rural poor. Examples from Kenya and Tanzania. Deutsche Gesellschaft für Technische Zusammenarbeit, Eschborn.

Haggblade S., G. Tembo, and C. Donovan. 2004. Household Level Financial Incentives to Adoption of Conservation Agricultural Technologies in Africa. Working paper no. 9. Food security research project. Lusaka, zambia

Kaumbutho P. and J. Kienzle, eds. 2007. Conservation agriculture as practised in Kenya: two case studies. Nairobi. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations.

Kaumbutho P., J. Kienzle, eds. 2007. Conservation agriculture as practised in Kenya: two case studies. Nairobi. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations.

Mrabet, R. 2002. Stratification of soil aggregation and organic matter under conservation tillage systems in Africa, Soil & Tillage Research 66 (2002) 119–128

Nyende, P., A. Nyakuni, J.P. Opio, W. Odogola. 2007. Conservation agriculture: a Uganda case study. Nairobi. African Conservation Tillage Network, Centre de coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations.

RELMA. 2007.Wetting Africa's appetite. Conservation agriculture is turning rainfall into higher crop yields and catching on. RELMA Review Series No. 3. ICRAF, Nairobi.

Rockström, J., P. Kaumbutho, J. Mwalley, A. W. Nzabi, M. Temesgen, L. Mawenya, J. Barron, J. Mutua and S Damgaard-Larsen. 2009. Conservation Farming Strategies in East and Southern Africa: Yields and Rainwater Productivity from On-farm Action Research. Soil & Tillage Research 103 (2009) 23–32.

Shetto R., M. Owenya, eds. 2007. Conservation agriculture as practised in Tanzania: three case studies. Nairobi. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations.

West T.O. and W.M. Post. 2002. Soil organic carbon sequestration rates by tillage and crop rotation. A global data analysis. Soil Science Society of America Journal, 66. Available from: http://soil.scijournals.org/cgi/content/abstract/66/6/1930?etoc

WOCAT, 2009. WOCAT databases on SLM technologies and SLM approaches. www.wocat.net, accessed on 15 September 2009

Woodfine, A. 2009. Using sustainable land management practices to adapt to and mitigate climate change in Sub-Saharan Africa: resource guide version 1.0. TerrAfrica. www.terrafrica.org

SMALL-SCALE CONSERVATION TILLAGE - KENYA

Small-scale conservation tillage involves the use of ox-drawn ploughs, modified to rip the soil. An adaptation to the ordinary plough beam makes adjustment to different depths possible and turns it into a ripper. Ripping is performed in one pass, to a depth of 10 cm, after harvest. Deep ripping (subsoiling) with the same implement is done, when necessary, to break a plough pan and reaches depths of up to 30 cm.

Ripping increases water infiltration and reduces runoff. In contrast to conventional tillage, the soil is not inverted, thus leaving crop residues on the surface. As a result, the soil is less exposed and not so vulnerable to the impact of splash and sheet erosion, and water loss through evaporation and runoff. In well-ripped fields, rainfall from storms at the onset of the growing season is stored within the rooting zone, and is therefore available to the crop during subsequent drought spells. Ripping the soil during the dry season combined with a mulch cover reduces germination of weeds, leaving fields ready for planting. In case of stubborn weeds, pre-emergence herbicides are used for control.

Yields from small-scale conservation tillage can be more than 60% higher than under conventional ploughing. In addition, there are savings in terms of energy used for cultivation. Crops mature sooner under conservation tillage, because they can be planted earlier (under inversion tillage the soil first has to become moist before ploughing is done).

Earlier crop maturity means access to markets when prices are still high. There are various supportive technologies in use which can improve the effectiveness of the ripping, including (1) application of compost / manure to improve soil structure for better water storage; (2) cover crops (e.g. *Mucuna pruriens*) planted at the end of the season to prevent erosion, control weeds and improve soil quality; and (3) Agroforestry (mainly *Grevillea robusta* planted on the field or along field boundaries).

SLM measure	Agronomic
SLM group	Conservation Agriculture
Land use type	Annual cropping
Degradation addressed	Water degradation: soil moisture problem; Soil compaction; Loss of topsoil through water erosion
Stage of intervention	Mitigation
Tolerance to climate change	Increased tolerance to climatic extremes due to water conservation effect.

Establishment activities

Note: Conservation tillage is based on agronomic measures which are carried out repeatedly each cropping season. All activities are listed under maintenance / recurrent activities (below). There is no establishment phase (as defined by WOCAT).

Maintenance activities

1. Spreading of crop residue as mulch: up to 3 t/ha (before planting, dry season).
2. Application of compost / household waste: up to 4 t/ha.
3. Ripping of soil with modified plough (dry season) to a depth of 10 cm, spacing between rip lines is 20-30 cm.
4. Subsoiling: every 3 years; or as required to break a plough pan.
5. Seeding and application of mineral fertilizer (nitrogen, phosphorus) at the rate of 20 kg/ha, close to seed.
6. Legume interplanting (*Dolichos lablab*) into the cereal crop (supplementary measure): Dolichos needs replanting every 3 years.

All activities are carried out using animal traction, mulching done manually. Equipment / tools: pair of oxen, modified ‘Victory’ plough beam, plough unit, ripper / chisel (tindo) used for ripping / deep ripping.

Labour requirements

For establishment: medium (initially high for weeding, decreasing with years)

For maintenance: low (compared to conventional tillage)

Knowledge requirements

For advisors: moderate

For land users: moderate

Photo 1: Demonstration of conservation tillage through shallow ripping of soil using draught animals. (Hanspeter Liniger)
Photo 2 and 3: ‘Victory’ ploughs modified into ripper by replacing the plough blade by a metal tine to provide extra penetration. (Hanspeter Liniger and Frederick Kihara)

Case study area: Umande, Laikipia District, Kenya

Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour	0
Equipment	0
Agricultural inputs	0
TOTAL	**0**

No establishment costs.

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 3-5 person-days	25
Equipment	0
Agricultural inputs: seeds (50 kg), fertilizer (20 kg), compost / manure (4,000 kg)	68
TOTAL	**93**
% of costs borne by land users	100%

Remarks: Cost calculated charges for hiring equipment, draught animals and operator: these are all rolled up into the 'cost of labour' at US$ 25/ha. Conventional tillage costs US$ 37.5/ha compared with US$ 25/ha for conservation tillage operations: other costs remain more or less the same.

Benefit-cost ratio

Inputs	short term	long term
Establishment	na	na
Maintenance	positive	very positive

Remarks: Initial investments can be high (purchasing of new equipment). Costs decrease in the long term and benefits increase.

Adoption

200 families accepted the technology without incentives. The area covered by the technology is 4 km². There is a growing trend for spontaneous adoption.

Ecological conditions

- Climate: semi-arid (lower highland zone IV)
- Average annual rainfall: 500 – 750 mm
- Soil parameters: moderately deep, loamy soils; organic matter and soil fertility: mostly medium, partly low (<1%); medium drainage / infiltration
- Slope: mostly moderate (5-8%), partly rolling (8-16%)
- Landform: plains / plateaus; high altitude and rolling terrain
- Altitude: mostly 1,500 – 2,000, partly 2,000 – 2,500 m a.s.l.
- Most of the soil and water loss occurs during a few heavy storms at the beginning of each growing season.

Socio-economic conditions

- Size of land per household: mainly <1 ha, partly 1-2 ha
- Type of land users: small-scale, groups; mostly average level of wealth, partly poor land users
- Population density: 100-200 persons/km^2
- Land ownership: individual titled
- Land use rights: mostly individual, partly leased
- Market orientation: mostly subsistence, partly mixed (subsistence / commercial)
- Level of mechanisation: animal traction
- More than 90% of families have less than two hectares of land, and few have alternative sources of income.

Production / economic benefits

+++ Increased crop yield (>60%)
++ Increased fodder production and increased quality
++ Increased farm income
++ Earlier crop maturity
++ Time saving

Ecological benefits

+++ Increased soil moisture; better rainwater harvesting
++ Reduced soil loss
++ Reduced evaporation
+ Improved soil cover
+ Reduced energy consumption

Socio-cultural benefits

++ Community institution strengthening
++ Improved conservation / erosion knowledge

Off-site benefits

++ Reduced downstream siltation
+ Improved streamflow characteristics
+ Reduced downstream flooding
+ Reduced river pollution (chemical contamination)

Weaknesses ➜ and how to overcome

- Male-oriented activity (heavy equipment / animals) compared to using the hoe ➜ training of women.
- Waterlogging ➜ contingency plans needed for draining excess water in very wet years (only in 1 in 10).
- No clear advantage in extreme climatic conditions ➜ make farmers aware about this so they do not become discouraged.
- More prone to weeds; may require annual use of pre-emergence herbicides ➜ mulch application reduces negative effects of weeds.
- Conflict between using residues as mulch and as livestock fodder ➜ greater yields mean more income can be generated to buy fodder, and more biomass / mulch material.
- High equipment and animal maintenance costs ➜ possible loan scheme (micro-finance option); farmer self-help groups to share costs.

Main contributors: Frederick Kihara, Nanyuki, Kenya; pdo@africaonline.co.ke
Key references: WOCAT. 2004. WOCAT database on SLM technologies, www.wocat.net. ■ Kihara F. 1999. An investigation into the soil loss problem in the Upper Ewaso Ng'iro basin, Kenya. MSc. Thesis. University of Nairobi, Kenya ■ Mutunga C.N. 1995. The influence of vegetation cover on runoff and soil loss – a study in Mukogodo, Laikipia district Kenya. MSc Thesis, University of Nairobi, Kenya ■ Ngigi S.N. 2003. Rainwater Harvesting for improved land productivity in the Greater Horn of Africa. Kenya Rainwater Association, Nairobi ■ Liniger HP. and D.B. Thomas. 1998. GRASS – Ground Cover for Restoration of Arid and Semi-arid Soils. Advances in GeoEcology 31, 1167–1178. Catena Verlag, Reiskirchen.

MINIMUM TILLAGE AND DIRECT PLANTING - GHANA

The traditional slash-and-burn land use system in the case study area – involving clearing natural vegetation followed by 2-5 years of cropping – has become unsustainable as land pressure has greatly increased, shortening fallow periods. Under the SLM practice of 'minimum tillage and direct planting', land is prepared by slashing the existing vegetation and allowing regrowth up to 30 cm height. A glyphosate-based herbicide is sprayed with a knapsack fitted with a low-volume nozzle. The residue is left on the soil surface without burning. After 7–10 days, direct planting is carried out in rows through the mulch. Maize is the main crop planted under this system. Planting is practiced manually using a planting stick.

The mulch layer has several important functions: it helps to increase and maintain water stored in the soil, reduces soil erosion, contributes to improve soil fertility (after crop residues have decomposed in subsequent seasons) and it efficiently controls weeds by hindering their growth and preventing weeds from producing seeds.

The use of herbicides requires adequate knowledge. An even better option is to introduce multipurpose cover crops to control weed populations, improve soil fertility, and enhance yields while diversifying crop production and thus reducing dependence on the use of herbicides.

Labour inputs for land preparation and weeding is considerably decreased under conservation agriculture. Women benefit most from the workload reduction since these time-consuming activities are their task. For men, the new technology usually means heavier work, especially during the 1st year, since they have to plant through the mulch. Using a jab planter makes the work easier.

SLM measure	Agronomic
SLM group	Conservation Agriculture
Land use type	Annual cropping (cereals)
Degradation addressed	Fertility decline and reduced organic matter content; Loss of topsoil by water; Reduction of vegetation cover: detrimental effects of fires; Biomass decline
Stage of intervention	Prevention and mitigation
Tolerance to climate change	The technology is tolerant to climatic extremes, contrary to the traditional slash-and-burn practice.

Establishment activities

Note: Minimum tillage and direct planting are agronomic measures which are carried out repeatedly each cropping season. All activities are listed under maintenance / recurrent activities (below). There is no establishment phase (as defined by WOCAT).

Maintenance activities

1. Initial land clearing: slash existing vegetation and allow regrowth (up to 30 cm); before onset of rainy season.
2. Spraying of pre-emergence herbicide; 300 ml (2 sachets) for every 15 litres water for annual weeds; 450 ml (3 sachets) for every 15 litres water for perennial weeds.
3. Leave residues on the soil surface without burning.
4. Planting through the mulch.
5. Spraying post-emergence herbicide; after regrowth of weeds (7-10 days after planting).
6. Harvesting.

All activities are carried out manually (each cropping season) using jab planter (or a planting stick) and knapsack sprayers.

Labour requirements

For establishment: na
For maintenance: low

Knowledge requirements

For advisors: moderate
For land users: moderate

Photo 1: Cover crop field sprayed with herbicides and left as mulch on the field to improve soil moisture and reduce soil erosion. (FAO)
Photo 2: Young maize plants are growing through a dense mulch layer. (WOCAT database)
Photo 3: Residue management on a field with mature maize plants. (Souroudjaye Adjimon)

Case study area: Sunyani and Atwima district; Brong Ahafo region; Ghana

Note: The technology 'minimum tillage and direct planting' is compared with the traditional slash-and-burn land use system.

Slash and burn (traditional): Maintenance inputs and costs per ha

Inputs	Costs (US$)
Labour: 83 person-days	142
Equipment	13
Agricultural inputs	65
Construction material	0
TOTAL	**220**

Minimum tillage and direct planting: Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 48 person-days	83
Equipment	18
Agricultural inputs	111
Construction material	0
TOTAL	**212**

Remarks: Input costs include Jab planter US$ 20; herbicides US$ 5-6/liter. A knapsack costs US$ 50, which is not affordable for small-scale farmers (they have to get organised in groups, or hire spraying gangs). Comparing to the traditional slash-and-burn system, 'minimum tillage and direct planting' has increased input costs but reduced labour costs, and results in higher yields, which makes the conversion profitable!

Benefit-cost ratio

Inputs	short term	long term
Establishment	na	na
Maintenance	neutral	positive

Remarks: Initial investments can be high (purchasing of new equipment). Costs decrease in the long term and benefits increase.

Ecological conditions

- Climate: subhumid
- Average annual rainfall: 1,400-1,850 mm (bimodal)
- Soil parameters: partly well drained with high organic matter content (forest area); partly poorly drained with low organic matter content (savanna belt)
- Slope: no data
- Landform: mainly plains, partly hill slopes
- Altitude: 220-380 m a.s.l.

Socio-economic conditions

- Size of land per household: 1-2 ha, partly 2-5 ha
- Type of land user: small-scale; poor
- Population density: 100-200 persons/km^2
- Land ownership: communal / family land tenure; some individual (titled)
- Land use rights: individual; partly leased
- Level of mechanisation: manual labour
- Market orientation: mainly subsistence; partly mixed (subsistence and commercial)

Production / economic benefits

+++ Increased crop yield (200-300%; from 0.75-1 t/ha to 3 t/ha)
+++ Increased farm income (150%; from US$ 50 to US$ 123 net return)
+++ Decreased workload (-42%; from 83 to 48 working days): less time needed for weeding and land preparation
\+ Decreased labour constraints: critical labour shortage at weeding time is avoided
\+ Early planting (benefit from early rains; due to minimal land preparation)

Ecological benefits

+++ Improved soil cover
\+ Reduced soil loss
\+ Improved harvesting / collection of surface runoff
\+ Increased soil moisture

Socio-cultural benefits

++ Improved situation of socially and economically disadvantaged groups: women / children benefit most from workload reduction

Weaknesses ➜ and how to overcome

- Knowledge / experience is needed for adequate application of herbicides and handling of jab planters ➜ training / advisory service.
- Increased expenses and dependence on herbicides ➜ introduce multipurpose cover crops to control weed populations, improve soil fertility, and enhance yields while diversifying crop production.
- Availability of / access to herbicides and equipment is limited; some dealers sell adulterated or fake products that are harmful to the environment ➜ hire spraying gangs; provide training; set up 'rent-a-knapsack'.
- Increased labour constraints in the first year; need for a long term investment ➜ good rates of return are achieved in the 2^{nd} year of continuous use of the technology; long term user rights are crucial.
- High amounts of soil cover impede germination of the main crop, thereby affecting productivity ➜ partial burning appears necessary in such cases to reduce the quantity of mulch on the field.
- Fields that had been ploughed for years recorded slightly lower yield with minimal tillage and herbicide application, probably due to ploughing pan formation (hindering root penetration) ➜ ripping.

Adoption

21 communities with 193 farmers (125 male, 68 female) apply the technology in the case study area (totally 2,845 km^2). Around 88% accepted the technology receiving incentives. There is little trend towards spontaneous adoption (through cross farmer visits); 30% of farmers ceased conservation farming practices after termination of projects input.

Main contributors: Souroudjaye Adjimon, Volta Environmental Conservation Organization, Ghana; volenvicon@gmail.com
Key references: Boahen P, B.A. Dartey, G.D. Dogbe, E. A. Boadi, B. Triomphe, S. Daamgard-Larsen, J. Ashburner. 2007. Conservation agriculture as practised in Ghana. Nairobi. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement,FAO. Rome, Italy.

CONSERVATION TILLAGE FOR LARGE-SCALE CEREAL PRODUCTION - KENYA

Conservation tillage (or 'No-Till') on large-scale commercial cereal farms is based on tractor-drawn equipment which allows furrow opening and planting in one pass. This technology minimizes soil disturbance, avoids formation of hard pans and considerably reduces machine hours used for crop production: time is saved as well as fossil fuels – and field operations are thus cheaper than under conventional farming. Crops can be planted early to make the best use of rainfall. During harvesting, the crop residues are chopped and left as mulch on the field (3 tonnes of crop residues per hectare give around 70-100% cover), to improve soil organic matter and protect the soil against erosion and evaporation.

Thanks to enhanced water conservation and infiltration, wheat and barley can be produced without irrigation and the risk of crop failure is reduced. Weeds are controlled with a broad spectrum herbicide (glyphosate) application (2 liters/ha) two months after harvesting and shortly before planting. The company minimizes usage of pesticides.

Conservation agriculture also includes contour planting (25 cm rows). Crop rotation is 3-4 years of wheat or barley followed by a season of legumes (for example peas) or canola (oilseed rape). If, after several years, the yields decrease due to compaction in the subsoil, crops with a strong tap root are planted (e.g. rape or sunflower) to break the hard pan - rather than using a ripper.

As a supplementary technology tree rows (e.g. pines, cypress, or eucalyptus) are planted as shelterbelts and for wood production along boundaries, in valleys or on steep slopes.

SLM measure	Agronomic
SLM group	Conservation Agriculture
Land use type	Annual cropping
Degradation addressed	Soil erosion by water: loss of topsoil; Fertility decline and reduced organic matter content; Compaction
Stage of intervention	Prevention and mitigation
Tolerance to climate change	More tolerant to prolonged dry spells and heavy rainfall events

Establishment activities

1. Purchasing no-till machinery.

Note: Conservation tillage is based on agronomic measures which are carried out repeatedly each cropping season. All activities are listed under maintenance / recurrent activities (below). There is no establishment phase (as defined by WOCAT).

Maintenance / recurrent activities

1. Harvesting and chopping of crop residues (end of growing season).
2. Herbicide application: glyphosate 4 liters/ha (2 months after harvesting and before planting).
3. Early planting, along contour (just before rains).
4. Furrow opening and planting in one pass, using direct seeder (beginning of rainy season).
5. In-crop spraying during growing season (once or more).

Labour requirements

For establishment: na
For maintenance: medium

Knowledge requirements

For land user: medium to high
For advisors: na

Photo 1: No-till wheat crop after harvesting showing crop residue on surface.
Photo 2: No-till machinery used in large scale cereal farming.
Photo 3: Discs used to cut crop residue before planting.
(All photos by Ceris Jones)

Case study area: Kisima Farm, Meru Central, Kenya

Establishment inputs and costs per farm

Machinery for no-till includes: Tractor (110,000 US$), combined harvester (160,000 US$), sprayer (160,000 US$), direct seeder (110,000 US$). Life span is 10-15 years. For conversion from conventional to conservation agriculture usually only a direct seeder is needed as new equipment. Total equipment costs are less than half of the conventional tillage.

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour	10
Equipment: 4 machine hours / ha	70
Agricultural inputs: biocides	25
TOTAL	**105**
% of costs borne by land user	100%

Remarks: Main factors affecting the costs are machinery, spraying and labour. It takes more than 3 years to fully establish the conservation tillage system. During the conversion phase yields might be lower, and costs are approx. 25% less.

Benefit-cost ratio

Inputs	short term	long term
Establishment	slightly positive	positive
Maintenance	positive	very positive

Remarks: Positive pay-backs against establishment costs depend on the point in time of the conversion. If replacement of equipment is required anyway, conversion to conservation tillage is a profitable option, since total equipment costs are lower than those for conventional agriculture.

Ecological conditions

- Climate: subhumid to semi-arid
- Average annual rainfall: 500-750 mm; two rainy seasons; rains are inadequate and / or poorly distributed
- Soil parameters: good drainage; soil organic matter is mostly medium and partly low
- Slope: moderate to rolling (5% - max. 16%)
- Landform: mainly footslopes, partly hillslopes
- Altitude: 2,000 – 2,900 m a.s.l.

Socio-economic conditions

- Size of land per household: 2,600 ha
- Type of land users: rich large-scale farmers, with employees, fully mechanised
- Population density: < 10 persons/km^2
- Land ownership: company (Ltd)
- Land use rights: leased
- Market orientation: commercial
- Level of mechanisation: highly mechanised

Production / economic benefits

+++ Increased crop yield (from 1 t/ha to 4 t/ha; after 20 years of CA)
+++ Increased farm income
+++ Increased product diversification (wheat, barley, legumes, oil seeds)
+++ Increased forest products

Ecological benefits

+++ Increased soil moisture
+++ Reduced hazard towards adverse events (drought, floods, storms, etc.)
+++ Increased biomass / above ground carbon
+++ Increased soil organic matter / below ground carbon
+++ Increased beneficial species (predators, earthworms, pollinators, e.g. lady birds)
+++ Reduced surface runoff (from 20% to almost 0%)
+++ Reduced soil loss (from around 15 to almost 0 t/ha/yr; only wind erosion during planting)

Off-site benefits

+++ Reduced downstream siltation (the heavy rains in 2003 did not cause erosion)
\+ Groundwater recharge during exceptional high rainfall seasons

Weaknesses ➜ and how to overcome

- High costs if new equipment is needed (particularly established brands) but less than half of the costs for conventional tillage equipment! ➜ encourage local production and regulation of prices or subsidising input purchase.
- Poor market for equipment ➜ establish a market association.
- During wet years more herbicides are needed, especially before planting (several sprayings) ➜ spray use is slightly more than conventional tillage. If after the harvest there are no more rains during the dry season, there is no application of herbicides needed and direct planting can be done.
- Takes more than three years to fully establish ➜ needs continuous adaptation.

Adoption

There is a strong trend towards spontaneous adoption. Neighbouring farmers are picking up the technology.

Main contributors: Martin Kisima, Farmer, Meru, Kenya; martin@kisima.co.ke ■ Kithinji Mutunga, FAO, Nairobi, Kenya; Kithinji.Mutunga@fao.org
Key references: WOCAT. 2009. WOCAT database on SLM Technologies; www.wocat.net.

RAINWATER HARVESTING

Small dam harvesting water for animals and smallholder irrigation, Kenya. (Hanspeter Liniger)

In a nutshell

Definition: Rainwater Harvesting (RWH) refers to all technologies where rainwater is collected to make it available for agricultural production or domestic purposes. RWH aims to minimise effects of seasonal variations in water availability due to droughts and dry periods and to enhance the reliability of agricultural production. A RWH system usually consists of three components: (1) a catchment / collection area which produces runoff because the surface is impermeable or infiltration is low; (2) a conveyance system through which the runoff is directed e.g. by bunds, ditches, channels (though not always necessary); (3) a storage system (target area) where water is accumulated or held for use - in the soil, in pits, ponds, tanks or dams. When water is stored in the soil - and used for plant production there - RWH often needs additional measures to increase infiltration in this zone, and to reduce evaporation loss, for example by mulching. Furthermore soil fertility needs to be improved by composting / manuring, or micro-dosing with inorganic fertilizers. Commonly used RWH techniques can be divided into micro-catchments collecting water within the field and macro-catchments collecting water from a larger catchment further away.

Applicability: RWH is applicable in semi-arid areas with common seasonal droughts. It is mainly used for supplementary watering of cereals, vegetables, fodder crops and trees but also to provide water for domestic and stock use, and sometimes for fish ponds. RWH can be applied on highly degraded soils.

Resilience to climate variability: RWH reduces risks of production failure due to water shortage associated with rainfall variability in semi-arid regions, and helps cope with more extreme events, it enhances aquifer recharge, and it enables crop growth (including trees) in areas where rainfall is normally not sufficient or unreliable.

Main benefits: RWH is beneficial due to increased water availability, reduced risk of production failure, enhanced crop and livestock productivity, improved water use efficiency, access to water (for drinking and irrigation), reduced off-site damage including flooding, reduced erosion, and improved surface and groundwater recharge. Improved rainwater management contributes to food security and health through households having access to sufficient, safe supplies of water for domestic use.

Adoption and upscaling: The RWH techniques recommended must be profitable for land users and local communities, and techniques must be simple, inexpensive and easily manageable. Incentives for the construction of macro-catchments, small dams and roof catchments might be needed, since they often require high investment costs. The greater the maintenance needs, the less successfully the land users and / or the local community will adopt the technique.

Development issues addressed	
Preventing / reversing land degradation	++
Maintaining and improving food security	++
Reducing rural poverty	+
Creating rural employment	+
Supporting gender equity / marginalised groups	+
Improving crop production	+++
Improving fodder production	++
Improving wood / fibre production	++
Improving non wood forest production	na
Preserving biodiversity	+
Improving soil resources (OM, nutrients)	+
Improving of water resources	+++
Improving water productivity	+++
Natural disaster prevention / mitigation	+
Climate change mitigation / adaptation	+++

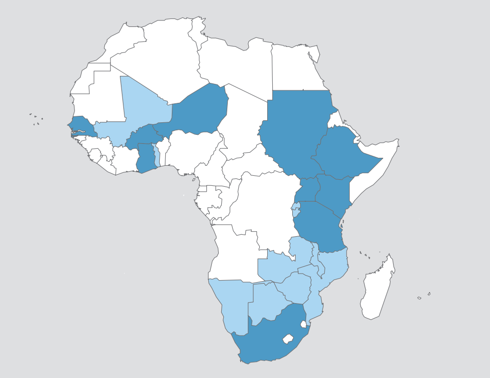
Climate change mitigation	
Potential for C Sequestration (tonnes/ha/year)	0.26-0.46 (+/-0.35)*
C Sequestration: above ground	+
C Sequestration: below ground	+

Climate change adaptation	
Resilience to extreme dry conditions	+++
Resilience to variable rainfall	+++
Resilience to extreme rain and wind storms	+
Resilience to rising temperatures and evaporation rates	++
Reducing risk of production failure	+

**for a duration of the first 10-20 years of changed land use management (Pretty et al., 2006)*

Origin and spread

Origin: A wide variety of traditional and innovative systems exists in the Sahelian zone e.g. Burkina Faso, Egypt, Kenya, Niger, Somalia, Sudan. In some cases these traditional technologies have been updated and (re-)introduced through projects or through the initiative of land users.
Mainly applied in: Burkina Faso, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Sudan, Tanzania, Uganda
Also applied in: Botswana, Burundi, Malawi, Mali, Mozambique, Namibia, Rwanda, Togo, Zambia, Zimbabwe



Spread of Rainwater Harvesting in SSA.

Principles and types

In-situ rainwater conservation (sometimes not classified as RWH) is the practice where rainfall water is captured and stored where it falls. Runoff is not allowed and evaporation loss is minimised. This is achieved through agronomic measures such as mulching, cover crops, contour tillage, etc. Those technologies are further described under conservation agriculture.
Micro-catchments (for farming) are normally within-field systems consisting of small structures such as holes, pits, basins, bunds constructed for the collection of surface runoff from within the vicinity of the cropped area. The systems are characterised by relatively small catchment areas 'C' (<1,000 m^2) and cropping areas 'CA' (<100 m^2) with C:CA = 1:1 to 10:1. The farmer usually has control over both the catchment and the storage area. The water holding structures are associated with specific agronomic measures for annual crops or tree establishment, especially fertility management using compost, manure and / or mineral fertilizers. Common technologies are *zaï* / tassa (planting pits), *demi-lunes* (half-moons), semi-circular / trapezoidal bunds, etc.
Micro-catchments such as *zaï / tassa* are often combined with conservation agriculture. This may be referred to as '**African-Adapted Conservation Agriculture**'. Its focus is on water harvesting and applying fertilizers rather than maintaining soil cover. Traditionally, CA is poorly suited to areas where water is a limiting factor and provision of permanent soil cover is a problem due to the competition between materials for mulch and livestock fodder. African style CA encompasses the following aspects: minimal soil disturbance (e.g. using jab planter), water harvesting, fertilizer application and hand weeding or low-cost herbicide.
Macro-catchments (for farming) are designed to provide more water for crop or pasture land through the diversion of storm floods from gullies and ephemeral streams or roads directly onto the agricultural field. Huge volumes of water can be controlled through large earth canals often built over many years. The systems are characterised by a larger catchment outside the arable land with a ratio of C:CA = 10:1 to 1000:1. Common technologies are: check-dams, water diversion channels / ditches, etc.
In the cultivated area through different practices and by manipulating the soil surface structure and vegetation cover, evaporation from the soil surface and surface runoff can be potentially reduced, infiltration is enhanced and thereby the availability of water in the root zone increased.
Small dams / ponds are structural intervention measures for the collection and storage of runoff from different external land surfaces including hillsides, roads, rocky areas and open rangelands. Sometimes runoff is collected in furrows / channels below terraces banks. Small dams / ponds act as reservoirs of surface and floodwater to be used for different purposes e.g. for irrigation, livestock and / or domestic use during dry periods.
Roof catchments: Rainwater harvesting from roofs is a popular method to secure water supplies for domestic use. Tiled roofs, or roofs covered with corrugated iron sheets are preferable, since they are the easiest to use and provide the cleanest water. Thatched or palm leafed surfaces are also feasible, but are difficult to clean and often taint the runoff. Water is collected and stored in plastic, metal or cement tanks. Roof catchments provide water at home, are affordable, easy to practice, can be shared by several houses or used on public infrastructure (schools, clinics, etc.).

Top: *Demi-lune* micro-catchments in an arid zone, Niger. (Hanspeter Liniger)
Middle: Collection and storing water in a small pond, Rwanda. (Malesu Maimbo)
Bottom: Roof catchment for domestic water use, Kenya. (Hanspeter Liniger)

Applicability

Land degradation addressed

Water degradation: aridification through decrease of average soil moisture content and change in the quantity of surface water
Erosion by water: loss of fertile topsoil through capturing sediment from catchment and conserving within cropped area
Physical soil deterioration: compaction, sealing and crusting
Chemical soil deterioration and biological degradation: fertility decline and reduced organic matter content

Land use

Mainly used on annual cropland with cereals (sorghum, millet, maize), leguminous grains / pulses (cowpeas, pigeon peas etc.) vegetables (tomatoes, onion, potatoes, etc.) and tree crops; also used on mixed extensive grazing land with trees. Micro-catchments are mainly used for single trees, fodder shrubs, or annual crops, whereas macro-catchments and concentrated runoff harvesting are mainly used for annual crops, but have also been used on mixed extensive grazing land with tree crops.

Ecological conditions

Climate: RWH techniques are most relevant in semi-arid and subhumid zones with poorly distributed rains, in particular in cereal–based areas. In more arid regions they are used for tree crops and / or establishing trees for afforestation. Micro-catchments are more suitable for areas with more reliable rainfall, whereas macro-catchments are effective in areas where few runoff events are expected.
Terrain and landscapes: Macro-catchments can be applied in depressions / valleys, whereas micro-catchments can be used on all landforms.
Soils: Clay or shallow soils with low infiltration rates in the collection area and deep soils with high moisture storage capacity in the storage areas. This makes them suitable for deep flooding for subsequent cropping on residual moisture - though waterlogging can be a problem. Sandy soils have quicker infiltration but lower storage capacity: they are thus relatively suitable for diversion schemes.

Socio-economic conditions

Farming system and level of mechanisation: Micro-catchments are mainly small-scale and constructed manually or by animal traction. Macro-catchments for runoff harvesting and small dams / ponds may be applied within medium or large-scale systems, and the construction is usually mechanised - but may be built up manually over many years.
Market orientation: Both subsistence and partly commercial.
Land ownership and land use / water rights: The absence of clear land and water use rights prevents water harvesting and conveyance techniques from being more widely spread.
Skill / knowledge requirements: For the establishment of rainwater harvesting techniques, medium to high level of know-how is required.
Labour requirements: Roof catchments, macro-catchments and small dams require high initial labour input, whereas micro-catchments usually need mainly medium labour input depending on the technique used. Micro-and macro-catchments and small dams also require a certain level of labour for maintenance. Many techniques can be implemented manually.

Land degradation

▩ Erosion by water
□ Erosion by wind
░ Chemical degradation
▩ Physical degradation
░ Biological degradation
■ Water degradation

■ High
▩ Moderate
░ Low
□ Insignificant

Land use

■ Cropland
▩ Grazing land
□ Forests / woodlands
▩ Mixed land use
□ Other

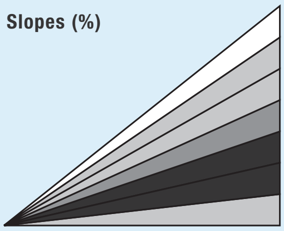
Climate

□ Humid
▩ Subhumid
■ Semi-arid
▩ Arid

Average rainfall (mm)

□ > 3000
□ 2000-3000
□ 1500-2000
□ 1000-1500
▩ 750-1000
■ 500-750
▩ 250-500
░ < 250

Slopes (%)



□ very steep (>60)
░ steep (30-60)
░ hilly (16-30)
▩ rolling (8-16)
■ moderate (5-8)
■ gentle (2-5)
░ flat (0-2)

Farm size

■ Small scale
▩ Medium scale
▩ Large scale

Land ownership

□ State
□ Company
▩ Community
■ Individual, not titled
■ Individual, titled

Mechanisation

■ Manual labour
□ Animal traction
▩ Mechanised

Market orientation

■ Subsistence
▩ Mixed
░ Commercial

Required labour

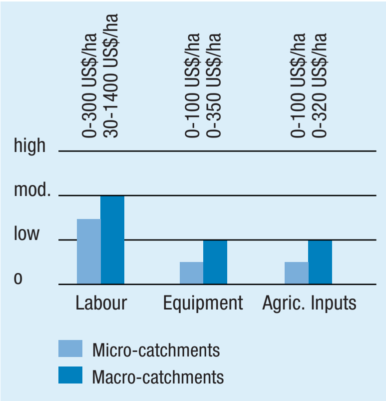
■ High
▩ Medium
□ Low

Required know-how

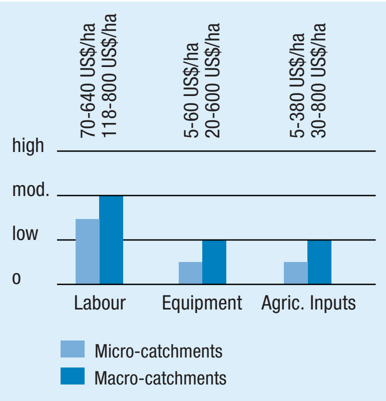
■ High
▩ Medium
□ Low

Economics

Establishment costs



Maintenance costs



Labour is valued as 1-2 US$ per person day (Source: WOCAT, 2009)

Micro-catchments: Main costs are for labour (establishment and maintenance); inputs are mainly agricultural such as compost, fertilizer, etc., equipment is less important than for macro-catchments. Labour days can vary considerably and range between 80 - 250 person days/ha.
Macro-catchments: Main costs are for labour. Maintenance costs depend heavily on the quality of the structures; they are usually low for well-built structures. In case of breakages maintenance costs can be very high (compared to micro-catchments).
Small dams: Costs for a size of 50-80,000 m^3 approximately 120,000-300,000 US$ (this translates to about 1.5-6 US$ per m^3 of earth dam material)
Ponds: Costs about 4 US$ per 1 m^3 excavation
Roof catchments: Storage tanks cost about 200 US$ per m^3 of water (a tank is typically 10 m^3 ➜ 2,000 US$) (the same if plastic tanks are used or ferrocement tanks (except that the cement tanks are logistically much more demanding and require much greater skills). Both of them last more than 10 years.

Production benefits

Crop	Yield without SLM (t/ha)	Yield with SLM (t/ha)	Yield gain (%)
Burkina Faso Millet	0.15 – 0.3	*Zaï* + manure 0.4 (poor rainfall) 0.7 - 1 (high rainfall)	30-400%

(Source: FAO, 2001)

Comment: For roof catchments and for small dams, ponds, etc. no directly related production benefits can be shown. The main benefits are related to the availability of clean and free household, as well as irrigation water.

Benefit-Cost ratio

System	short term	long term	quantitative
Micro-catchments	+/++	++	
Small dams, etc.	– –	++/+++	
Macro-catchments	– –	++/+++	Returns to labour, 10-200 US$/PD vegetables 10 US$/PD* for maize
Roof catchments	– –	+++	
Overall	–	++/+++	

– – negative; – slightly negative; –/+ neutral; + slightly positive; ++ positive; +++ very positive
**PD: person days. (Sources: WOCAT, 2009 and Hatibu, et al., 2004)*

Comment: Due to the required level of maintenance activities the costs for micro-catchments are slightly less positive in the long term than for roof catchments and small dams / ponds, etc.

Example: Niger
Cost of selected RWH techniques

Erosion control / SLM techniques	Indicative costs US$/ha
Stone lines *Cordon de pierres*	31
Stone lines with direct seeding *Cordon de pierres avec semis direct*	44
Earth bunds *Banquette en terre*	137
Earth bunds manual *Banquette en terre manuelle*	176
Half-moon for crops *Demi-lune agricole*	111
Half-moon for trees *Demi-lune forestière*	307
Planting pits *Zaï*	65

(Sources: Projet d'Aménagement Agro-Sylvo-Pastoral Nord Tillabéry (PASP); Projet Développement Rural Tahoua (PDRT))

Example: Tanzania

In Tanzania a study was conducted on the productivity of RWH techniques. The results showed that farmers using RWH for maize and paddy could increase crop yields. However the yield achieved can be depressed through higher labour requirements as well as low market prices. Other factors in production, such as fertility management, are essential for higher crop yields. Micro-catchments led to higher benefits than the use of storage ponds and macro-catchments, even though the increase in crop yield was higher with the latter, but the return to labour for storage ponds and macro-catchments is lower than for micro-catchments. The study also showed that using RWH techniques like storage ponds and macro-catchments is very beneficial for the production of vegetables with returns to labour of between 10 US$ and 200 US$ per person day, whereas for maize and paddies it rarely exceeds 10 US$ per person day. One reason for the better return under vegetables is the higher market price (Hatibu, et al., 2004).

Crops	Return to labour* (US$/person days)
Maize	4.6
Paddy	5.2
Tomatoes	13
Onions	87

**for RWH techniques using external runoff and storage ponds (mean return from 1998 to 2002)*

Impacts

Benefits	Land users / community level	Watershed / landscape level	National / global level
Production	+ + increased crop yields (a, b, c)* ++ enhanced water availability ++ increased fodder production (a, b, c) + increased wood production (a, b, c) + diversification of production	++ reduces risk of crop failure (a, b, c) +++ access to clean and free drinking water (d) +++ reduced damage to neighbouring fields	+++ improved food and water security
Economic	+++ access to clean / free drinking water (d) ++ increased farm income	++ less damage to off-site infrastructure + stimulation of economic growth + diversification and rural employment creation	+++ improved livelihood and well-being
Ecological	+++ improved water availability ++ can be used for rehabilitation of highly degraded land (a, b) ++ improved water infiltration (a) ++ reduced velocity of runoff (a) ++ reduced net surface runoff (a and b) ++ increased net soil moisture (a) ++ reduced soil erosion and soil loss (a) ++ improved excess water drainage (a) + increases soil organic matter and soil fertility (a) + improved soil cover (a) + biodiversity enhancement + sediment traps for nutrient (a, b)	++ reduced degradation and sedimentation (a) ++ increased stream flow in dry season / reliable and stable low flows (a, b, c) + groundwater recharge + reduced groundwater / river pollution (a, b) + intact ecosystem	+++ increased resilience to climate change ++ reduced degradation and desertification incidence and intensity + enhanced biodiversity
Socio-cultural	+++ less pressure on water resources for drinking water, irrigation, etc. ++ community institution strengthening ++ improved conservation / erosion knowledge (a, b, c) ++ can reduce the time used for gathering water for domestic use	+ increases awareness for environmental 'health' ++ reduced water conflicts ++ national institution strengthening + attractive landscape	+ protecting national heritage

**a) Micro-catchments, b) Macro-catchments, c) Small dams / ponds, d) Roof catchments*

	Constraints	How to overcome
Production	• Very often RWH alone does not always lead to a significant production increase, additional fertility management is needed (a, b, c)	➜ combine with improved soil fertility management
Economic	• Increased input constraints especially for the establishment • Availability of manure to improve soil fertility especially within micro-catchments • Establishment and construction can be labour intensive and requires a high level of technical knowledge • Maintenance of the system and limited life-span of certain types of structures – for micro-catchments this mainly refers to annual agronomic activities, whereas for small dams and macro-catchments maintenance includes also reparation and protection against animals as well as siltation • Loss of land (decreased production area) especially for very small farms (a, b, c) • Lack of market (a, b, c) • Cost of transportation of the material (a, b, c)	➜ access to market for inputs and equipment and if necessary support for establishment ➜ technical support in form of training and education on the system is needed ➜ for small-dams, ponds, etc. community organisation is needed for the establishment and the maintenance with clear responsibilities ➜ most successful techniques are simple, inexpensive, easily manageable by local community (includes stone bunds, semi-circular bunds, vegetative strips)
Ecological	• Waterlogging can be a problem under poor drainage systems (a, b, c,) • Water can only be harvested when it rains	
Socio-cultural	• Conflicts in areas formerly used by nomads • Where RWH is used over a significant area, there may be upstream / downstream conflicts in terms of water availability • Socio-cultural conflicts concerning rehabilitated land • Eliminates women's burden of collecting water for domestic use (d)	➜ clear land and water use rights and improved watershed planning with allocation of water resources ➜ farmer and community involvement

Adoption and upscaling

Adoption rate

In general adoption rates remain low. Farmers hesitate to invest time and money in RWH without security of land and limited access to local markets where they can sell surpluses. However some RWH technologies like *zaï* have been widely adopted with (and in some areas, without) external support.

Upscaling

Profitability: The techniques recommended must be profitable for land users and local communities, and techniques must be simple, inexpensive and easily manageable.

Capacity building and knowledge sharing on suitable RWH techniques is needed. One of the constraints hindering adoption is lack of information, education and training

The level of maintenance is an important criterion. The techniques should be manageable at farm level and involve community action, especially for larger-scale construction such as ponds, small dams and macro-catchments which are very often out of the land user's control.

Clear land and water tenure and property rights are necessary to motivate land users to invest in RWH.

Market access: A better linkage and access to markets is necessary, and assistance for small-scale farmers to change from subsistence to commercial farming.

Micro-catchments usually need a low level of material and technical support . However, depending on the techniques, a certain level of material and / or technical support is needed, e.g. *demi-lune* / half moon techniques in West Africa require a relatively high level of material support for the establishment. In Burkina Faso the *zaï* system has been successfully spread through farmer-to-farmer visits. Farmer-to-farmer exchange can be a highly successful tool for upscaling of micro-catchment systems.

Macro-catchments and small dams are very often not within reach of small communities and usually require material and technical support for the establishment as well as community involvement / organisation in the planning and maintenance of the system.

Roof catchments: Relative high investment costs might require initial material support for the construction. Community involvement is needed for the establishment and maintenance. Trained extension services and self-help groups and organisations are very effective and needed for spreading of the technology.

Incentives for adoption

(1) For micro-catchments a low level of material and technical support is needed; (2) macro-catchments and small dams require high material and technical support for establishment; and (3) roof catchments need high levels of material and technical support for establishment.

Enabling environment: key factors for adoption	
Inputs, material, incentives, credits	++
Training and education	++
Land tenure, secure land use rights	+++
Access to markets	++
Research	++
Infrastructure	++
Genuine ownership on the part of communities	+++

References and supporting information:

AQUATSTAT. 2009. http://www.fao.org/NR/WATER/AQUASTAT/main/index.stm, access on 15 July 2009

FAO, 2008. Water and Rural Poverty - Interventions for Improving Livelihoods in sub-Saharan Africa.

FAO. 1991. A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production. W. Critchley and K. Siegert

FAO. 2001. Compendium of Land and SARD Cases: Supporting Document to Task Managers' Report to CSD+10 on the Land and Agriculture Cluster for Chapters 10, 12 and 14 of Agenda 21. http://www.fao.org/wssd/land/docs/Comp_Cases2001.doc, accessed on 15 July 2009.

Hatibu N., E. M. Senkondo, K. Mutabazi and A.S.K. Msangi. 2004. Economics of Rainwater Harvesting for Crop Enterprises in Semi-Arid Areas. 'New directions for a diverse planet'. Proceedings of the 4th International Crop Science Congress, 26 Sep – 1 Oct 2004, Brisbane, Australia. Published on CDROM.

IWMI. 2009. Vallerani-System. http://www.iwmi.cgiar.org/africa/west/projects/Adoption%20Technology/RainWaterHarvesting/26-ValleranisSystem.htm

Malesu, M., J. K. Sang, J. Orodi Odhiambo, A. R. Oduor and M. Nyabenge. 2006. Hydrologic impacts of ponds on land cover change, Runoff water harvesting in Lare, Kenya, Maimbo, Technical Report No. 32. Regional Land Management Unit (RELMA-in-ICRAF), Netherlands Ministry of Foreign Affairs and Swedish International Development Cooperation Agency (Sida)

Mati B. M. 2005. Overview of water and soil nutrient management under smallholder rainfed agriculture in East Africa. Working Paper 105. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Pretty J. N., A. D. Noble, D. Bossio, J. Dixon, R. E. Hine, F. W. T. Penning de Vries, and J. I. L. 2006. Resource-conserving Agriculture Increases Yields in Developing Countries. Environmental Science & Technology, Vol. 40, No. 4.

RAF Publication. 2001. La collecte des eaux de surface en Afrique de l'Ouest et du Centre - Water harvesting in western and central Africa

UNEP. 2009. Rainwater Harvesting: A Lifeline for Human Well-Being. A report prepared for UNEP by Stockholm Environment Institute.

UNESCO. 2002. Proceedings of the International Seminar on Combating Desertification: Freshwater Resources and the Rehabilitation of Degraded Areas in the Drylands, held in N'Djamena, Chad, 30 October to 4 November 2000

Vohland K. and B. Barry. 2009. A review of in situ rainwater harvesting (RWH) practices modifying landscape functions in Africa drylands. Agriculture, Ecosystems and Environment 131 (2009) 119-127

Wateraid. 2009. Roof Catchments. http://www.wateraid.org/documents/plugin_documents/technology_notes_07_web_1.pdf, accessed on 15 July 2009

WOCAT. 2009. WOCAT database on SLM technologies and SLM approaches. www.wocat.net, accessed on 15 September 2009

Woodfine, A. 2009. Using sustainable land management practices to adapt to and mitigate climate change in sub-Saharan Africa: resource guide version 1.0. TerrAfrica. www.terrafrica.org.

TASSA PLANTING PITS - NIGER

Tassa planting pits are used for the rehabilitation of degraded, crusted land. This technology is mainly applied in semi-arid areas on sandy / loamy plains, often covered with a hard pan, and with slopes below 5%.

Planting pits are holes of 20-30 cm diameter and 20-25 cm depth, spaced about 1 m apart in each direction. They are dug by hand. The excavated earth is formed into a small ridge downslope of the pit for maximum back capture of rainfall and runoff. Manure is added to each pit, though its availability is sometimes a problem. The improved infiltration and increased nutrient availability brings degraded land into cultivation.

Common crops produced in this water harvesting system are millet and sorghum. At the start of the rainy season, seeds are sown directly into the pits. Silt and sand are removed annually. Normally the highest plant production is during the second year after manure application. The technology does not require external inputs or heavy machinery and is therefore favourable to spontaneous adoption.

Tassa are often combined with stone lines along the contour to enhance water infiltration, reduce soil erosion and siltation of the pits. Grass growing between the stones helps increase infiltration further and accelerates the accumulation of fertile sediment.

SLM measure	Structural
SLM group	Rainwater Harvesting
Land use type	Silvopastoral / wasteland (before), cropland (after)
Degradation addressed	Loss of topsoil (by water and wind); Soil compaction / crusting; Soil fertility decline; Soil moisture problem
Stage of intervention	Rehabilitation
Tolerance to climate change	Increased tolerance due to water harvesting

Establishment activities

1. Digging pits (*tassa*) with a hoe in the dry season (20-25 cm deep, 20-40 cm in diameter): the excavated earth forms ridges downslope of the hole. The pits are spaced 0.8-1 m apart, giving approximately 10,000 pits/ha.
2. Manuring the pits with approx. 250 g per pit (2.5 t/ha).
3. Optionally: Digging out stones from nearby sites (using a pick-axe and shovel) and aligning the stones along the contour with the help of a 'water tube level': maximum of 3 stones wide. The distance between the stone lines is a function of the slope: at a 2% slope (or less) the lines are spaced 50 m apart, at a 5% slope, spacing is 25m.

All activities are carried out by manual labour.

Maintenance / recurrent activities

1. Removing sand from the *tassa* (annually, March-May).
2. Manuring the pits with about 250 g per pit (2.5 t/ha) every second year in October / November or March-May.

All activities are carried out by manual labour.

Labour requirements

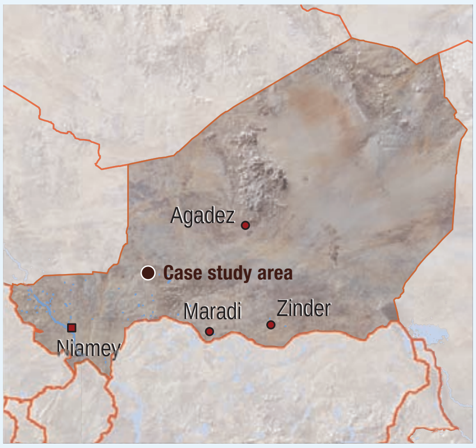
For establishment: high
For maintenance: low

Knowledge requirements

For advisors: moderate
For land users: low

Photo 1: Adding manure to the pits (*tassa*) before planting. (William Critchley)
Photo 2: Digging pits and piling up a small bund on the downstream side, using a traditional hoe. (William Critchley)
Photo 3: Sorghum growing in planting pits. (Philippe Benguerel)

Case study area: Tahoua, Niger



Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour: 100 person-days	150
Equipment	5
Agricultural inputs	5
TOTAL	**160**
% of costs borne by land users	100%

Remarks: Establishment costs are for 2 pits.

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 20 person-days	30
Equipment	0
Agricultural inputs	2.5
TOTAL	**32.5**
% of costs borne by land users	100%

Remarks: Labour costs are indicated for establishment of *tassa* only (without application of stone lines). Maintenance costs refer to removing sand from the pits from the second year onwards, and to manuring every second year (costs are spread on an annual basis). If applicable, costs for transporting the manure need to be added. The general assumption in these calculations is that adequate manure is readily available close by. Land users bear 100% of all costs.

Benefit-cost ratio

Inputs	short term	long term
Establishment	neutral	slightly positive
Maintenance	slightly positive	positive

Remarks: Initial labour inputs pay out on the medium to long term.

Ecological conditions

- Climate: semi-arid
- Average annual rainfall: 250-500 mm
- Soil parameters: well drained, sandy, shallow soils; low to very low soil fertility; low organic matter (<1%); soil crusting
- Slope: mostly gentle (2-5%), partly flat (0-2%)
- Landform: mainly plains / plateaus, partly footslopes
- Altitude: 100-500 m a.s.l.

Socio-economic conditions

- Size of land per household: 2-5 ha
- Type of land user: small-scale farmers
- Population density: no data
- Land ownership: mostly individual, titled
- Land use rights: individual
- Market orientation: mostly subsistence, partly mixed (subsistence and commercial)
- Level of mechanisation: manual labour

Production / economic benefits

+++ Increased crop yield
++ Increased farm income

Ecological benefits

+++ Improved soil cover (long term)
++ Increased soil moisture
++ Increased soil fertility
++ Increased soil organic matter
++ Reduced soil loss

Socio-cultural benefits

++ Improved conservation / erosion knowledge
+ Community institution strengthening through mutual aid in technology implementation

Off-site benefits

++ Reduced downstream flooding
+ Reduced downstream siltation

Weaknesses ➜ and how to overcome

- Implementation constraint: availability / transport of manure and transporting manure to the plateaus and slopes ➜ subsidise transport means (or supply donkey carts).
- High labour input for implementation and maintenance ➜ mechanisation of tasks: transportation of manure. However, this would raise the cost.
- Instability of planting pits in loose soil, increased erosion on steeper slopes and with heavy rains ➜ avoid sandy soils and steep slopes; combine with additional measures (e.g. stone lines).
- The effectiveness can be compromised if the various geo-morphological units (plateaus, slopes) are not treated simultaneously ➜ catchment area approach if downstream flooding is an issue.
- Possibility of land use conflicts concerning rehabilitated land, in particular with pastoralists (because grazing land is being turned into cultivated fields) ➜ better coordination / consultation before implementing the technology in an area.

Adoption

There is a moderate trend towards spontaneous adoption (for rehabilitation of the plains). Area covered by the technology was approx. 40 km^2 in 2000.

Main contributors: Adamou Oudou Noufou, Tahoua, Niger
Key references: Bety A, A. Boubacar, W. Frölich, A. Garba, M. Kriegl, A. Mabrouk, Noufou O, Thienel M and Wincker H (1997): Gestion durable des ressources naturelles. Leçons tirées du savoir des paysans de l'Adar. Ministère de l'agriculture et de l'élevage, Niamey, 142 pp. ■ Hassane A, Martin P and Reij C (2000) Water harvesting, land rehabilitation and household food security in Niger: IFAD's Soil and Water Conservation Project in Illela District. IFAD, Rome, 51 pp. ■ WOCAT 2009, WOCAT Database on SLM Technologies, www.wocat.net

SMALL EARTH DAMS - ZAMBIA

Small earth dams are water harvesting storage structures, constructed across narrow sections of valleys, to impound runoff generated from upstream catchment areas. Construction of the dam wall begins with excavation of a core trench along the length of the dam wall which is filled with clay and compacted to form a central core ('key') that anchors the wall and prevents or minimises seepage. The upstream and downstream embankments are built using soil with a 20-30% clay content. During construction – either by human labour, animal draught or machine (bulldozer, compacter, grader etc.) – it is critical to ensure good compaction for stability of the wall. It is common to plant Kikuyu grass (*Pennesetum clandestinum*) to prevent erosion of the embankment. The dam is fenced with barbed wire to prevent livestock from eroding the wall.
Typical length of the embankment is 50-100 m with water depth ranging 4-8 m. An emergency spillway (vegetated or a concrete shute) is provided on either, or both sides, of the wall for safe disposal of excess water above the full supply level. The dam water has a maximum throwback of 500 m, with a capacity ranging from 50,000 – 100,000 m^3. The dams are mainly used for domestic consumption, irrigation or for watering livestock.
If the dams are located on communal lands, their establishment requires full consultation and involvement of the local community. The government provides technical and financial assistance for design, construction and management of these infrastructures. Community contribution includes land, labour and local resources. The community carries out periodic maintenance of the infrastructure – including vegetation management on embankment, desilting etc. – and of the catchment areas (through soil and water conservation practices).

SLM measure	Structural
SLM group	Rainwater Harvesting
Land use type	Cropland; Grazing land
Degradation addressed	Water degradation: reduced surface water availability
Stage of intervention	Mainly prevention and mitigation, partly rehabilitation
Tolerance to climate change	Sensitive to climatic extremes (e.g. floods); Tolerant with respect to rainfall variability, prolonged dry spells, etc.

Establishment activities

1. Site selection in consultation with community.
2. Dam survey and design: Topographical survey of dam area; using levelling equipment (dumpy level or theodolite); Determination of dam wall dimensions.
3. Dam wall construction: Excavate core trench (usually 4 m wide; 2 m deep). Excavate and transport clay-rich soil to the dam site. Construct core and embankments (slope angles 3:1). Continuously compact placed soil.
4. Construct lateral spillway(s), 5-30 m wide (depending on the flood flow and the return slope).
5. Design and installation of irrigation and drainage infrastructure (in case of crop production).
6. Completion: plant Kikuyu grass on dam embankment, spillway and irrigation canals and fence of; alternatively line with cement.

Maintenance / recurrent activities

1. Catchment conservation to minimise siltation of dam and irrigation infrastructure (continuous).
2. (Re-)planting grass on dam and irrigation infrastructure (annually, using hand hoes).
3. Desiltation of the dam (every 5-10 years): excavate and remove the silt deposited in the dam.
4. Cleaning of dam and irrigation infrastructure: remove trees / shrubs from dam / canals. If concrete lined: repair of any damages.

Establishment and maintenance of structures is carried out by human or animal labour or by machine (i.e. bulldozers or tractors with scoop).

Labour requirements

For establishment: high
For maintenance: low to medium

Knowledge requirements

For advisors: high
For land users: high

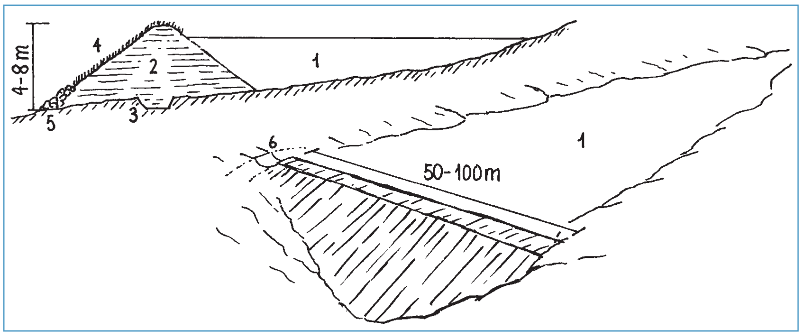
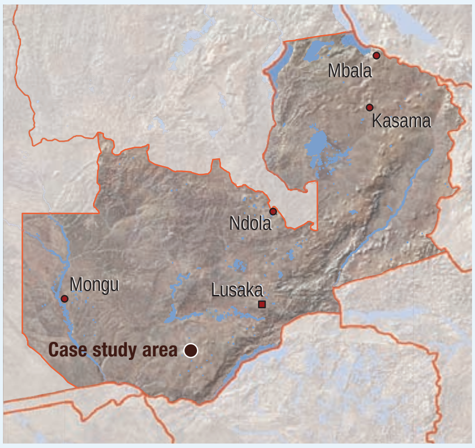


Photo 1: Manual construction of a small dam requires community action: soil is transported in bags, piled up and compacted layer by layer.
Photo 2: Fetching water for domestic use at a small dam.
Photo 3: Water point for livestock. (All photos by Maimbo Malesu)
Technical drawing: Dimensions and main components of a small dam: (1) water body; (2) dam wall (with layers of compacted soil; side slopes 3:1); (3) central core ('key'); (4) grass cover; (5) stone apron; (6) spillway (Mats Gurtner).

Case study area: Southern Province, Zambia



Establishment inputs and costs per dam

Inputs	Costs (US$)
Labour: 633 person-days	2,000
Equipment / tools: machinery, ox-ripper, hoe / pick, shovel (US$ 3/m^3 of earth work)	30,000
Agricultural inputs: termicide, grass seed, fertilizer	3,000
Construction material: cement, sand, stones, abstraction pipes, screen, valve, bolts and nuts	15,000
TOTAL	**50,000**
% of costs borne by land users	20%

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 63 person-days	200
Equipment / tools: hoe, axe, shovel	2,000
Agricultural inputs: grass seed, fertilizer	300
Construction material: cement, stones, building sand	1,500
TOTAL	**4,000**
% of costs borne by land users	80%

Remarks: Establishment costs are calculated for a dam with an earthwork volume of 10'000 m^3 (44 m long; 8 m deep; side slopes 3:1). 20% of costs are borne by the community (in-kind contribution: labour and local materials such as sand, stones). Construction machinery can include: tipper truck, bulldozer, motor scraper, compactor, tractor, grader.

Benefit-cost ratio

Inputs	short term	long term
Establishment	negative	very positive
Maintenance	neutral	very positive

Ecological conditions

- Climate: semi-arid, subhumid
- Average annual rainfall: 700 mm (400-800 mm)
- Soil parameters: medium fertility; medium depth, well drained, medium organic matter content; loamy to sandy soil texture
- Slope: plains (2-15%) and valleys (15-40%)
- Landform: plains and valleys
- Altitude: 300-1,200 m a.s.l for mid Zambezi valley and Southern plateau respectively

Socio-economic conditions

- Size of land per household: 2 ha
- Type of land user: small-scale; land user groups; poor
- Population density: 10 persons/km^2
- Land ownership: communal (not titled)
- Land use rights: communal (organised)
- Level of mechanisation: animal traction
- Market orientation: mixed (subsistence and commercial)

Production / economic benefits

+++ Increased crop yield
+++ Increased irrigation water availability
++ Increased animal production
++ Increased farm income

Ecological benefits

+++ Increased water quantity
+++ Improved water harvesting / collection
++ Recharge of groundwater table / aquifer
+ Reduced hazard towards adverse events

Socio-cultural benefits

+++ Improved food security
++ Community institutional strengthening
+ Increased recreational opportunities

Off-site benefits

+++ Increased water availability
+++ Reduced downstream flooding

Weaknesses ➜ and how to overcome

- Dams are communally owned ➜ requires strong organisation and commitment by community.
- Risk of siltation ➜ de-silting and catchment conservation is essential
- Vulnerability to climate change ➜ increase depth and design storage to last at least for two rainy seasons.
- Evaporation and seepage losses ➜ maintain minimum design depth of 4 meters; if seepage is high: provide impervious material on the upstream embankment, i.e. clay or plastic lining if necessary.

Adoption

Records of 1991 indicate at least 537 such dams exist in Zambia. In the study area there are over 293 dams serving a cattle population of 1.1 million and human population of nearly 1 million people. Communities require government or NGO support for establishment.

Main contributors: Maimbo Malesu, ICRAF-CGIAR; Nairobi, Kenya; m.malesu@cgiar.org
Key references: The Jesuit Centre for Theological Reflection. 2010. Social Conditions Programme. http://www.mywage.org/zambia/main/minimum-wage/comparitive-minimum-wage. ■ Nissen-Petersen E. 2006. Water from small dams. A handbook for technicians, farmers and others on site investigations, designs, cost estimations, construction and maintenance of small earth dams ■ Morris P. H. 1991. Statement of Policy: Progress Review of the Drought Relief Dam Cons/ruction Project, Southern Province. Part 1 — Main Report. Irrigation and Land Husbandry Branch, Department of Agriculture, Chôma. ■ Sichingabula H.M. 1997. Problems of sedimentation in small dams in Zambia. Human Impact on Erosion and Sedimentation (Proceedings of the Rabat Symposium, April 1997. IAHS Publ. no. 245, 1997

RUNOFF AND FLOODWATER FARMING - ETHIOPIA

Runoff and floodwater farming is a traditionally practiced water harvesting system which helps overcome problems of soil moisture and crop failure in a hot, dry area with erratic rainfall and shallow, highly erodible soils: floodwater and runoff from ephemeral rivers, roads and hillsides is captured through temporary stone and earth embankments. A system of hand dug canals – consisting of a main diversion canal and secondary / tertiary canals – conveys and distributes the captured water to the cultivated fields in naturally flat or leveled areas. The total length of the canal system is 200 – 2,000 m. The harvested water is used for growing high value crops, vegetables and fruit trees. Irrigated fields are divided into rectangular basins bordered by ridges to maximise water storage and minimise erosion risk.

Runoff and floodwater management requires preparedness for immediate action by the farmers: When a flood is expected in the ephemeral river, farmers rush to the diversion site and start erecting the embankment across the bed of the stream. Similarly, each famer starts to maintain the canal which leads water to his field. A schedule defines the date and time each farmer is allocated his turn to irrigate. When the water reaches the field, it is spread either through flooding or distributed in furrows which are opened and closed using a local tool.

The ratio between catchment area and production area is 10:1 – 100:1 or greater. While the diversion canals / ditches and basins for tree planting are permanent structures, basins for annual crops are seasonal. Soil fertility is improved by additional measures such as composting and mulching. Maintenance, including repairs to breaks along the canal and water conveying ditches, is needed every season before the onset of rains.

SLM measure	Structural
SLM group	Rainwater Harvesting
Land use type	Annual crops, tree crops
Degradation addressed	Loss of water, aridity; Loss of topsoil through erosion by water
Stage of intervention	Mitigation
Tolerance to climate change	Increased tolerance to drought and seasonal variations; sensitive to extreme flood events

Establishment activities

1. Construction of diversion canals with lateral embankments, from runoff source to the fields. Embankments are stabilised with stones – if possible (hand dug during dry season).
2. Seed bed preparation before the water is diverted to the fields: construction of rectangular basins separated by small bunds (0.3 m high; 0.3 m wide).
3. Watering the field for better seed germination. The field is watered before the seeds are planted otherwise germination will be affected.

Main canal: 3-4 m wide, 0.5-0.75 m high
Secondary canal: 2-3 m wide, 0.5 m high
Tertiary canal: 0.5-1 m wide

Maintenance / recurrent activities

1. Runoff management. This is essentially the activity of spreading water to the field which includes cleaning the canals for directing water to the field.
2. Seed bed preparation (reconstruction of basins is done every season, before the water is diverted to the field).
3. Regular maintenance / repairing of runoff diversion canals: scouring, removing sediment / silt, repairing breaks in the embankment.

Labour requirements

For establishment: high (very labour-intensive structures)
For maintenance: medium to high

Knowledge requirements

For advisors: medium
For land users: medium

Photo 1: Main canal for diverting flood water from seasonal rivers to the field. Lateral embankments are stabilised with stones.
Photo 2 and 3: Cropland prepared for floodwater farming: basins allow controlled flooding of the fields. In the background the river bed from which the water is extracted.
(All photos by Daniel Danano)

Case study area: Dire Dawa, Ethiopia

Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour: 295 person-days	253
Equipment: shovels, hoes	24
Agricultural inputs	106
TOTAL	**383**
% of costs borne by land users	100%

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 525 person-days	450
Equipment	64
Agricultural inputs: seeds	300
TOTAL	**814**
% of costs borne by land users	100%

Remarks: Establishment costs include the construction of diversion ditch, construction of blocks (irrigation basins); seeds and seedlings. Maintenance costs include the reconstruction of blocks / seedbed preparation; seeds and seedlings; weeding and cultivation; irrigation; harvest. Costs have been calculated assuming that 0.5 ha of the land is planted by fruit trees and 0.5 ha planted with vegetables. Daily wage cost of hired labor to implement SLM is 0.85 US$. All costs are met by the land users themselves.

Benefit-cost ratio

Inputs	short term	long term
Establishment	positive	very positive
Maintenance	very positive	very positive

Remarks: Net benefits are positive from the beginning due to rapid production increase.

Ecological conditions

- Climate: semi-arid (also suitable for arid areas)
- Average annual rainfall: 500-750 mm; erratic, not well distributed
- Soil parameters: good drainage, low organic matter
- Slope: flat to gentle (0-5%)
- Landform: footslopes and valley floors
- Altitude: 1,000-2000 m a.s.l.

Socio-economic conditions

- Size of land per household: 1-2 ha
- Type of land users: better-off small-scale farmers
- Population density: 150 persons/km^2
- Land ownership: state
- Land use rights: private
- Market orientation: mainly commercial, partly mixed (90% of vegetables and fruits are sold)
- Level of mechanisation: manual labour

Production / economic benefits

+++ Increased farm income (net benefit 1st year: 226 US$; from 4th year onwards: 711 US$)
+++ Increased crop yield (gross production value increases by 200% after 3 years and 400% after 10 years)
+++ Increased fodder production and increased fodder quality
+++ Increased wood production

Ecological benefits

+++ Increased soil moisture
+++ Increased infiltration
+++ Reduced runoff (from 50% to 5% of annual rainfall)
+++ Reduced soil loss (from 60 to 6 t/ha)
+++ Increased soil fertility

Socio-cultural benefits

+++ Community strengthening
+++ Improved conservation / erosion knowledge

Off-site benefits

+++ Reduced downstream flooding
+++ Increased stream flow in dry season
+++ Reduced downstream siltation

Weaknesses ➜ and how to overcome

- Increased labour constraints: construction of diversion ditches, preparation of irrigation basin and spreading the runoff water and regular maintenance / reconstruction of structures is very labour intensive ➜ providing improved farm tools could improve efficiency of operation, organising farmers in groups for sharing labor would curtail labor problems; Placing permanent structures at the diversion head (concrete) and paving ditches to improve channel stability would reduce maintenance activities.
- Social inequity: mainly better-off farmers apply the technology (due to high costs) ➜ providing credit solves financial problems and facilitating market would motivate land users to get more engaged in the business.
- Loss of land (through conservation structures) ➜ is outweighed by the high production benefits.

Adoption

100% of land users that have applied the technology, have done it wholly voluntarily, without any incentives except technical guidance. There is enough local skill and support to expand the technology.

Main contributors: Daniel Danano, Ministry of Agriculture and Rural Development, Addis Ababa, Ethiopia; ethiocat@ethionet.et
Key references: Danano, D. 2008; (unpublished): Soil and Water Conservation Practices for Sustainable Land Management in Ethiopia. Ethiocat.

SMALLHOLDER IRRIGATION MANAGEMENT

Low-cost drip irrigation for vegetable production on a small plot in Niger. (William Critchley)

In a nutshell

Definition: A Smallholder Irrigation Management (SIM) unit is typically a plot covering an area less than 0.5 ha. SIM schemes may be managed either by an individual land user or by groups / communities.

The guiding principle of sustainable SIM is 'more crop per drop', in other words efficiency of water use. This can be achieved through more efficient (1) water collection and abstraction; (2) water storage; (3) distribution and; (4) water application in the field. Two main categories of SIM can be distinguished, traditional surface irrigation systems and recent micro-irrigation systems including drip irrigation. Micro-irrigation systems are commonly used for, and are very important in, the production of vegetables, fruits and flowers. More efficient water use can enhance production benefits remarkably. However, additional measures including soil fertility management, introduction of high value crops and appropriate pest and disease control are necessary for a substantial increase in production. As water resources in SSA are generally scarce and very unevenly distributed, any dream of widespread irrigation schemes is unrealistic. However, there is scope for improved irrigation management - making the most efficient use of precious water resources, especially for small-scale farming. Priority areas for SIM in SSA are in semi-arid and subhumid areas, where a small amount of irrigation water leads to a significant increase in yield - or at least a reduction in crop failure. Often there are possible synergies to be made by basing such schemes on water collected through rainwater harvesting. Therefore, SIM builds on the principles of supplementary irrigation, with rainfall as the principle source of water, and supplementary irrigation helping during dry spells and extending the growing period.

Applicability: SIM is most applicable to arid, semi-arid and subhumid areas. In water-scarce regions, the amount of irrigation water is limited and irrigation competes with other water demands.

Resilience to climate variability: SIM systems can enhance the resilience to droughts and temperature increase. The storage of excess rainfall and the efficient use of irrigation are critical in view of growing water scarcity, rising temperatures and climatic variability.

Main benefits: This system can increase incomes of the farmers by producing more, and higher-value, crops. Helping land users to move from subsistence farming to producing cash crops contributes to poverty reduction, primarily by enhancing the productivity of both labour and land. Agricultural production risks can be reduced, and food security enhanced.

Adoption and upscaling: The major constraint to smallholder irrigation is the availability of water. Financing (high costs of equipment), and the lack of a functioning market system to sell products, are further constraints. Therefore it is important that access to financial services is provided to land users. Land user group organisations can be a means to pool land users and resources and develop irrigation schemes.

Development issues addressed	
Preventing / reversing land degradation	+
Maintaining and improving food security	+++
Reducing rural poverty	++
Creating rural employment	++
Supporting gender equity / marginalised groups	++
Improving crop production	+++
Improving fodder production	+
Improving wood / fibre production	na
Improving non wood forest production	na
Preserving biodiversity	na
Improving soil resources (OM, nutrients)	+
Improving of water resources	-/+
Improving water productivity	+++
Natural disaster prevention / mitigation	+
Climate change mitigation / adaptation	-/+

Climate change mitigation	
Potential for C Sequestration (tonnes/ha/year)	0.15 (+/- 0.012)*
C Sequestration: above ground	+
C Sequestration: below ground	+

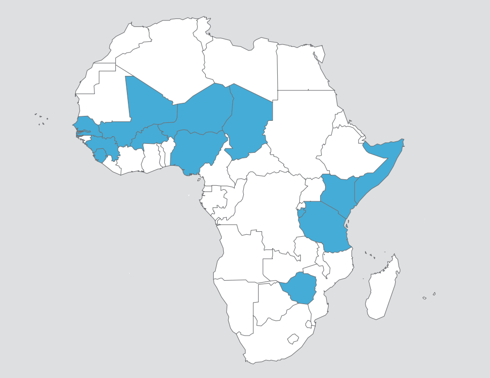
Climate change adaptation	
Resilience to extreme dry conditions	+
Resilience to variable rainfall	++
Resilience to extreme rain and wind storms	na
Resilience to rising temperatures and evaporation rates	+
Reducing risk of production failure	++

**for a duration of the first 10-20 years of changed land use management (Pretty et al., 2006)*

Origin and spread

Origin: Traditional SIM systems in SSA are mainly based on gravity systems using mountain streams. Spate irrigation is another traditional system, with a long history in the Horn of Africa. In the 1970s -1980s there was much investment in large-scale irrigation projects to intensify agriculture: these often ended in failure, because of either poor governance, or lack of maintenance, or both. In the 1980s investments in irrigation turned to a more integrated approach by financing small-scale irrigation with little or no government support. The use of drip irrigation systems has accelerated over the last decades with the mass production of plastic pipes. Initially it was a capital-intensive system. Recent innovations have helped to make drip irrigation more affordable to smallholders.

Mainly applied in: Burundi, Burkina Faso, Chad, Gambia, Guinea, Kenya, Mali, Niger, Nigeria, Senegal, Sierra Leone, Somalia, Tanzania, Zimbabwe


Spread of Smallholder Irrigation Management in SSA.

Principles and types

'More crop per drop' can be achieved through more efficient use of water:

(1) Efficient water abstraction, storage and distribution: SIM needs emphasis on efficient water storage, abstraction and distribution to the field. Water sources for irrigation can be rivers, lakes, groundwater, or water collected through rainwater harvesting systems (see RWH group). The water can be either abstracted through pumps or wells, or it can be gravity-fed. Treadle pumps, which are food-operated water lifting devices, have been very successfully introduced in SSA for the production of vegetables. More efficient water distribution can be achieved through the usage of pipelines instead of open water channels.

(2) Efficient water application in the field: In a SIM-system the water is used efficiently by applying appropriate quantities at strategic times, principally through providing supplementary irrigation water at particular growth stages. Excessive flooding can be harmful, as it may lead to nutrient leaching, as well as inducing greater evaporation and salinisation. The application of too little water is also wasteful, since it will fail to provide the desired benefits. Under the 'deficit irrigation method' crops are exposed to different levels of water stress resulting in enhanced root development - and thereby substantial saving of water can be achieved while maximum yields can be almost attained.

a) Micro-irrigation techniques are promising systems for increased water use efficiency. Within micro-irrigation, a small volume of water is applied at frequent intervals to the spot where the roots are concentrated. Micro-irrigation techniques are gaining popularity among small-scale farmers, especially those systems using water harvested in tanks and small ponds. The most common micro-irrigation system is drip irrigation.

In a **drip irrigation system**, water flows under pressure through a filter into drip pipes, with emitters located at variable spacings. Water is discharged directly onto the soil near the plants. Drip lines should be placed close to the plants to avoid salt accumulation in the root zone, and to minimise water loss. Fertilizer and nutrients can be applied easily, and more precisely, through the system.

b) Surface irrigation is the application of water by gravity flow to the surface of the field. Either the entire field is flooded, or the water is led into basins, or fed into furrows, or strips of land (borders). Surface irrigation is the main traditional irrigation method and still plays a significant role in SSA. An example is:

Spate irrigation: Floodwater diversion or spate irrigation techniques divert the water from its natural course. Storm-floods are harvested from rainfall-rich highlands, and diverted into levelled basins in the dry lowlands. Floodwater is channelled through a network of different channels. Collection areas may range from anything between a few hectares to over 25,000 ha. The schemes are expensive to construct and difficult to maintain due to frequent bund breakages during floods. Spate irrigation is mainly applied in Ethiopia, Eritrea, Kenya, Senegal, Somalia and Sudan.

Informal irrigation can be defined as the irrigation sector established purely by land users without public funding (often synonymously with smallholder irrigation). Informal irrigation is widespread in urban and peri-urban agriculture, especially in West Africa. It is common in market gardening of cash crops. Intensive irrigation relies mainly on watering cans, due to its low investments costs and precise water application, yet it is labour intensive. The value of urban agriculture and informal irrigation is still underestimated in SSA.




Top: Water distribution for irrigation, Kenya. (Hanspeter Liniger)
Middle: Large private vegetable producer using watering cans for irrigation, Senegal. (Christoph Studer)
Bottom: Detail of a drip irrigation system: water from the pipe is being emitted directly onto the soil close to the plant, Niger. (William Critchley)

Applicability

Land degradation addressed

Water degradation: aridification – decrease of average soil moisture content, overuse / over-abstraction of surface and groundwater / aquifer level due to inefficient water use and too high demand on irrigation water

Physical soil deterioration: waterlogging, sealing and crusting through inappropriate irrigation management

Chemical soil deterioration: salinisation of soil through inappropriate irrigation management and through bad quality of irrigation water

Unsuitable for areas prone to salinisation where salts cannot be washed out by drainage.

Land use

Mainly used on cropland and mixed land and in homegardens for food and cash crops (vegetables, fruit trees, etc.), rice, cotton, etc.

Sometimes used for establishment of tree plantations.

Micro-irrigation system mainly used for vegetables, fruits and cash crops or for tree seedlings and establishment of trees.

Spate irrigation is used mainly for cereal crops.

Ecological conditions

Climate: Mainly for semi-arid and subhumid areas, partly for arid areas. Smallholder irrigation systems are valid options in almost all types of agro-ecological zones. They are naturally most relevant in areas where water is a constraint to crop production, and where water resources are limited, very variable or overused: thus in semi-arid to subhumid zones. Drip irrigation systems are very suitable for water-scarce areas. In arid areas with annual rainfall of less than 500 mm, irrigation management is mainly related to permanent rivers, based on water harvesting methods, or withdrawals from groundwater.

Terrain and landscape: Spate irrigation requires a highland catchment area which supplies runoff in seasonal or ephemeral rivers. Drip irrigation can irrigate sloping land and even quite steep slopes.

Soils: No restrictions, apart from soils with high sodium (Na) content (sodic soils); needs good management on heavy clays due to risk of waterlogging. Drip irrigation can reduce or eliminate runoff and deep percolation, making it possible to irrigate difficult soils – e.g. crusting or porous soils, through frequent and controlled application of water.

Socio-economic conditions

Farming system and level of mechanisation: Traditional irrigation systems are mainly applied on small-scale farms. Modern irrigation systems were used originally on large-scale farms. The newly popularised system of drip irrigation, for example, is now also affordable and suitable for small-scale farming due to the development of smaller units and kits for smaller areas, tended by hand. Smallholder irrigation systems are mainly maintained with manual labour.

Market orientation: SIM can be used for subsistence and small-scale farming. Irrigation can help farmers to move from solely subsistence to a mixed subsistence / commercial system.

Land ownership and land use / water rights: SIM-systems are normally privately owned by the land users or land user groups, therefore secure rights and full control over water are essential for the users. Additional permits for the use of scarce water resources may be needed.

Skill / knowledge requirements: Needs high level of knowledge for the establishment, and also for the maintenance, of the system (especially micro-irrigation systems). Timing and amount of water application requires considerable skill.

Labour requirements: Depending on the system, the labour requirements are medium to high; a spate irrigation system needs higher labour inputs for establishment than micro-irrigation. The maintenance of a drip irrigation system can be very demanding, but the labour days needed for watering can be significantly reduced through the implementation of drip irrigation, compared to watering with cans.

Land degradation

□	Erosion by water
□	Erosion by wind
▨	Chemical degradation
■	Physical degradation
□	Biological degradation
■	Water degradation

■	High
▨	Moderate
░	Low
□	Insignificant

Land use

■	Cropland
□	Grazing land
□	Forests / woodlands
▨	Mixed land use
□	Other

Climate

□	Humid
■	Subhumid
■	Semi-arid
▨	Arid

Average rainfall (mm)

□	> 3000
□	2000-3000
▨	1500-2000
■	1000-1500
■	750-1000
■	500-750
■	250-500
□	< 250

Slopes (%)

□	very steep (>60)
□	steep (30-60)
▨	hilly (16-30)
▨	rolling (8-16)
■	moderate (5-8)
■	gentle (2-5)
■	flat (0-2)

Farm size

■	Small scale
▨	Medium scale
□	Large scale

Land ownership

░	State
■	Company
▨	Community
▨	Individual, not titled
■	Individual, titled

Mechanisation

■	Manual labour
░	Animal traction
░	Mechanised

Market orientation

░	Subsistence
■	Mixed
▨	Commercial

Required labour

■	High
▨	Medium
□	Low

Required know-how

■	High
□	Medium
□	Low

Economics

Establishment and maintenance costs

Establishment costs for SIM-systems vary considerably. Drip irrigation systems carry relatively high investment costs. Some traditional systems are (or were) high in initial labour – where for example intricate networks of channels brought water down from highland streams. Maintenance of the latter has almost always been carried out with no external support. If the costs for a drip irrigation system are worked out per hectare then the prices appear high. Yet it is the low incremental cost that allows land users to start on a small area (e.g. for horticultural production). The costs for small-scale drip kits have decreased dramatically which makes them now affordable for small-scale users. Even so it still requires initial investment and hence access to micro-credit: this means it is not a possibility for the poorest of land users. Land user groups provide an opportunity for joint investment in the equipment.

SIM-system	Establishment costs
Drip irrigation:	
Bucket system (for home gardens)	5 US$ for 50m^2 ➜ 2,000 US$ per ha
Drum kit irrigation system	10 US$ for 40 m^2 ➜ 2,500 US$ per ha
Farm kit drip irrigation	25 US$ for 125 m^2 ➜ 2,000 US$ per ha 424 US$ with 1,000 litre tank, for 2,500 plants per one-eight acre (= 500 m^2) 150–240 US$ for 1,000 m^2 ➜ 1,500 – 2,400 US$ per ha
Treadle pump	50-120 US$ per pump (for about 0.4 ha)
Spate irrigation systems	1,000 US$/ha

(Sources: FAO, 2001; GTZ, 2001; Grid, 2008)

Maintenance costs for SIM cannot be neglected: drip irrigation systems, especially, need careful maintenance. However, the implementation of a drip irrigation system in place of watering with cans lessens the labour input, reduces the water used and therefore the fuel costs. An example based on drip irrigation introduced in an African Market Garden system (AMG: see case study) has shown a reduction in workload from 240 man hours when irrigating with watering cans compared to 90 man hours with drip irrigation in the AMG system.

Production benefits

	Yield without SLM (kg/m^2)	Yield with SLM (kg/m^2)	Yield gain (%)
	Traditional irrigation	AMG* system	
Lettuce (Niger)	1.14	1.95	+ 70%
Onion (Ghana)	1.21	1.65	+ 36%

**AMG: African Market Garden system based on drip irrigation and crop species selection (Woltering, et al., 2009).*

Comment: The figures presented above show the higher crop yield for the AMG system compared to the traditional system with watering cans. Beside the improved irrigation system the crop varieties selected also influence the yield.

Benefit-Cost ratio

Irrigation system	short term	long term	quantitative
Drip irrigation	+	+++	AMG* (50 m^2), Burkina Faso: Return to labour: 12.6 US$/day Return to land: 1.7 US$/$m^2$
Bucket kit	+	+++	Income / cost per bucket kit, Kenya: 26-40/15 US$
Spate irrigation	++	+++	
Overall	+/++	+++	

– – negative; – slightly negative; –/+ neutral; + slightly positive; ++ positive; +++ very positive;

**AMG: African Market Garden system based on drip irrigation and crop species selection (Source: Mati, 2005; Woltering, et al., 2009)*

Comment: The AMG system clearly shows the profitability of drip irrigation, which is around double that of traditional irrigated gardens. The returns to labour are about three times higher for the AMG than for the traditional system.

Example: *A simple bucket system costing US$ 10, allowing the irrigation of 40 m^2, represents an investment of US$ 2,500 per ha, which, depreciated over 2-3 years, results in annual depreciation costs of US$ 833 – 1,250 per ha. In comparison, some gravity-based communal schemes providing water for an irrigation area of 100 ha with high initial investment costs can be depreciated over 5 years at a rate of US$ 400/ha. Despite the large difference in investment costs per ha, the small units are on a par with the larger schemes with respect to the financial income they are able to generate (GTZ, 2006).*

Example: Zambia

In Zambia, treadle pumps could significantly increase incomes of small-scale land users. With the former used bucket irrigation system the income achieved was about 125 US$ per 0.25 ha of land, whereas with treadle pumps the income increased to 850-1,700 US$. This was attributed not only to increased crop yields, but also to the greater area of land irrigated. Cropping intensity rose in some cases by 300% with an associated increase in crop varieties. Because of the better water availability land users were more willing to invest in new crops (FAO, 2001).

Example: African Market Gardens in the North of Benin

Studies conducted through ICRISAT and partner organisations in West Africa have clearly shown the high profitability of African Market Gardens (AMG). The profitability of AMG is around double that of vegetable gardens irrigated with traditional methods. Returns to labour are more than three times higher for AMG and the investment can be paid back in little more than one year. The payback period can even be shorter if the investments are made through a land users / commune group. (Woltering, et al., 2009)

Impacts

Benefits	Land users / community level	Watershed / landscape level	National / global level
Production	+++ informal irrigation in urban areas helps to diversity livelihoods and diets of the poor dwellers +++ higher crop yields ++ enhanced productivity of labour and land ++ increased diversity of cropping	++ reduced risk of crop failure	+++ improved food and water security
Economic	+++ increased income and new income streams + reduced labour (through reduction of weeds, because no watering between plants and less time needed for watering)	++ stimulation of economic growth ++ new labour opportunities for landless labourers + less damage to off-site infrastructure	+++ improved livelihood and well-being
Ecological	++ through more efficient water use reduced pressure on water resources ++ allows to produce crops in the off-season if water storage available + micro-irrigation: reduced salinisation hazard: through reduced evaporation and salt accumulation on soil surface + reduced soil erosion (by water / wind) + improved soil cover + increased soil fertility + biodiversity enhancement + improved micro-climate	++ increased water efficiency and reduced pressure on water resources	
Socio-cultural	++ strong gender component, as marketing of vegetables is the domain of women	+ increased awareness for environmental 'health' + attractive landscape	+ protecting national heritage

	Constraints	How to overcome
Production	• Lack of reliable water supply • Land users tend to use more water than needed by using a micro-irrigation system, since water can be applied more easily	➜ storage facilities (but has additional cost) ➜ needs good training of the land users
Economic	• Lack of market access and incentives for agricultural intensification • Lack of market for low cost irrigation material • High investment costs especially a problem for poor land users • Requires a high level of technical knowledge also for maintenance of the system	➜ promoting markets for smallholder irrigation systems ➜ access to credits and financial support to improve the ability to invest in smallholder irrigation systems
Ecological	• Abstraction / overuse of surface water and non-renewable ground and / or fossil water • Waterlogging and salinisation • If dependant on water harvesting or surface water during dry years / periods, water supply for irrigation can be threatened • Over-irrigation facilitates the development of diseases, weed growth and nutrient leaching Drip irrigation: • Salt accumulation at root zone (especially in areas with rainfall <100 mm) • Only a fraction of root zone is wetted, is more susceptible, and depends on the continuous operation of the system	➜ use of improved rainwater harvesting systems to collect and store additional irrigation water ➜ good crop rotation, appropriate irrigation practices, balance supply and demand of water ➜ needs good technical knowledge and appropriate maintenance of the system ➜ regular leaching of salts and drainage for removal of salts is necessary
Socio-cultural	– Over-abstraction of surface and groundwater resources can lead to a decline of river flows and groundwater table and endangering supply of drinking water – Conflicts over water	➜ specialists providing technical and economic information are needed ➜ proper planning and regional assessment of water resources as well as restricted allocation of irrigation water

References and supporting information:

Andersson, L. 2005. Low-Cost Drip irrigation – On farm implementation in South Africa. Master Thesis, Master of Science Programme, Environmental Engineering, Lulea University of Technology.

Community spate irrigation. 2009. http://www.spate-irrigation.org/spate/spatehome.htm, accessed on 28 September 2009.

FAO. 1988. Irrigation Water Management: Irrigation Methods. Irrigation Water Management, Training Manuals – 5. Prepared jointly by C. Brouwer and K. Prins, M. Kay, M. Heibloem.

FAO. 1997. Small-scale irrigation for arid zones. http://www.fao.org/docrep/W3094E/w3094e00.htm

FAO. 2001, Smallholder irrigation technology: prospects for sub-Saharan Africa. International Programme for Technology and Research in Irrigation and Drainage Knowledge Synthesis Report No. 3 - March 2001 Melvyn Kay FAO/IPTRID Consultant.

FAO. 2008. Water and Rural Poverty - Interventions for Improving Livelihoods in Sub-Saharan Africa.

Grid. 2008. International Programme for Technology and Research in Irrigation and Drainage (IPTRI), Issue 28, February 2008.

Adoption and upscaling

Adoption rate

SSA shows one of the lowest degrees of investment in irrigation among developing regions, and recent surveys do not show any sign of change, the annual increase in irrigation being slightly more than 1% between 1995 –2005.

Upscaling

The adoption of small-scale irrigation systems will also be determined by the capacity of land users to take risks in the uptake and investments with a new technology. Therefore the following aspects are crucial:

Reliable water supply: The access to reliable supply of water is often the major constraint to irrigation.

Profitability: The benefit-cost ratio must make it worthwhile for land users to invest in irrigation. For poor land users the high investment cost and the payback time pose a major obstacle.

Access to financial services: The financing and managing of irrigation systems need to be market-driven and are to a large degree the responsibility of smallholders. The self-financing capacity of farmers needs to be strengthened and credit must be easy accessible to smallholders. Land user groups / community organisations can be an opportunity for poor land users to receive credit and to make the initial investment.

Access to markets and infrastructure: Functioning markets and market access is a prerequisite for the success of SIM. Irrigation can help subsistence land users to become more market-oriented.

Market for low-cost drip irrigation systems: Even though a market very often exists for equipment generally, low-cost drip irrigation systems may be hard to obtain. Therefore, setting up a working supply chain and ensuring sufficient manufacturing capacity is essential.

Technical support and capacity development: The utilisation of the full potential of irrigation production needs adequate training and technical support for the land users also for appropriate water application and maintenance of the system. Competent specialists providing technical and economic information are needed.

Policy: Usually a Ministry of Agriculture is separate from a Ministry of Water, which often leads to administrative confusion and administrative hurdles. The water and agricultural sector must be coordinated.

If an irrigation system is used in common, the number of users sharing the infrastructure should be low. Operational simplicity is a major criterion for the success of small-scale community-based irrigation schemes.

Comment: The dream of many land users in SSA to increase production and income with irrigation is limited by the availability of water. Already today, scarce water resources are often overused. Therefore, the main aim should be to improve water use efficiency and to develop more decentralised smaller irrigation systems without causing land or water degradation.

Incentives for adoption

For SIM to be used by individuals these ideally should not be subsidised but should be self-financed by land users. For that reason, the access to micro-credit must be ensured. Yet, SIM techniques are still only accessible to land users who can afford to buy them or to access micro-credit. Therefore poorest land users need appropriate financial and technical support for the establishment of a SIM system.

Enabling environment: key factors for adoption	
Inputs, material incentives, credits	+++
Training and education	++
Land tenure, secure land use rights	+++
Access to markets	+++
Research	++
Infrastructure	++

Example: Kenya

In the study conducted by Kulecho and Weatherhead (2006) NGOs were asked what they considered as the main problems for smallholder irrigation in Kenya. The systems used were mainly drip, furrow and sprinkler systems. The results showed that the highest number of responses were related to the problem of crop marketing, low-cost drip irrigation maintenance, followed by water supply problems. The report clearly showed that farmers need adequate technical support, reliable water supplies, and affordable access to markets if they are to maximise the economic and poverty-reducing benefits of low-cost drip systems.

Example: Burkina Faso and Niger

ICRISAT has introduced the African Market Garden (AMG) system as a commercial irrigation and production system in Niger. There was little follow-up and in most cases non-educated land users were left on their own to operate the systems, which resulted in zero maintenance. Only 4 years after the implementation 20% of the systems were still found operational. The producers who abandoned the systems found that there were no clear savings in labour and water. Based on these experiences a new project started in Burkina Faso. This time only the wealthier small-scale farmers were approached and they paid 70% of the investments. Most of the systems are still operational. It demonstrates that the more educated and the wealthier a producer is, the more likely he / she is to adopt small-scale drip irrigation (Woltering, et al., 2009).

References and supporting information (continued):

GTZ. 2006. Financing Small-scale Irrigation in Sub-Saharan Africa. Grimm J., M. Richter. Volume 1: Desk Study, December 2006. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Commissioned by The World Bank .

IWMI. 2007. Recognising Informal Irrigation in Urban and Peri-Urban West Africa. Water Policy Briefing, Issue 26.

Pretty, J. N., A. D. Noble, D. Bossio, J. Dixon, R. E. Hine, F. W. T. Penning de Vries, and J. I. L. 2006. Resource-conserving Agriculture Increases Yields in Developing Countries. Environmental Science & Technology, Vol. 40, No. 4.

Kulecho,I.K. and K. Weatherhead. 2008. Issues of irrigation of horticultural crops by smallholder farmers in Kenya. Irrig Drainage Syst (2006) 20:259–266

Mati, B. M. 2005. Overview of water and soil nutrient management under smallholder rainfed agriculture in East Africa. Working Paper 105. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Mati, B. M. 2008. Capacity Development for Smallholder Irrigation in Kenya. IRRIGATION AND DRAINAGE. Irrig. and Drain. 57: 332–340 (2008)

Postel, S., P. Polak, F. Gonzales, and J. Keller. 2001. Drip Irrigation for Small Farmers - A New Initiative to Alleviate Hunger and Poverty. International Water Resources Association. Water International, Volume 26, Number 1, Pages 3–13, March 2001

Woltering, L., D. Pasternak, and J. Ndjeunga. 2009. The African Market Garden: Development of an Integrated Horticultural Production System for Smallholder Producers in West Africa. Submitted to Irrigation and Drainage.

AFRICAN MARKET GARDENS - SENEGAL

The African Market Garden (AMG) is a horticultural production system based on low-pressure drip irrigation. According to the level of experience, market orientation or social structure of the land users, four different AMG models have been developed. This case study focuses on the 'Cluster System' which is suitable for an organised group of independent vegetable producers sharing a common water delivery system.

From a central source, water is distributed through a pipe network to a cluster of plots. Each farmer operates a 1,000 m^2 unit, and each is equipped with an elevated 200 litre barrel and a standard irrigation kit, including a tap, filter and thick-tube drip laterals. Minimal size of an AMG unit should be 500 m^2. Affordable high-quality material is used and the design and operation is simple. The barrel also serves as a fertilizer tank. A float ensures a constant pressure head. Water supply is calculated by the time needed for delivery of the daily water dosage, or through the use of water dosing valves. Producers have individual control of water use. Since the AMG requires only 1 meter pressure for operation, it can draw on low-capacity renewable energy sources such as elevated dams, solar pumps or reservoirs. To supply an area of 50,000 m^2 with 8 mm/day in the hot season a 400 m^3-reservoir is required. The crops are planted on elevated beds. Water mixed with urea as fertilizer is applied daily. Drip irrigation improves growing conditions for crops while at the same time saving labor, water and other inputs.

AMG is promoted as a holistic management package, integrating all aspects of production, post-harvest and marketing in one system. This includes the use of improved vegetable varieties, improved crop husbandry, integrated pest management, as well as improved storage, processing and marketing of products, and improved access to inputs.

SLM measure	Agronomic
SLM group	Smallholder Irrigation Management
Land use type	Annual crops: vegetables; Tree crops: fruit trees
Degradation addressed	na
Stage of intervention	Prevention
Tolerance to climate change	AMG especially suitable for seasons with high evapotranspiration demand, because AMG permits daily irrigation that eases water stress

Establishment activities

1. Build concrete reservoir.
2. Drill borehole (110 mm diameter; 12 m deep, hand drilled).
3. Install motor pump and tubes to connect well with reservoir.
4. Install drip kit with tap, filter and drip laterals (8-16 mm in diameter).
5. Establish a fence to protect the garden.

Maintenance / recurrent activities

1. Prepare elevated beds with a basic dressing of 4 kg/m^2 manure and 0.1 kg/m^2 NPK fertilizer biannually.
2. Add urea to irrigation water (concentration: 50-100 ppm N).
3. Operate water supply system.

Labour requirements

For establishment: high
For maintenance: low

Knowledge requirements

For advisors: high
For land users: high

Remark: Installation of the system requires basic knowledge on engineering for the sizing of the PVC distribution network.

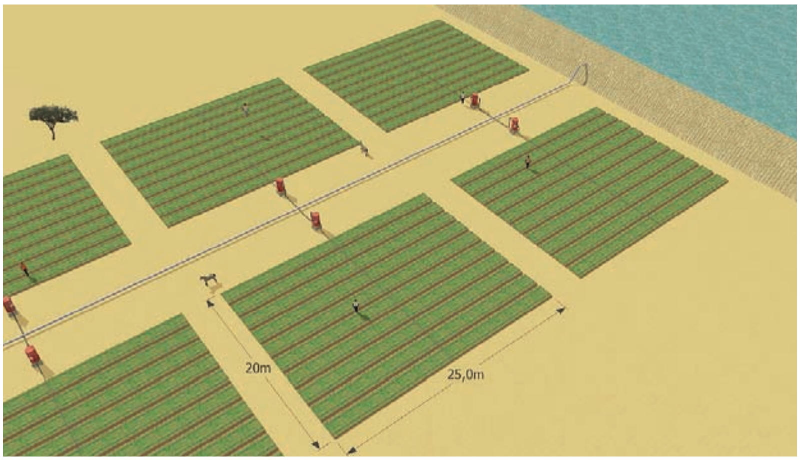
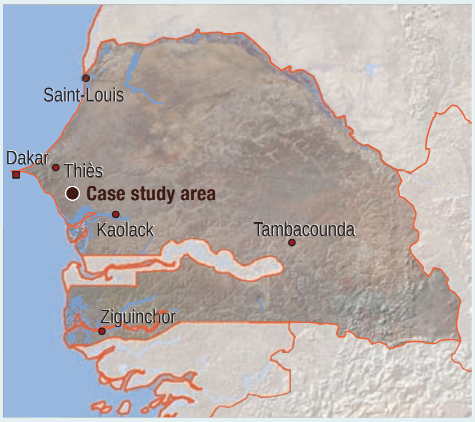


Photo 1: AMG system with elevated barrels for irrigation of cash crops (okra) through drip laterals. (ICRISAT)
Technical drawing: Cluster system with several AMG plots connected to a central water source - in this case a small elevated dam. (ICRISAT)

Case study area: Ngoyé Ndioffogor and Mbassis Tatadem, Senegal



Establishment inputs and costs per unit

Inputs	Costs (US$)
Drip system	300
Oil drum (200 l)	56
Well / borehole	16
Motor pump (3 hp)	34
Farming tools	65
Fence	25
PVC connections	79
TOTAL	**575**

Maintenance inputs and costs per unit and year

Inputs	Costs (US$)
Labour, fuel and agricultural inputs	510
TOTAL	**510**

Remarks: A unit corresponds to the area irrigated by one producer (= 500 m^2). Establishment costs include labour inputs (2 US$ per person-day). Annual maintenance costs include labour, fuel and agricultural inputs (e.g. fertilizer, seeds; based on ICRISAT recommended rates). For a 1,000 m^2-unit prices are doubled (except for tools and fence).

Benefit-cost ratio

Inputs	short term	long term
Establishment	slightly positive	very positive
Maintenance	very positive	very positive

Remarks: Payback period is only 6 months. Net income per farmer after all deduction is about US$ 1,000 per year. The profitability of the AMG is around double that of vegetable gardens irrigated with traditional methods.

Ecological conditions

- Climate: semi-arid
- Average annual rainfall: 400-500 mm
- Soil parameters: sandy soils, low fertility and organic matter content
- Slope: flat (0-2%)
- Landform: plains
- Altitude: no data

Socio-economic conditions

- Size of land per household: no data
- Type of land user: small to medium-scale, land user groups, poor to average level of wealth
- Land ownership: individual (titled)
- Land use rights: individual - secure land use rights are a precondition
- Level of mechanisation: manual labour / mechanised
- Market orientation: commercial
- AMG is suitable for urban / periurban areas where producers have access to credit, markets, technical support
- Strong organisation in groups is important for the maintenance of the system and for access to training / backstopping

Production / economic benefits

+++ Reduced production costs: costs for drip irrigated gardens are 50% lower than for traditional irrigated gardens due to savings in labour, water and consequently in fuel

+++ Reduced workload: total workload for AMG is 11.5 man-days compared to 30 man-days in traditional irrigation system

+++ Increased income due to doubled profits from vegetable production (compared to traditional irrigation methods)

Ecological benefits

+++ Improved water availability / reduced pressure on water resources

+++ Reduced evaporation / effective use of water due to accurate and equal distribution of water at optimal rates

+++ Effective application of fertilizer with the water

Socio-cultural benefits

+++ Improved nutrition and food security through year-round availability of quality vegetables and fruits

+++ Improved knowledge on irrigation techniques / horticulture

+++ Improved organisation (farmer associations, user groups, etc.)

Weaknesses ➜ and how to overcome

- Irrigated vegetable production is a capital intensive undertaking ➜ sharing infrastructure, land and water through producer groups can cut investment costs by 60% per unit area. Set-up and operation costs further decrease if producer groups can use communally owned infrastructure and / or alternative energy sources (e.g. elevated dams, solar pumps, artesian well).
- The AMG system is not suitable for farmers with limited access to knowledge, marketing and services ➜ improve access to markets and training programs (for extensionists and farmers); guarantee technical assistance during 2-3 years; target the system to educated producers who make a living out of vegetable production. Set up AMG service and demonstration centres offering credit, farm inputs, marketing support, training and technical advice.

Adoption

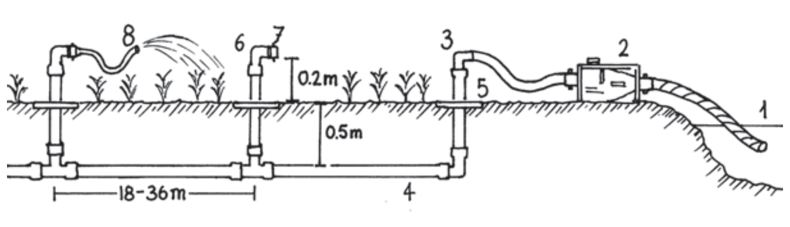
AMG is spreading fast in Senegal and Burkina Faso. Cost reduction (e.g. alternative energy sources), collective action and intensive training / backstopping are very important provisions for successful adoption. Upscaling of AMG in dry West Africa will depend on access to technology, inputs, knowledge and organisation, and a conducive institutional environment.

Main contributors: Dov Pasternak, Head Crops and Systems Diversification and Director of IPALAC, ICRISAT-WCA, Niamey, Niger; d.pasternak@icrisatne.ne; d.pasternak@cgiar.org
Key references: Woltering L., D. Pasternak and J. Ndjeunga. 2009. The African Market Garden: Development of an Integrated Horticultural Production System for Smallholder Producers in West Africa – Draft Submitted to Irrigation and Drainage 21-10-2009 ■ ICRISAT. 2009. The African Market Garden - Advanced Horticulture for the Poor (Flyer).

LOW-PRESSURE IRRIGATION SYSTEM 'CALIFORNIAN' - SENEGAL

The low pressure pipe distribution system called 'Californian' has proven to be a very efficient irrigation system for smallholder farmers group in Africa. The principle of the Californian system is to convey water to the crops through fixed underground rigid PVC pipes (40–75 mm diameter). The pipe network is buried at 0.50 m depth to avoid deterioration by UV radiation and agricultural practices. Risers with hydrants are fixed to those rigid pipes at regular distance (18-36 m). To each riser a 14 m long flexible hose is attached which can be dragged around to irrigate the individual plots and crops. The installation of the pipe network can be made locally by plumbers. Water is supplied through a pump (manual, pedal or small motor) from a well, a reservoir or a river. From the intake water is conveyed to the highest point of the plot which allows the conveyance to the field's most distant point (irrespective of topographical conditions - upslope or downslope).

The system is remarkably efficient in sandy or salty soils. It is adapted to small–scale farming especially for vegetable crops, rice and tree crops and is suitable for areas ranging between 0.25 - 1 ha; one riser irrigates an area of 500-1000 m^2. The system as such does not require maintenance. In case of deterioration of pipes or fittings, the farmer can easily fix the problem himself or with the assistance of a local plumber. The estimated life expectancy for the Californian system is 6-10 years in West African conditions. Ideal conditions for transfer / adoption of the technology include: (1) availability of shallow aquifers, and other water sources; (2) occurrence of sandy soils and sandy clay soils; (3) clearly defined land legislation and tenure; (4) access to markets and to microfinance institutions.



SLM measure	Agronomic
SLM group	Smallholder Irrigation Management
Land use type	Annual cropping
Degradation addressed	na
Stage of intervention	Prevention
Tolerance to climate change	High tolerance as long as water source is not depleted

Establishment activities

1. Layout of pipe network by putting stakes along the line to indicate the orientation of the canal to be dug.
2. Excavate network of canals (0.2 m wide, 0.5 m deep; straight and regular). In sandy soil the interval between risers is 30 m x 18 m or 36 m x 18 m (intervals are multiples of 6 m = PVC pipe unit length). Density of risers is 10 -15 risers/ha.
3. Install the pipes into the open canals, fittings are assembled by sticking.
4. Install hydrants composed by a 0.2 m high riser, a PVC elbow and a locally made flow control device (plug); the risers are anchored in the soil through a small concrete slab.
5. Put the pipe under flow condition to verify the water tightness of the system.
6. Bury the canals.
7. Protect risers from sun.

Maintenance / recurrent activities

1. Before starting to pump it is recommended to let open one of the hydrants in order to avoid excessive pressure and blasting of pipes.
2. In case of deterioration of the pipes or fittings, land users can easily fix the problem themselves or request the intervention of a local plumber.

Labour requirements

For establishment: medium
For maintenance: low

Knowledge requirements

For advisors: high
For land users: high

Remark: Technical assistance needed for design, installation and operation of the system; installation of pipes is quick and easy; no need for topographical survey.

Photo 1: Hand pump for supply of irrigation water;
Photo 2: Pipes for the distribution of irrigation water are buried in 0.5 m deep canals;
Photo 3: Growing onions on an irrigated plot (All photos by Sourakata Bangoura)
Technical drawing: Dimensions and main components of the low-pressure irrigation system: (1) water source; (2) manual or motor pump; (3) input hydrant; (4) rigid PVC pipes; (5) small concrete slab; (6) elbow; (7) plug; (8) flexible hose for irrigation.

Case study area: Diourbel, Senegal

Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour	50
Equipment/tools	no data
Construction material	1333
TOTAL	**1383**
% of costs borne by land users	0%

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour, equipment, construction material	no data
TOTAL	**no data**

Remarks: If soil is not sandy labour input for establishment increases. Hand or treadle pumps are provided by the project. Motor pumps (with pump capacity 2 HP) increase costs for establishment and maintenance (fuel) but reduce labour inputs for operation.

Benefit-cost ratio

Inputs	short term	long term
Establishment	positive	very positive
Maintenance	positive	positive

Remarks: The estimated life expectancy for the Californian system is 6-10 years in the West African conditions.

Adoption

Totally 468 farmers (64% of them women) have adopted the technology. Inputs were paid by project. There is high demand for the technology. Full participation of stakeholders in the whole project process and the involvement of local leaders, local NGOs and private companies are prerequisites for successful implementation.

Ecological conditions

- Climate: semi-arid; sudano-sahelian, 9 months dry period: Oct.-June
- Average annual rainfall: 450 mm
- Soil parameters: sandy soils, with low organic matter content, low fertility, good drainage (tropical ferralitic soils)
- Slope: flat or gentle (0-5%)
- Landform: plains
- Altitude: 25 m a.s.l.
- Availability of shallow aquifers, and other water sources is crucial; sandy soils and sandy-clay soils are suitable.

Socio-economic conditions

- Size of land per household: 0.5 ha
- Type of land user: poor small-scale farmers, implemented individually or within farmer groups
- Population density: no data
- Land ownership: mostly individual
- Land use rights: mostly individual
- Level of mechanisation: mostly manual labour and animal traction
- Market orientation: mixed (subsistence and commercial)
- Strong local leadership, long term land use rights and external funding or access to microfinance institutions are preconditions.

Production / economic benefits

+++ Increased crop yield (in combination with improved agricultural inputs (fertilizer, pesticides, seeds)

+++ Increased production area (from 0.1 to 2 ha per farmer group)

+++ Reduced risk of production failure

+++ Increased drinking / household water availability (from < 10 to 20 liters/person-days)

+++ Increased irrigation water availability

+++ Increased farm income and diversification of income sources

++ Increased product diversification

Ecological benefits

+++ Increased water quantity

+++ Reduced hazard towards adverse events (droughts)

+++ Increased plant diversity

+++ Increased soil moisture

++ Increased water quality

++ Reduced surface runoff

++ Reduced salinity

++ Improved soil cover and increased biomass

Socio-cultural benefits

+++ Improved cultural opportunities (pilgrimage to Mecca, marriages, etc.)

+++ Community institution strengthening

+++ Conflict mitigation (group management of irrigation facilities)

+++ Improved food security / self-sufficiency

++ Improved situation of socially and economically disadvantaged groups

++ Improved health

Weaknesses

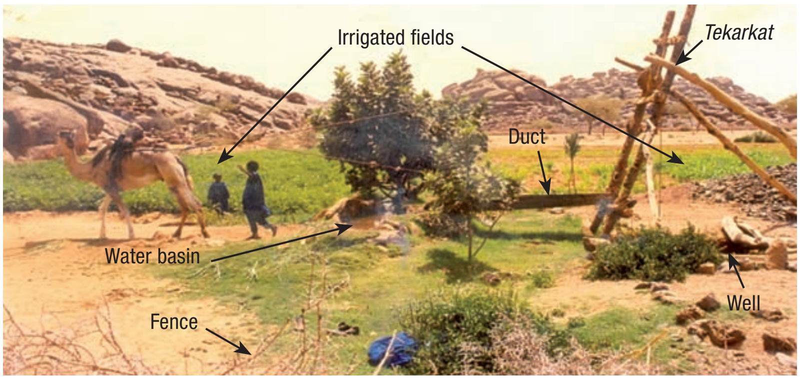
- Initial investment cost of construction material and equipments.
- Breakage of riser pipes.
- Scarcity of surface water resources, poor water quality (salinity), low water discharge from the shallow wells and boreholes limit the applicability of the system.
- Lack of farmers knowledge on irrigation techniques and lack of qualified personnel for training and supervision hinder successful implementation.

Main contributors: Sourakata Bangoura, Land and Water Resources Officer for Central Africa, Subregional Office for Central Africa, Libreville, Gabon; sourakata.bangoura@fao.org

IRRIGATED OASIS GARDENS - NIGER

In the Oasis of Timia in the Aïr, small irrigated gardens (< 0.3 ha) have been used for over a century, producing dates and tree crops (figs, citrus, cherries, etc.) for sale and cereals for consumption (wheat, maize and pearl millet). With the onion boom in the 1990s, the establishment of new gardens grew dramatically. The new gardens cover a bigger area (0.5 - 1 ha) and focus on cash crops - mainly onions, but also potatoes and garlic. Gardens are fenced using branches from acacia trees. The water supply system in most cases is based on traditional wells with an animal-drawn scoop. The wells are less than 20 meters deep and generally built without a casing. Local experts were trained by GTZ project staff in well construction and maintenance. Modern motor pumps have recently become common and are used in new gardens. Water is conveyed to the plots through a hand-dug network of distribution channels. The channels are lined with clay and stones to minimise water loss through infiltration, evaporation, or breaching. Irrigating a whole garden takes about two hours.

There are two cropping seasons per year: the rainy season (June-September) with staple crops such as maize and millet; and the dry / cold season (October-February) with wheat-barley associations and cash crops such as onions, garlic, tomatoes and vegetables. Fruit trees covering up to a fifth of the gardens; one section of the garden is reserved for keeping small ruminants. Agricultural residues are used as fodder and manure produced by livestock ensures fertility of gardens in combination with inorganic fertilizers. Traditional techniques (local plants, ash, etc.) are used for pest management. Seed production and selection is done strictly locally.



SLM measure	Structural and vegetative
SLM group	Smallholder Irrigation Management
Land use type	Annual cropping, Tree cropping
Degradation addressed	Chemical and biological degradation of soil; Soil erosion by water and wind
Stage of intervention	Rehabilitation and mitigation
Tolerance to climate change	Technology is sensitive to drought, temperature increase, floods and storms

Establishment activities

1. Identify and demarcate of a free area to be converted into a garden. Fence area with acacia branches and living hedge.
2. Establish a traditional or cement well, max. 2 m wide and 15-20 m deep (contract with local well builder) in the middle of the field.
3. Installation of traditional water conveyance system (*Tekarkat*): wooden poles hold a pulley which conducts a rope with a scoop for extraction of water from the well. The system is powered by a dromedary. A 5 m duct (palm stem or iron sheet) conducts the water to a small reservoir.
4. Mark and dig irrigation canal system and basins for crop cultivation (8 m^2): Main canal and secondary canals (perpendicular to main canal) are reinforced with clay or stones.
5. Purchase inputs (local market): seeds, seedlings, fertilizer, tools.
6. Plant fruit trees.

Activities 1. and 4. are done collectively. All activities are carried out by manual labour.

Maintenance / recurrent activities

1. Maintenance of fence: replace missing branches; plant new tree seedlings to reinforce the living hedge (biannually).
2. Irrigation (daily).
3. Maintenance of *Tekarkat* and canal system: control (and replace) poles; periodic weeding, cleaning, repair leaks and improve lining with clay/stones (biannually, after harvest).
4. Field preparation and application of organic manure (beginning of each cropping season).
5. Maintenance of well: cleaning (hot season), reinforce walls with cement (if needed).
6. Feeding draught animal using natural grassland and crop residues.

Labour requirements

For establishment: medium to high
For maintenance: medium to high

Knowledge requirements

For advisors: medium to high
For land users: low (indigenous knowledge)

Photo 1: Components of an irrigated oasis garden with a traditional *Tekarkat* water supply system. The dromedary pulls up the water filled scoop.
Photo 2: *Tekarkat* established in an oasis North of Tahoua.
Photo 3: Irrigated gardens in Timia. (All photos by Abdoulaye Sambo Soumaila)

Case study area: Timia oasis, Aïr, Niger

Establishment inputs and costs per 0.5 ha

Inputs	Costs (US$)
Labour: 90 person-days	180
Land (opportunity costs)	400
Equipment: traditional well and *tekarkat*	500
camel / dromedary	400
Other equipment:	200
Agricultural inputs: seedlings (50)	200
TOTAL	**1880**
% of costs borne by land users	100%

Maintenance inputs and costs per 0.5 ha per year

Inputs	Costs (US$)
Labor: 104 person-days	208
Equipment: traditional well and *tekarkat*	100
camel (fodder, health)	1460
Other equipment:	100
Agricultural inputs: seedlings, organic fertilizer	240
TOTAL	**2108**
% of costs borne by land users	100%

Remarks: Cost calculation is based on local land prices and traditional irrigation systems. Maintenance costs include also fodder (for draught animal) and organic manure.

Benefit-cost ratio

Inputs	short term	long term
Establishment	very positive	vey positive
Maintenance	very positive	very positive

Remarks: The technology serves a double purpose: food security and income generation.

Ecological conditions

- Climate: arid
- Average annual rainfall: <120 mm
- Soil parameters: sandy soils, with usually good drainage, medium water storage capacity, medium soil fertility and soil organic matter; and low soil depth
- Slope: mostly flat (0-2%) in oasis
- Landform: mainly mountains, valley floors
- Altitude: 800 m a.s.l.

Socio-economic conditions

- Size of land per household: <1 ha
- Type of land users: individuals / families; mainly poor land users
- Population density: 10,000 persons/km^2 (oasis)
- Land ownership: mostly individual, untitled
- Land use rights: individual, communal (unorganised)
- Market orientation: mostly subsistence (self-supply), partly mixed (subsistence and commercial)
- The land user can be (1) the owner of the garden; (2) a family member managing the family-owned garden; (3) a paid labourer; (4) a usufructuary

Production / economic benefits

+++ Increased crop yield, fodder and animal production
+++ Increased fodder quality and animal diversity
+++ Increased farm income

Ecological benefits

+++ Improved soil cover
+++ Reduced wind velocity and soil loss
+++ Increased soil fertility
(+++Increased biomass / above ground carbon)
++ Reduced fire risk

Socio-cultural benefits

+++ Conflict mitigation
+++ Community institution strengthening through mutual aid in technology implementation
+++ Improved cultural opportunities
+++ Improved food security

Off-site benefits

++ Reduced damage on public / private infrastructure
+++ Reduced wind transported sediments

Weaknesses ➜ and how to overcome

- High implementation costs ➜ establish national financial support systems for acquisition of garden area by very poor people.
- High maintenance costs ➜ promote efficient irrigation technologies that reduce maintenance costs (such as drip irrigation).
- Uncontrolled spread of the technology resulting in an overexploitation of groundwater and over-production of e.g. onions ➜ increase water use efficiency; regulate market and promote agro-industrial food processing.
- High dependency on climatic factors influencing the recharge of the groundwater level ➜ exploitation of deep water resources through artesian wells and introduction of adapted drip irrigation technologies.

Adoption

The gardens are traditional with a high trend of spontaneous adoption. The technology was an answer to the successive droughts in the 1970ies and 1980ies which have caused heavy livestock losses in the region. Pastoralists adopted the technology to diversify their livelihoods and minimise risk. Since the 1990ies, 700 new irrigated gardens were established in Timia (as compared to 100 gardens).

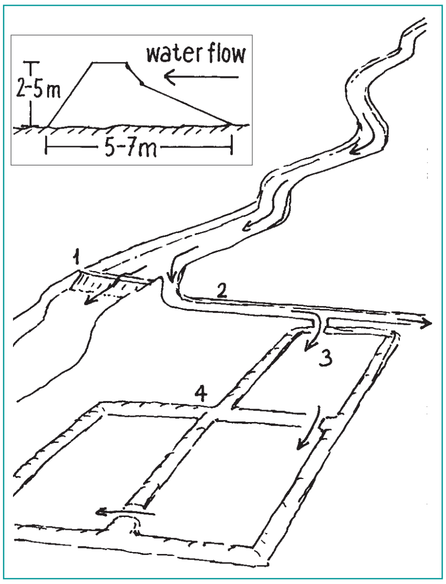
Main contributors: Abdoulaye Sambo Soumaila, Groupe de Recherche d'Etude et d'Action pour le Développement (GREAD), Niamey, Niger; leffnig@yahoo.fr

Key references: Suchantke, J. and A. S. Soumaila. 2001. Etude cadre pour le programme NIGETIP IV, KfW, Niamey, Niger ■ Soumaila, A. S., 2005. Rapport du symposium international sur le développement des filières agropastorales en Afrique organisé par GREAD. ■ UCMA. 2005, 2007, 2008, 2009. Rapports annuels de commercialisation ■ PPEAP. 2006. Rapport final d'évaluation du projet de promotion des exportations agropastorales ■ Ministère du développement agricole. 2008, 2009. Données statistiques sur la production maraichère.

SPATE IRRIGATION - ERITREA

Spate irrigation has a long history in Eritrea and still forms the livelihood base for rural communities in arid lowlands of the country. It is a traditional water diversion and spreading technique under which seasonal floods of short duration – springing from the rainfall-rich highlands – are diverted from ephemeral rivers (wadis) to irrigate cascades of leveled and bunded fields in the coastal plains. The diversion structures include the following elements: (1) the '*agim*', a temporary 3-4 m high river diversion structure on the low-flow side of the wadi, made from brushwood, tree trunks, earth, stones and / or boulders, erected to divert a large part of the flow during a spate flow to adjacent agricultural fields; (2) a primary, and several secondary distribution canals; unlined, bordered by earthen embankments; convey and spread the floodwater to the irrigable fields; (3) the fields, rectangular shaped, of about 1–2 ha, separated by earthen bunds. Floodwater is distributed from field to field: when a field is completely flooded (to a depth of about 0.5 m), water is conveyed to the immediate downstream field by breaching one of the bunds. This process continues until all the water is used up. Arable fields need to be flooded several times.

The water soaks deep into the soil profile (up to 2.4 m) and provides moisture sufficient for two or even three harvests: crop growth is entirely dependent on the residual soil moisture. The main crop grown is sorghum; maize is the next most important. Sedimentation is as important as water management: With each flood, soil is built up by depositing rich sediment on the fields. Due to the force of the floods, the diversion structures are frequently damaged and / or washed away. Reconstruction and maintenance are labour-intensive and require collective community action. Elaborate local regulations, organisation and cooperation at the community level are prerequisites for successful management of spate irrigation systems.



SLM measure	Structural
SLM group	Smallholder Irrigation Management
Land use type	Annual cropping
Degradation addressed	na
Stage of intervention	na
Tolerance to climate change	Tolerant to climatic extremes (adapted to unpredictable heavy floods)

Establishment activities

1. Construction of diversion structure (*agim*).
2. Construction of main distribution canal.
3. Construction of secondary distribution canals.
4. Leveling of fields.
5. Establish embankments around fields and within fields.

All activities are carried out by manual labour and animal traction, before the highland rainy season.

Maintenance / recurrent activities

1. Reconstruction / repair of diversion structures (2-4 times/year; collective community action).
2. Annual desilting / repair of distribution canals.
3. Annual raising of bund heights due to silting up of fields.
4. Flood fields (community action, during highland rainy season: July-September). Most likely a field receives 3 irrigation turns, on a bi-weekly interval between any 2 turns.
5. Soil tillage (15 cm deep; using oxen-drawn plough) to break capillary uplift of soil water and to create evaporation barrier (end of the flooding season).
6. Sowing (10 days after last flooding; Mid September).

Labour requirements

For establishment: high
For maintenance: high

Knowledge requirements

For advisors: high
For land users: high

Photo 1: Social organisation and community action are prerequisites for spate irrigation systems: construction of an *agim* in a dry river bed. (IFAD)
Photo 2: Fertile sediments and spate irrigation result in high sorghum yields. (IFAD)
Technical drawing: Cross section of an agim (top left); Components of a traditional spate irrigation system: (1) agim; (2) main distribution canal; (3) irrigated fields; (4) earthen embankments. Arrows indicate the water flow. (Mats Gurtner)

Case study area: Wadi Laba, Sheeb area, Eastern lowlands, Eritrea

Establishment inputs and costs per unit

Inputs	Costs (US$)
Labour: 12 person-days	no data
Equipment / tools: 4 camel-days, 10 pairs-of-ox-days, scouring and tillage implements, shovels	no data
Agricultural inputs: none	no data
Construction material: tree trunks, brushwood, stones, boulders, earth	no data
TOTAL	**60**
% of costs borne by land users	100%

Maintenance inputs and costs per unit* and year

Inputs	Costs (US$)
Labour	no data
Equipment: camels, oxen, scouring and tillage implements	no data
Agricultural inputs: none	no data
Construction material: tree trunks, brushwood, stones, boulders, earth	no data
TOTAL	**48-96**
% of costs borne by land users	100%

* unit = 10 m long *agim* (1 m high, 3 m wide), constructed with mixed material (stones, earth, brushwood)

Remarks: Data on labour inputs for construction / maintenance of canals and field bunds are not included, therefore not included in the tables above. Costs for *agim* reconstruction are 40% of establishment. Total maintenance costs depend on the number of reconstructions during normal spate season (2-4 times). The yearly cost (establishment and maintenance) reaches US$ 60-156.

Benefit-cost ratio

Inputs	short term	long term
Establishment	no data	no data
Maintenance	no data	no data

Ecological conditions

- Climate: arid (hot, high evapotranspiration)
- Average annual rainfall: < 200 mm
- Soil parameters: very deep and fertile soil (alluvial silts), formed by annual sedimentation; well drained, soil texture: loams to silt loams
- Slope: flat (0-2%)
- Landform: plains (alluvial plains of the coastal area)
- Altitude: 200 m a.s.l.
- The alluvial plains are cut through by wadis discharging into the Red Sea. The spates account for 65% of the annual flow volume. 75% of the irrigated land in Sheeb is watered by the main wadi. Floodwater is unpredictable in timing and volume, and has high destructive potential.

Socio-economic conditions

- Size of land per household: no data
- Type of land user: small-scale, poor to very poor land users; water management carried out communally, crop management individually
- Population density: low
- Land ownership: state
- Land use rights: individual
- Level of mechanisation: manual labour and animal traction

Production / economic benefits

+++ Increased crop yield
+++ Increased fodder production (residues are fed to livestock)
+++ Increased production area (without irrigation, agricultural production is not possible)
+++ Increased water availability
+++ Increased farm income

Ecological benefits

+++ Improved harvesting / collection of water
+++ Increased soil moisture
+++ Increased soil fertility

Socio-cultural benefits

+++ Improved food security
+++ High level of cooperation and organisation on community level

Weaknesses ➜ and how to overcome

- Highly labour-intensive and time consuming maintenance; water diversion structures are frequently breached / washed away by heavy floods; canals are obstructed through deposition of boulders, gravel and coarse sediments ➜ yearly repair / reconstruction is required.
- Great demand for wood: huge numbers of trees are annually needed for (re-) constructing diversion structures.
- Irrigation efficiency is only about 20% because of the difficulty of controlling large amounts of water in a short period of time (and often at night) and because water is lost by percolation, seepage and evaporation ➜ to overcome all 3 problems, recommendations focus on building permanent flood diversion and distribution structures which: (1) withstand the force of heavy floods and divert the water effectively; (2) eliminate the need to cut trees; (3) reduce human and animal labour inputs; (4) increase productivity. Lining the main canals with cements would reduce water loss by percolation and seepage. Proper leveling of basin fields helps to distribute the floodwater uniformly.

Adoption

Spate irrigation is an indigenous technology, originally introduced from Yemen. Spontaneous spread takes place throughout the lowlands. Current spate irrigation area in Eritrea is 16,000 ha. Potential area is estimated at 60,000–90,000 ha.

Main contributors: Abraham Mehari Haile, UNESCO-IHE Institute for Water Education, Delft, The Netherlands; A.MehariHaile@unesco-ihe.org

Key references: Abraham Mehari H, Van Steenbergen F, Verheijen O, Van Aarst S:Spate Irrigation, Livelihood Improvement and Adaptation to Climate Variability and Change; ■ Mehretab Tesfai Stroosnijder L:The Eritrean spate irrigation system ■ Abraham Mehari, Depeweg, H, Schultz B (2005): Hydraulic Performance Evaluation of The Wadi Laba Spate Irrigation System in Eritrea, in Irrigation and Drainage. 54: 389–406; online: Wiley InterScience (www.interscience.wiley.com). ■ Berhane Haile G, Van Steenbergen F: Agricultural Water Management in Ephemeral Rivers: Community Management in Spate Irrigation in Eritrea; in African Water Journal ■ Berhane Haile G: Community Spate Irrigation in Bada, Eritrea ■ Mehretab Tesfai, Stroosnijder L (2000): The Eritrean spate irrigation system; on-line: linkinghub.elsevier.com/retrieve/pii/S0378377400001153

CROSS-SLOPE BARRIERS


Fanya juu with grass for stabilisation, Kenya. (Hanspeter Liniger)

In a nutshell

Definition: Cross-slope barriers are measures on sloping lands in the form of earth or soil bunds, stone lines, and / or vegetative strips for reducing runoff velocity and soil loss, thereby contributing to soil, water and nutrient conservation. This is achieved by reducing steepness and / or length of slope. Terraces are not usually constructed per se, but rather develop gradually behind earth bunds, vegetative strips (usually grass) or stone barriers, due to soil movement from the upper to the lower part of the terrace. Erosion between the barriers helps to achieve the levelling of the terrace bed. While cross-slope barriers are primarily intended to reduce soil erosion, they also enable / ease cultivation between the barriers, which are usually sited along contours. However, in high rainfall areas they may be graded at 0.5 – 2.0% across the slope to allow safe discharge of excess surface water along the barriers to reach watercourses. Some common technologies used by smallholder farmers include contour bunds, *fanya juu* and *fanya chini* terraces, stone lines and vegetative barriers. Bench terraces can be the eventual result – though in some circumstances may be constructed through excavation and shaping.

To ensure sustained fertility of the land it is necessary to employ soil fertility management measures such as composting, green manures, cover crop, etc. (see group on Integrated Soil Fertility Management).

Applicability: Applicable from gentle to steep slopes. Suitable for the whole range of arid to humid areas; in subhumid and humid areas cross-slope barriers are used for protection against soil erosion, whereas in semi-arid areas they are employed for in-situ water conservation and even water harvesting purposes.

Resilience to climate variability: Terraces and vegetative strips can, to a certain extent, cope with extreme rainfall events.

Main benefits: Improved water management through reduced soil erosion by water in subhumid areas, increased water infiltration and storage in semi-arid areas - hence helping to maintain soil fertility, increase crop yields and food security.

Adoption and upscaling: Depending on the type of measure, very often the investment costs for establishment exceed the short term benefits. Due to these high initial costs, incentives to compensate land users for part of the establishment investments may be needed. However, land users and communities should be able to maintain the system without any external support.

Development issues addressed	
Preventing / reversing land degradation	++
Maintaining and improving food security	+
Reducing rural poverty	+
Creating rural employment	+
Supporting gender equity / marginalised groups	+
Improving crop production	++
Improving fodder production	++
Improving wood / fibre production	+
Improving non wood forest production	na
Preserving biodiversity	+
Improving soil resources (OM, nutrients)	+
Improving of water resources	++
Improving water productivity	++
Natural disaster prevention / mitigation	++
Climate change mitigation / adaptation	++

Climate change mitigation	
Potential for C Sequestration (tonnes/ha/year)	0.5-1.0*
C Sequestration: above ground	+
C Sequestration: below ground	+

Climate change adaptation	
Resilience to extreme dry conditions	++
Resilience to variable rainfall	+
Resilience to extreme rain and wind storms	+
Resilience to rising temperatures and evaporation rates	+.
Reducing risk of production failure	+

** based on expert estimation for a duration of the first 10-20 years of changed land use management*

Origin and spread

Origin: Terracing steep lands in Africa is an indigenous technology. The same is true of earth bunds, stone lines and vegetative strips. New methods have evolved over the years in response to increasing population and land pressure. Under colonial regimes, large areas of communal lands were compulsorily terraced in the 1950s (e.g. in Kenya, Malawi and Zambia) through the construction of ridges or bunds. Often rejected immediately after independence such techniques made a come-back in the 1970s having been improved and promoted through projects / programmes. *Fanya juu* terraces first developed in the 1950s and are currently spreading throughout East Africa. The period of rapid spread occurred during the 1970s to 1980s with the advent of the National SWC Programme in Kenya. In the West African Sahel, contour stone lines (and vegetative barriers) have been promoted successfully since the 1980s, as water harvesting structures.

Mainly applied in: Terracing systems in steep areas throughout Africa; Stone lines on low slopes mainly West Africa (Burkina Faso, Mali, Niger); Earth bunds / ridges mainly in East Africa (Ethiopia, Kenya) and Southern Africa (Malawi, Zambia, Zimbabwe, etc.), *Fanya juu* mainly in East Africa (Kenya; also Ethiopia, Tanzania, Uganda); vegetative strips throughout Africa especially in the more humid zones.

Principles and types

Bench terraces are commonly developed on steep slopes as a result of constructing cross-slope barriers, and then erosion (water and tillage) progressively causing the bed to level. A bench terrace is defined by a flat or slightly backward or forward-sloping bed. Stone-faced terrace risers are characteristic of areas where stone is available (e.g. the Konso terraces in Ethiopia), otherwise the earth risers are protected by grass. Due to the heavy labour input they are usually constructed to support production of high-value crops such as irrigated vegetables and coffee. The design of the benches is usually calculated by a formula that relates their size and spacing to the slope. Bench terraces are rarely excavated and constructed directly, as this is very expensive.

Earth bunds (sometimes referred to as 'ridges' in Southern Africa) are soil conservation structures that involve construction of an earthen bund along the contour by excavating a channel and creating a small ridge on the downhill side. Usually the earth used to build the bund is taken from both above and below the structure. They are often reinforced by vegetative cover to stabilise the construction. Bunds are gradually built up by annual maintenance and adding soil to the bund.

Fanya juu ('do upwards' in Kiswahili) terraces are made by digging ditches and trenches along the contour and throwing the soil uphill to form an embankment. A small ledge or 'berm' is left between the ditch and the bund to prevent soil sliding back. In semi-arid areas they are normally constructed to harvest and conserve rainfall, whereas in subhumid zones they may be laterally graded to safely discharge excess runoff. The embankments (risers) are often stabilised with fodder grasses. *Fanya juu* terraces can develop into bench terraces.

In a ***Fanya chini*** system ('do downwards' in Kiswahili) soil is piled below a contour trench. These are used to conserve soil and divert water and can be used up to a slope of 35%. *Fanya chini* involve less labour than *Fanya juu*, but they do not lead to the formation of a bench terrace over time as quickly as the former.

Stone lines and bunds: In areas where stones are plentiful, stone lines are used to create bunds either as a soil conservation measure (on slopes) or for rainwater harvesting (on plains in semi-arid regions). Stones are arranged in lines across the slope to form walls. Where these are used for rainwater harvesting, the permeable walls slow down the runoff, filter it, and spread the water over the field, thus enhancing water infiltration and reducing soil erosion. Furthermore, the lines trap fertile soil sediment from the external catchment.

Vegetative strips are the least costly or labour-demanding type of cross-slope barriers. Such strips are a popular and easy way to terrace land, especially in areas with relatively good rainfall. The spacing of the strips depends on the slope of the land. On gentle sloping land, the strips are given a wide spacing (20-30 m), while on steep land the spacing may be as little as 10-15 m. Vegetative strips can also provide fodder for livestock if palatable varieties of grass (or densely spaced bushes) are used.

Top: Konso Terraces in Ethiopia. (Rima Mekdaschi Studer)
Top middle: *Fanya juu* terrace with napier grass, Kenya. (Hanspeter Liniger)
Bottom middle: Vegetative strips along contour line for reducing surface runoff and erosion, Kenya. (Christoph Studer)
Bottom: Stone lines catching run-off water and fertile soil sediments, Niger. (Hanspeter Liniger)

Applicability

Land degradation addressed

Soil erosion by water: mainly loss of topsoil / surface erosion, partly gully erosion / gullying

Physical soil deterioration: runoff can contribute to crusting and soil sealing

Water degradation: sedimentation and pollution of water downstream, partly aridification

Land use

Mainly on annual cropland and / or partly on mixed land with tree and shrub cropping.

Partly on intensive grazing fodder production: rarely on grazing land.

Ecological conditions

Climate: Mainly in subhumid and semi-arid, partly in humid and arid areas. In subhumid to humid areas mainly for protection against soil erosion, whereas in semi-arid areas mainly for water conservation purposes.

Earth bunds are not suitable for very wet areas unless graded; Vegetative strips are most effective in moist areas and least effective in dry areas; *Fanya juu* terraces are not suitable in dry areas unless used for rainwater harvesting.

Terrain and landscape: Bench terraces: moderate to very steep slopes; Earth bunds: gentle to moderate slopes; Stone bunds: gentle to steep slopes; *Fanya juu* terraces: moderate to steep slopes (up to 50%); *Fanya chini* terraces: moderate to hilly slopes (up to 35%); Vegetative strips: gentle to steep slopes.

Soils: Not suitable for very shallow and sandy soils – bench terraces must not be built on shallow soils (to avoid risk of landslides).

Socio-economic conditions

Farming system and level of mechanisation: Mainly animal traction (oxen, with plough) and manual labour (hand tools, on steeper slopes where oxen can not be used, etc.), very often a combination of animal traction and manual labour; only partly mechanised (e.g. for transportation of stones)

Market orientation: Mainly subsistence (self-supply), partly mixed and partly commercial / market.

Land tenure and land use / water rights: Secure individual land use rights are needed, otherwise the land users are not willing to invest in structural conservation measures. Land tenure is often formally state- or communal-(village) property and individually not-titled.

Skill / knowledge requirements: A high level of know-how is required for the establishment and the maintenance of terraces and bunds.

Planting and construction of vegetative strips is relatively simple and can be done by local land users with minimum investment and with local equipment.

Labour requirements: The establishment of terraces and bunds requires high input; sometimes outside labour needs to be hired for the construction of the terraces or the bunds. *Fanya juu* terraces are associated with hand construction, and are well suited to small-scale farms. In Kenya they are often established through self-help groups.

Maintenance can usually be done by individuals and is very important for all kind of terraces and bunds. Earth structures often need considerable maintenance - building up and reshaping the structure every year and stabilising through vegetative cover.

Vegetative strips often require less establishment work compared to terraces and bunds. Maintenance work is also very important e.g. grass strips require trimming and gap-filling to keep them dense.

Land degradation

■	Erosion by water
□	Erosion by wind
□	Chemical degradation
▩	Physical degradation
□	Biological degradation
▩	Water degradation

■	High
▩	Moderate
░	Low
□	Insignificant

Land use

■	Cropland
▩	Grazing land
□	Forests / woodlands
□	Mixed land use
□	Other

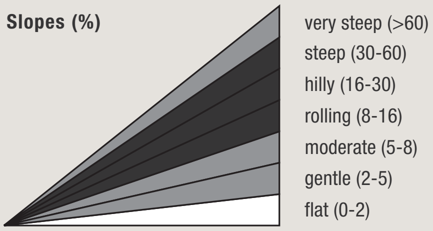
Climate

■	Humid
■	Subhumid
■	Semi-arid
░	Arid

Average rainfall (mm)

▩	> 3000
▩	2000-3000
■	1500-2000
■	1000-1500
■	750-1000
■	500-750
■	250-500
□	< 250

Slopes (%)



Farm size

■	Small scale
▩	Medium scale
□	Large scale

Land ownership

■	State
□	Company
■	Community
■	Individual, not titled
▩	Individual, titled

Mechanisation

■	Manual labour
▩	Animal traction
░	Mechanised

Market orientation

■	Subsistence
▩	Mixed
░	Commercial

Required labour

■	High
▩	Medium
□	Low

Required know-how

■	High
▩	Medium
□	Low

Economics

Establishment and Maintenance costs

	Establishment costs (US$/ha)			Maintenance costs (US$/ha)		
Costs	Terraces	*Fanya juu*	Veg. strips	Terraces	*Fanya juu*	Veg. strips
Labour cost PDays*	High 150-1200 150-600	High 40-600 40-300	Medium-high 7-80 7-40	Medium 10-300 10-150	Low 10-60 10-30	Low 0-30 0-15
Equipment	Low-medium 10-50	Low-medium 20-60	Low 10-50	Low 0-20	Low 0-10	Low 0-10
Material inputs	Medium-high 50-300	Low-medium 10-80	Medium 20-100	Low 0-50	Low 0-15	Low 0-10
Total	**210-1350**	**70 – 740**	**37-230**	**10-370**	**10-85**	**0-50**

**PD: Person days (labour is valued as 1-2 US$ per day), (Source: WOCAT, 2009)*

Comment: Very often the high establishment costs related to labour for the construction of terraces are the main obstacle for establishment. The construction costs depend on the slope of the area (number of barriers needed), the distance to the material (e.g. stones), the level of mechanisation and labour costs. The construction of vegetative strips requires least working days and can provide a cost-saving alternative to terracing. The equipment needed does not differ a lot between the three measures.

Production benefits

	Yield without SLM (t/ha)	Yield with SLM (t/ha)	Yield gain %
Maize, Kenya	2.1 – 3.4	2.3 – 3.7 (grass strips) 3.1 – 4.5 (*fanya juu*)	10-45%
Beans, Tanzania	1.5 – 1.8	2 (grass strips) 2.8 (*fanya juu*) 2.1 – 2.7 (bench terraces)	10-85%
Sorghum, Ethiopia	Non-terraced	Terraced (stone bunds)	
15% slope	0.96	2.18	127%
25% slope	0.67	1.83	173%
35% slope	0.43	1.7	297%

(Sources: Mwangi et al., 2001; Tenge et al., 2005; Alemayehu et al., 2006)

Comment: With increasing slope the difference in sorghum yields between terraced and non-terraced lands increases. Terraces result in remarkably higher yields on steep slopes compared with non-terracing.

Benefit-Cost ratio

	short term	long term	quantitative
Bench terraces	– –	++	Internal rate of return, Tanzania: 19%
Bunds	–	++	
Stone lines	–	++	
Fanya juu	–	++	14%
Vegetative strips	+/–	++	6%
Overall	–	++	

– – negative;– slightly negative; –/+ neutral; + slightly positive; ++ positive; +++ very positive
(Sources: Tenge et al., 2005 and WOCAT, 2009)

Comment: The internal rate of return as shown above suggest that, farmers who are able to invest in bench terraces, will be able to recover their investment faster than from the *fanya juu* and grass strips. However, the short term benefit-cost ratio for cross-slope barriers is mostly negative due to high investment costs. It can take up to 2 years until the barriers lead to a positive return. The profitability of barriers also depends on the opportunity costs for labour. For land users with an off-farm income the establishment of cross-slope barriers is often financially not attractive.

Examples: Burkina Faso
The analysis of different structural conservation measures in Burkina Faso, has shown shown that the construction of stone lines generally leads to the highest establishment costs (140-400 US$/ha), the construction of earth bunds is slightly cheaper (95-200 US$/ha), whereas vegetation barriers show relatively low establishment costs if local grasses are used (approx. 60-70 US$/ha) (Spaan, 2003).

Example: Tanzania
A study in the West Usambara Highlands has shown significant increase in the crop yield for maize and beans by implementing bench terraces, fanya juu or grass strips (see production benefits). However, the results clearly showed that cross-slope barriers alone may not significantly increase crop yields unless these are followed by other practices such as manure and fertilizer. Grass strips and / or the introduction of grass on the risers, can lead to an additional increase in yield which can be either used as fodder for livestock or it can be sold (Tenge et al., 2005).

Example: Burkina Faso
A cost-benefit analysis for stone lines in the region of Kaya shows that, from the farmer's point of view, the implementation of stone lines alone is only profitable if a lorry is provided for the transport of stones. If the farmer has to pay the transport himself the net present value of stone lines is negative. The benefits (20% yield increase in wet years and 30% yield increase in dry years) are not high enough to compensate for the costs of transport and construction. Thus profitability of stone lines depends closely on transport and distance to the source of the stones (Kempkes, 1994).

Impacts

Benefits	Land users / community level	Watershed / landscape level	National / global level
Production	++ increased crop yield (long term) ++ increased grass / fodder production (through grass strips and / or grass on risers) can be used for livestock, sold, as mulch or to thatch roofs + increased wood production	++ reduced risk and loss of production + access to clean dinking water	+++ improved food and water security
Economic	++ increased farm income (long term)	++ less damage to off-site infrastructure + stimulation of economic growth	+++ improved livelihood and well-being
Ecological	+++ reduced soil loss (mainly in subhumid areas) ++ increased soil moisture (mainly in semi-arid areas) ++ reduced soil erosion (by wind / water) ++ increased infiltration rates ++ decrease in runoff velocity and control of dispersed runoff + improved soil cover + increase in soil fertility (long term) + biodiversity enhancement + improved micro-climate	++ reduced degradation and sedimentation ++ improved water quality + increased water availability + intact ecosystem	++ increased resilience to climate change ++ reduced degradation and desertification incidence and intensity ++ enhanced biodiversity
Socio-cultural	++ improved conservation / erosion knowledge + community institution strengthening	++ increased awareness for environmental 'health' ++ attractive landscape	++ protecting national heritage

	Constraints	How to overcome
Production	• Loss of land for production due to risers of terraces, ditches for *Fanya juu* / chini, vegetative strips, etc.	➜ integrating and incorporating vegetative measures in the system, widen the spacing between bunds, make bund area productive (e.g. grass on terraces for livestock), increase productivity of fodder trees on bunds, etc.
	• The constructions can easily be damaged by cattle interference	➜ controlled grazing management of the terraces
	• Planting of vegetative strips falls in the period with highest agricultural activity	
	• If not adequately managed soil and water conservation function can be lost or can even be accelerated	➜ needs good capacity building and training for appropriate management of the measures
	• Competition for water and nutrients in the case of vegetative barriers	
Economic	• High investments costs, usually exceeding short term benefits	➜ credits and financial incentives for initial investments should be easily accessible to land users
	• Shortage of labour, especially for the construction; very high labour input is needed. Some cross-slope barriers can also lead to high maintenance requirement, e.g. soil bunds.	➜ establishment with labour-sharing groups, financial incentives or credit facilities or phasing the establishment over several years to overcome. For maintenance less support is needed but land users should be organised (individually or in groups) to undertake maintenance and repairs
	• Shortage of construction material and hand tools	
	• Lack of market infrastructure	
Ecological	• Possible waterlogging before bund / embankment	➜ additional measures such as vegetation / mulch cover
	• Uneven flood water distribution, breakages of terraces	➜ maintenance and adjustments of the barriers
	• Rodent and other pests hiding in the vegetation	➜ provision of appropriate measures, provision of rodent and pest controlling mechanisms
	• Competition of vegetative strips + bunds with crop	➜ trimming of vegetation during crop growing period
	• Unprotected bunds, which have not been planted with grass, are prone to erosion	➜ additional measures such as vegetation / mulch cover to reduce runoff
Socio-cultural	• Often traditional system, but not properly maintained, especially when populations move away from rural areas	➜ incentives for 'renovation' of traditional structures (e.g. Konso terraces in Ethiopia)

Adoption and upscaling

Adoption rate

The labour requirement can be a major constraint to the adoption of cross-slope barrier technologies. Vegetative strips have the lowest labour requirements leading to higher adoption. However, establishment of these very often coincides with the labour peak of the normal agricultural activities.

The loss of land and temporal yield decline in the short term are the main obstacles, especially for small-scale farmers, to adoption of structural measures such as terraces or bunds, even though long term benefits are likely.

High investment costs and the uncertain benefits in the short term further hinder the adoption and upscaling of this group of measures.

Upscaling

For adoption, a substantial yield gain is essential to overcome the high investment costs and the loss of agricultural productive land. Land users need to be well informed in terms of yields and / or monetary values which can be gained through the implementation of cross-slope barriers.

Awareness raising: Land users need to recognise the multiple resource losses due to runoff and erosion on sloping land.

Clear **land use rights** are needed for investments to be made in structural measures.

Access to knowledge must be ensured for land users; training of land users is essential to establish knowledge and technical skill about appropriate establishment and also maintenance.

Micro-credit for financial investments: The self-financing capacity of farmers needs to be strengthened and credits must be easily accessible also for small-scale land users.

Access to material inputs and markets is necessary for establishment of cross-slope barriers.

Incentives for adoption

The construction of cross-slope barriers usually requires considerable labour but material inputs also, and hence the investment costs often exceed the short term benefits. Therefore it is crucial that land users have access to micro-credit to enhance self-financing. Incentives should only be given if there is no other possibility of establishing cross-slope barriers. Two reasons to justify the provision of incentives are: (1) the costs are only slowly recuperated by on-site benefits; (2) part of the benefits are obtained by people downstream. Possible options for incentives can be transport facilities for stones (for example) or subsidies on inputs such as seedlings for the vegetative strips. Payment for ecosystem services (PES) is another incentive that specifically addresses the benefits of downstream users. Maintenance work should be conducted without any external support.

Enabling environment: key factors for adoption	
Inputs, material incentives, credits	++
Training and education	++
Land tenure, secure land use rights	++
Access to markets	+
Research	++
Infrastructure	+
Conflicts of interest	+

Example: Kenya

During the colonial period in Kenya, in the 1950s, bench terracing used to be forced on local people, and after independence in 1963, many terraces were destroyed or neglected. After the soil conservation extension campaigns of the 1970s-1980s, bench terraces were adopted by farmers living on steep mountain slopes of Central and Eastern Provinces, especially on farms where coffee was grown (Mburat, 2006).

Example: Tanzania

Despite decades of efforts to promote cross-slope barriers in the West Usambara Highlands in Tanzania, there is still minimal adoption by land users. Among the major reasons for this could be that land users do not recognise the losses caused by runoff and soil erosion, that the recommended measures are not effective enough or not financially attractive. Furthermore, the establishment period competes with other activities for scarce labour resources and equipment. It is crucial that land users are well informed about costs and benefits of implementing the measures in order to achieve greater motivation to implement cross-slope barriers (Tenge et al., 2005).

References and supporting information:

Alemayehu M., F. Yohannes, and P. Dubale. 2006. Effect of Indigenous Stone Bunding (KAB) on Crop Yield at Mesobit-Gedeba, North Shoa, Ethiopia. Land Degrad. Develop. 17: 45–54 (2006).

Amsalu, A. and J. de Graaff. 2007. Determinants of adoption and continued use of stone terraces for soil and water conservation in an Ethiopian highland watershed. Ecological Economics, 61 (2007) 294-302.

Bodnar, F. 2005. Monitoring for impact: evaluating 20 years of soil and water conservation in southern Mali.

IWMI. 2009. http://www.iwmi.cgiar.org/africa/west/projects/Adoption%20Technology/Soil&WaterConservation/56-ImprovedStoneTerracing.htm, accessed on 15 September 2009.

IWMI. 2009. http://www.iwmi.cgiar.org/africa/west/projects/Adoption%20Technology/RainWaterHarvesting/50-Fanya%20juu.htm, accessed on 15 September 2009.

Kempkes, M. 1994. Analyse financière des cordons pierreux: cas d'étude de Tagalla, province du Sanmatenga au Burkina Faso; rapport des étudiants 44a Antenne Sahélienne, Ouagadougou.

Mati B. M. 2005. Overview of water and soil nutrient management under smallholder rainfed agriculture in East Africa. Working Paper 105. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Mwangi J.N., T.O. Mboya and Kihumba. 2001. Improved Maize Production in Central Kenya with Adoption of Soil and Water Conservation Measures. Seventh Eastern and Southern Africa Regional Maize Conference, 11th-15th February, 2001. pp. 299-300.

Spaan, W.P. 2003. Consuming the savings: water conservation in a vegetative barrier system at the Central Plateau in Burkina Faso., Wageningen University and Research Centre, Wageningen.

Tenge, A.J., J. De Graaff, J.P. Hella. 2005. Financial efficiency of major soil and water conservation measures in West Usambara highlands, Tanzania. Applied Geography 25, 348-366.

UNEP. 1998. Sourcebook of Alternative Technologies for Freshwater Augumentation in Africa. Newsletter and Technical Publications.http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-8a/fanya.asp, accessed on 28.10.2009.

WOCAT. 2009. WOCAT databases on SLM technologies and SLM approaches. www.wocat.net, accessed on 15 September 2009.

ALOE VERA LIFE BARRIERS - CAPE VERDE

Aloe vera is a drought tolerant, fleshy plant which is planted in the form of live barriers to recuperate degraded slopes on the Cape Verde Islands. The plants are closely planted along the contour to build an efficient barrier for retention of eroded sediments and surface runoff. The hedgerows stabilise the soil, and increase soil humidity by improving infiltration and soil structure. Soil is accumulating behind the *Aloe* strips and slope angle is considerably reduced over time. Groundwater is recharged indirectly. Soil cover is improved, and thus evaporation reduced.

Implementation is relatively simple. The contour lines are demarcated using line- or water-levels. Seedlings are planted at a distance of 30-50 cm between plants; Spacing between the rows varies between 6–10 m according to the slope. The technology is applied in subhumid and semi-arid areas, on steep slopes with shallow soils, sparse vegetative cover and high soil erosion rates. These areas are generally used by poor subsistence farmers for rainfed agriculture with crops such as maize and beans, which are considered inappropriate for such slopes. On slopes steeper than 30% the live barriers are often combined with stone walls (width 40-50 cm; height 80-90 cm). The plants stabilise the stone risers, making this combined technology one of the most efficient measures for soil erosion control on Cape Verde.

Aloe vera is well adapted to the local biophysical conditions and to the prevailing land use system: it can be used with any crop and is available to all farmers; establishment and transport is simple, its leaves are not palatable to livestock, the plant is extremely resistant to water stress and grows in any bioclimatic zone on the island. Furthermore, *Aloe vera* is known for its multiple uses in traditional medicine.

SLM measure	Vegetative
SLM group	Cross-Slope Barriers
Land use type	Annual cropping (maize, beans)
Degradation addressed	Soil erosion by water
Stage of intervention	Mitigation and rehabilitation
Tolerance to climate change	Tolerant; *Aloe vera* is resistant to water stress, and establishes well in different climatic zones

Establishment activities

1. Demarcation of contour lines, using line or water levels; spacing between barriers is minimum 6 meters (early June).
2. Collection of *Aloe vera* plants; *Aloe vera* is growing naturally in abundant quantity on the upper slopes, in depressions / hollows, in arid as well as in more humid zones.
3. Planting of *Aloe vera* seedlings, one next to the other, or at a spacing of 30-50 cm between plants; (end of June) manually, using hoe / pickaxe.
4. From the second year on the gaps between the plants are plugged by naturally expanding *Aloe vera* plants.

Maintenance / recurrent activities

1. Vegetative control: removal of *Aloe vera* plants that are invading cropland (maize, peas) between the life barriers.
2. Replanting of *Aloe vera* to fill gaps in life barriers (very rare; survival rate is over 95%).

Labour requirements

For establishment: medium

For maintenance: low

Knowledge requirements

For advisors: low

For land users: low

Photo 1: Well established *Aloe vera* life barriers on steep slopes. (Jacques Tavares)

Photo 2 and 3: Detailed view of *Aloe vera* life barriers; soil is accumulating on the upper side of the barriers. (Jacques Tavares)

Photo 4: *Aloe vera* life barriers are often combined with stone walls to enhance the erosion control on steep slopes. (Hanspeter Liniger)

Case study area: Santiago, Cape Verde

Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour: 65 person-days	215
Equipment: levels, hoes, shovels	13
Agricultural inputs: 5,000 plants	0
TOTAL	**228**
% of costs borne by land users	0%

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 1 person-day	3
Equipment	0
Agricultural inputs	0
TOTAL	**3**
% of costs borne by land users	100%

Remarks: Labour inputs for implementation are rewarded by project: Individuals of poor communities receive a salary of 3 US$ per day. Plants are collected locally. Establishment costs do not include labour-intensive construction of stone risers (supportive measure). Maintenance costs are borne by land users.

Benefit-cost ratio

Inputs	short term	long term
Establishment	slightly negative	very positive
Maintenance	neutral / balanced	very positive

Remarks: Maintenance is not costly, it's simply vegetative control and punctual replanting.

Ecological conditions

- Climate: mainly semi-arid, partly subhumid
- Average annual rainfall: mainly 500-750 mm, >800 mm in wetter areas
- Soil parameters: mainly shallow loamy soils, with medium fertility and low-medium organic matter content; drainage is medium while water storage capacity is high to very high
- Slope: steep (30-60%), partly less
- Landform: mountain slopes and ridges
- Altitude: mainly 500-1,000 m a.s.l., partly 100-500 m a.s.l.

Socio-economic conditions

- Size of land per household: 1-2 ha (poor), 2-5 ha (better-off)
- Type of land user: small-scale, poor; partly medium-scale, better-off
- Population density: 100-200 persons/km^2
- Land ownership: individual (titled) and communal (Diocese)
- Land use rights: mainly leased, partly individual or hereditary
- Level of mechanisation: mainly manual, few farms are mechanised
- Market orientation: mainly subsistence, few mixed (subsistence and commercial)

Production / economic benefits

++ Reduced risk of production failure
+ Increased crop yield
+ Increased fodder production
+ Increased production area

Ecological benefits

+++ Improved harvesting / collection of surface runoff
+++ Reduced surface runoff
++ Improved soil cover
++ Increased biomass / above ground carbon
+ Increased soil moisture
+ Increased water quality
+ Increased water quantity

Socio-cultural benefits

+++ Improved conservation / erosion knowledge
+ Conflict mitigation
+ Improved food security / self-sufficiency
+ *Aloe vera* is used in traditional medicine / personal hygiene: pills against anaemia, diabetes and digestion problems; bactericide for wound treatment

Off-site benefits

+++ Recharge groundwater table / aquifer

Weaknesses ➜ and how to overcome

- Reduction of the production area, which is occupied by strips of *Aloe vera* ➜ annual vegetative control within cultivated area and by cutting *Aloe vera* plants growing outside the life barriers.

Adoption

Most of the land users have implemented the technology by receiving financial incentives (payments). Totally 380 land users have adopted the technology; the area treated with *Aloe vera* life barriers is 71.5 km^2. There is a small trend towards spontaneous adoption.

Main contributors: Jacques Tavares and Larissa Varela, Instituto Nacional de Investigação e Desenvolvimento Agrário (INIDA), Praia, Cape Verde; inida@inida.gov.cv
Key references: WOCAT. 2010. WOCAT database on SLM technologies. www.wocat.net. DESIRE-project. 2010. http://www.desire-project.eu/

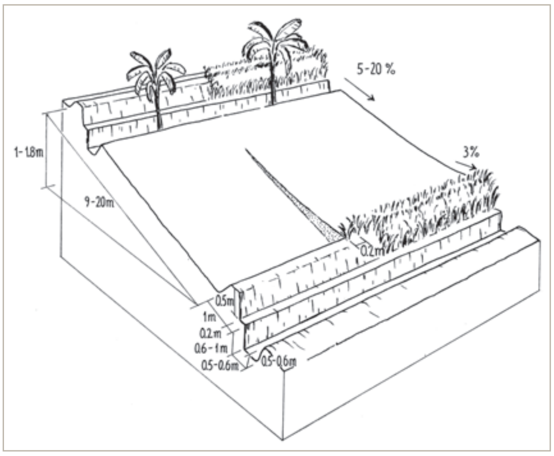
GRASSED *FANYA JUU* TERRACES - KENYA

A *fanya juu* terrace is made by digging a trench and throwing the soil uphill to form an embankment. A berm prevents the embankment soil from sliding back into the trench. On the embankment a grass strip is established, serving a triple purpose: it stabilises the earth structure through its roots, it enhances siltation of eroded soil particles, and it is used as a fodder source for livestock. Often napier (*Pennisetum purpureum*), or makarikari (*Panicum coloratum* var. *makarikariensis*) are used in the drier zones.

In semi-arid areas the structures are laid out along the contour to maximise water retention, whereas in subhumid zones they are laterally graded to discharge excess runoff. Spacing of terraces ranges from 9 - 20 m, according to slope and soil depth. On a 15% slope with a moderately deep soil, the spacing is 12 m between the structures and the vertical interval around 1.7 m.

The purpose of the *fanya juu* is to reduce loss of soil and water, and thereby to improve conditions for plant growth. The embankment impounds runoff water, eroded soil and nutrients. As a consequence of water and tillage erosion, sediment accumulates behind the bund, making it necessary to periodically build up the embankment (by throwing silted material from the trench upslope). In this way *fanya juu* terraces gradually develop into forward sloping terraces. Grass strips require trimming to keep them dense.

Fanya juu terraces are associated with hand construction, and are well suited to small-scale farms. *Fanya juu* is applicable where soils are too shallow for level bench terracing and on moderately steep slopes (e.g. < 20%), they are not suitable for stony soils.



SLM measure	Structural combined with vegetative
SLM group	Cross-Slope Barriers
Land use type	Cropland: annual crops
Degradation addressed	Loss of topsoil (water erosion); Soil moisture problem
Stage of intervention	Mitigation
Tolerance to climate change	Tolerant to climatic extremes (e.g. rain storms); Water conservation effect increases resilience to periods of water stress

Establishment activities

1. Layout (alignment and spacing) of terraces: (a) on the contour in dry areas; (b) on a slight grade in more humid areas, using ‘line levels’.
2. Loosen soil for excavation (forked hoe, ox-drawn plough).
3. Dig a ditch / trench and throw the soil upwards to form a bund, leaving a berm of 15-30 cm in between (using hoes and shovels).
4. Levelling and compacting bund.
5. Digging planting holes for grass.
6. Creating splits of planting materials (*Makarikari* or Napier grass).
7. Manuring and planting of grasses.

All activities are done manually before the rainy seasons start (March and October) except planting of grasses, at the onset of rains. Duration of establishment: usually within one year.

Maintenance / recurrent activities

1. Desilting the trench and throwing silt upslope.
2. Repairing breaches in embankment where necessary.
3. Building up embankment annually.
4. Cutting grass to keep low and non-competitive, and provide fodder for livestock.
5. Maintaining grass strips weed-free and dense.

Labour requirements

For establishment: high
For maintenance: low to medium

Knowledge requirements

For advisors: moderate
For land users: low

Photo 1: Napier grass strip on the upper part of a *Fanya juu* bund; maize trash was deposited in the ditch below after harvest. (Hanspeter Liniger)
Photo 2 : *Fanya juu* terraces with well established grass strips in a semiarid area have developed over time into bench terraces. (Hanspeter Liniger)
Technical drawing: Schematic representation of *fanya juu* terraces with dimensions of structures; initial stage (left) and mature stage with well established grass strip and soil accumulating on the upper side of the embankment (right). (Mats Gurtner)

Case study area: Eastern Province, Kenya

Establishment inputs and costs per ha

Inputs	Costs (US$)
Labour: 90 person-days	270
Equipment / tools	20
Agricultural inputs: compost, manure	30
Grass establishment	60
TOTAL	**380**
% of costs borne by land users	100%

Maintenance inputs and costs per ha per year

Inputs	Costs (US$)
Labour: 10 person-days	30
Equipment	
Agricultural inputs: compost	
TOTAL	**30**
% of costs borne by land users	100%

Remarks: These calculations are based on a 15% slope with 830 running metres of terraces per hectare with typical dimensions and spacing (see technical drawing).

Benefit-cost ratio

Inputs	short term	long term
Establishment	slightly negative	positive
Maintenance	positive	very positive

Remarks: As the terrace is built up gradually over the years, establishment costs can be limited.

Ecological conditions

- Climate: subhumid, semi-arid
- Average annual rainfall: 500-1,000 mm
- Soil parameter: moderately deep, loamy soils, with medium soil fertility, low to medium organic matter content; medium water storage capacity, medium to good drainage
- Slope: mainly moderate-rolling (5-16%); partly hilly
- Landform: hillslopes and footslopes
- Altitude: 500-1,500 m a.s.l.

Socio-economic conditions

- Size of land per household: mainly < 1ha, partly 1-2 ha, some 2-5 ha
- Type of land user: small-scale, average level of wealth to poor land users
- Population density: 100-200 km^2
- Land ownership: individual titled and individual not titled
- Land use rights: individual
- Market orientation: subsistence and mixed (subsistence and commercial)
- Level of mechanisation: mainly animal traction, partly manual labour

Production / economic benefits

++ Increased crop yield (25%)
++ Increased fodder production and fodder quality
\+ Increased farm income

Ecological benefits

++ Increased soil moisture (semi-arid)
++ Increased efficiency of excess water drainage (subhumid)
++ Reduced soil loss
++ Increased soil fertility (in the long term)
++ Improved soil cover

Socio-cultural benefits

++ Improved conservation / erosion knowledge
++ Community institution strengthening

Off-site benefits

++ Reduced downstream siltation
\+ Increased stream flow in dry season
\+ Reduced downstream flooding

Weaknesses ➜ and how to overcome

- Loss of cropping area for terrace bund ➜ site-specific implementation: only where *fanya juu* terraces are absolutely needed, i.e. where agronomic (e.g. mulching, contour ploughing) and vegetative measures are not sufficient in retaining / diverting runoff; use the bund for production of valuable fodder / fruit (trees).
- High amounts of labour involved for initial construction ➜ spread labour over several years and work in groups.
- Risk of breakages and therefore increased erosion ➜ accurate layout and good compaction of bund.
- Competition between fodder grass and crop ➜ keep grass trimmed / harvest for livestock feed.

Adoption

Fanya Juu is a wide-spread technology – covering approx. 3,000 km^2 in the case study area – with high degree of spontaneous adoption throughout East Africa, and further afield also. The terraces first came into prominence in the 1950s, but the period of rapid spread occurred during the 1970s and 1980s with the advent of the National Soil and Water Conservation Programme.

Main contributors: Kithinji Mutunga, FAO Kenya, Nairobi, Kenya; kithinji.mutunga@fao.org ■ Hanspeter Liniger, Centre for Development and Environment; Bern, Switzerland; hanspeter.liniger@cde.unibe.ch
Key references: Thomas D (Editor) 1997: Soil and water conservation manual for Kenya. Soil and Water Conservation Branch, Nairobi ■ WOCAT 2004, WOCAT Database on SLM Technologies; www.wocat.net