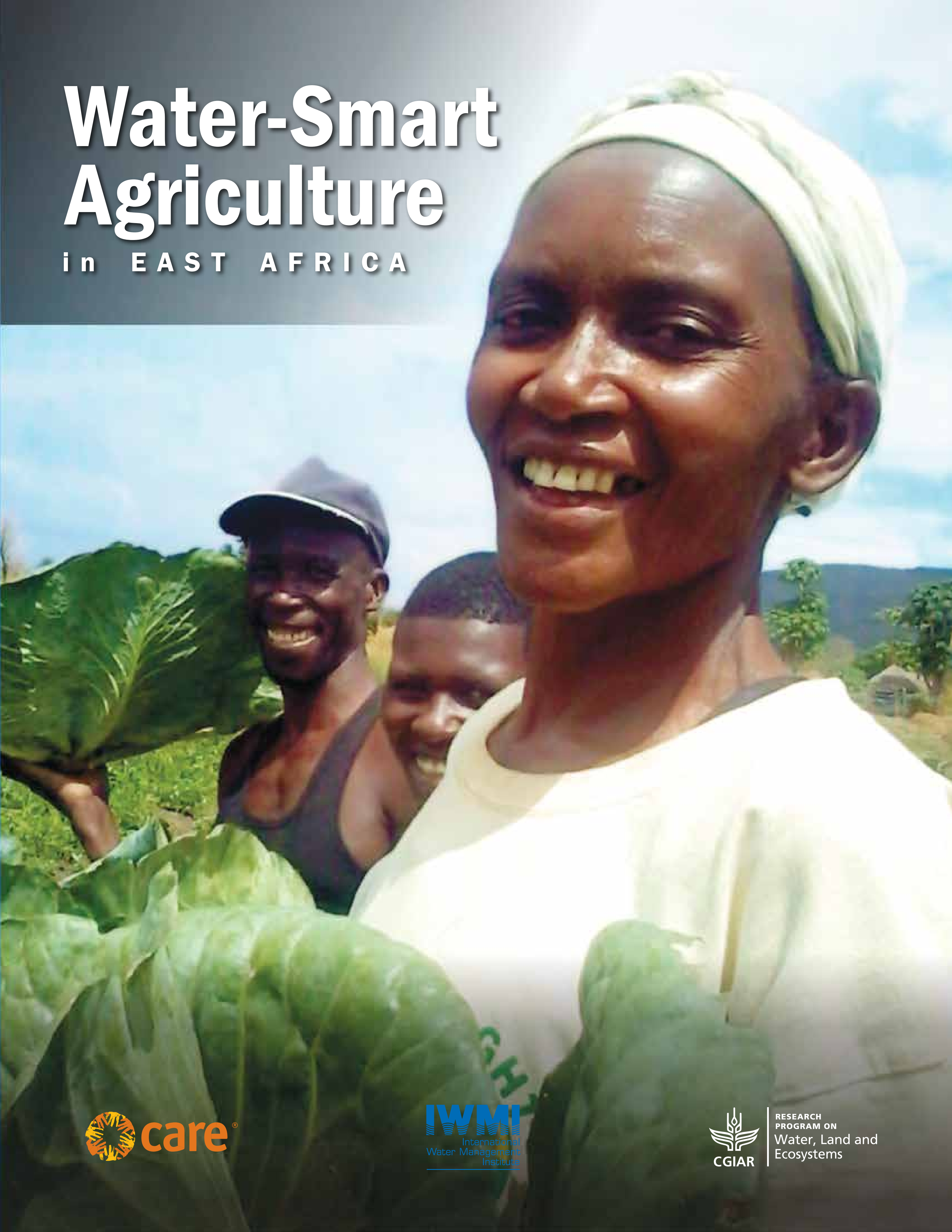
Water-Smart Agriculture

in EAST AFRICA



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IWMI
International Water Management Institute

CGIAR

RESEARCH PROGRAM ON
Water, Land and Ecosystems

Water-Smart Agriculture

in EAST AFRICA

Editors

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Addis Ababa, March 2015

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About the cover photos

FRONT COVER: Grace and family in Otuke District, Uganda. The cabbage crop, which was sold in the local trading center and community markets, provided additional income for the household in 2014. Grace used most of the additional income to pay her children's school fees. On their farm, they use a number of soil and water conservation practices. They harvest runoff water and store it in a pond for supplementary irrigation. The water conserves soil fertility and the weeds are useful for making mulch. The family also applies composted manure and uses planting ridges and basins to enable infiltration of rainwater.

BACK COVER: Farmer Tom Acuma is 49 years old. He is chairperson of the Bed ijo farmers' group and is married with one wife and eight girls—five of school age and three in pre-school. Tom owns about 60 acres, 20 of which he uses for crop cultivation and animal rearing and the rest is left fallow. He grows maize, pigeon pea, millet, sorghum, beans, groundnut, sesame, cassava, sweet potato and rice. His major cash crops are rice, maize and sesame in addition to which he grows tomato, cabbage, onion and eggplant for both cash and own consumption.

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Acronyms

°C	degree Celsius
AASS	African Advisory Services Symposium
ACF	Action Against Hunger
ACT	African Conservation Tillage Network
AEZ	agro-ecological zone
AGP	agriculture growth program
AHI	African Highland Initiative
AMCEN	African Ministerial Conference on Environment
ANOVA	analysis of variance
ARARI	Agriculture Research Institute
ASAL	arid and semiarid land
asl	above sea level
AWD	alternate wetting and drying
AWM	agricultural water management
BBM	broadbed and furrow maker
BCR	benefit-cost ratio
BoWRD	Bureau of Water Resources Development
BRN	Big Results Now
BWO	Basin Water Office
C	conventional practice
CA	conservation agriculture
CAADP	Comprehensive Africa Agriculture Development Programme
CARE	Cooperative for Assistance and Relief Everywhere
CASL	Community Adaptation and Sustainable Livelihood
CBO	community-based organization
CC & V	climate change and variability
CDI	conventional drip irrigation
CF	conservation farming
CF	conventional practice with added fertilizer
CFW	cash-for-work
CGIAR	A global research partnership for a food-secure future
CLUSA	Cooperative League of the United States of America
cm	centimeter
CO_2	carbon dioxide
COMESA	Common Market for Eastern and Southern Africa
CPWF	CGIAR Challenge Program on Water and Food
CRiSTAL	Community-based Risk Screening Tool – Adaptation and Livelihoods
CSO	civil society organization
CT	conservation tillage
CUC	Christiansen's uniformity coefficient
DAICO	Directorate for Agriculture, Irrigation and Cooperatives
DAO	district agricultural officer
DAP	diamonium phosphate
DA	development agent
DDP	District Development Plan
DED	Deutscher Entwicklungsdienst Ded
DIDT	district irrigation development team
DNH	Do-No-Harm
DRRAP	Drought Risk Reduction Action Plan
DU	distribution uniformity
E	evaporation
EA	evergreen agriculture

ECHO	European Commission's Humanitarian Aid and Civil Protection Programme
ECO	Ecological Christian Organization
EHRS	Ethiopian Highland Reclamation Study
ELMT	Enhanced Livelihoods in the Mandera Triangle
EPA	Environmental Protection Authority
ESA	Eastern and Southern Africa
ESR	ecosystems and resilience
ET	evapotranspiration
EU	emission uniformity
FAO	Food and Agriculture Organization of the United Nations
FARM–Africa	Food & Agricultural Research Management–Africa
FBO	faith-based organization
FFS	farmer field school
FFW	food-for-work
FGDs	focus group discussions
FREG	farmer research extension group
ft	feet
g	gram
GDP	gross domestic product
GEF	Global Environment Facility
GHG	greenhouse gas
GIS/RS	geographic information system/remote sensing
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GRET	Groupe de Recherches et d'Echanges Technologiques
GTZ	Gesellschaft für Technische Zusammenarbeit
GWD	ground water development
GWI	Global Water Initiative
GWI EA	Global Water Initiative East Africa
ha	hectare
HIV/AIDS	human immunodeficiency virus/acquired immunodeficiency syndrome
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDP	internally displaced person
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IGAD	Intergovernmental Authority on Development
IHE	International Institute for Hydraulic and Environmental Engineering
IIRR	International Institute of Rural Reconstruction
ILAC	Institutional Learning and Change
ILRI	International Livestock Research Institute
IMAWESA	Improved Management of Agricultural Water in Eastern and Southern Africa
IPCC	Intergovernmental Panel on Climate Change
IRR	internal rate of return
ISRIC	International Soil Reference and Information Centre
ISWM	integrated soil and water management
ITV	Independent Television
IUCN	International Union for Conservation of Nature and Natural Resources
IWM	integrated watershed management
IWMI	International Water Management Institute
IWRM	international water resources management
IWP	irrigation water productivity
JESE	Joint Effort to Save the Environment
JICA	Japan International Cooperation Agency
JLA	joint learning approach
KADLACC	Kapchorwa District Landcare Chapter
kcal	kilocalorie
KDWSP	Kigezi Diocese Water and Sanitation Programme
kg	kilogram
l	liter
LCDI	low-cost drip irrigation

LPA	Learning and Practice Alliance
LPA	Learning and Planning Alliance
LUPIS	Land Use Policies and Sustainable Development in Developing Countries
LVB	Lake Victoria Basin
LVIA	Lay Volunteers International Association
LWP	livestock water productivity
m	meter
M&E	monitoring and evaluation
m^2	square meter
m^3	cubic meter
MAAIF	Ministry of Agriculture Animal Industry and Fisheries
MAM	March to May
MARI	Mlingano Agricultural Research Institute
masl	meters above sea level
MDG	Millennium Development Goal
MEFECAP	Meru Forest Environment Conservation & Protection Association
MERECEP	Mt. Elgon Ecosystems Regional Program
MERET	Managing Environmental Resources to Enable Transitions
mg	milligram
MICCA	Mitigation of Climate Change in Agriculture
mm	millimeter
MoA	Ministry of Agriculture
MOU	memorandum of understanding
MSc	Master of Science
MSWoARD	Menjar Shenkura Woreda Office of Agriculture and Rural Development
MTNRE	Ministry of Tourism, Natural Resources and Environment (Tanzania)
MWE	Ministry of Water and Environment
NAADS	National Agricultural Advisory Services
NABU	Nature Conservation Alliance
NaCRRI	National Agricultural Crop Research Institute Namulonge
NAPA	national adaptation programs of action
NARL	National Agricultural Research Laboratories
NARO	National Agricultural Research Organisation
NBDC	Nile Basin Development Challenge
NEMA	National Environmental Management Authority
NEMC	National Environmental Management Council
NgeZARDI	Ngetta Zonal Agricultural Research and Development Institute
NGO	non-government organization
NPHC	National Population and Housing Census
NPV	net present value
NRM	natural resource management
OECD	Organisation for Economic Co-operation and Development
OND	October to December
PA	peasant association
PEER	Partnership for Enhanced Engagement in Research
PF	pitting + fertilizer
PhD	Doctor of Philosophy
PPBs	permanent planting basins
PPP	public-private partnership
PRA	participatory rural appraisal
PROCA	Participatory Rapid Opportunities and Constraints Analysis
PVC	polyvinylchloride
REGLAP	Regional Learning and Advocacy Project
REST	Representational State Transfer
RF	ripping and fertilizer
RiPPLE	Research-inspired Policy and Practice Learning in Ethiopia and the Nile region
RMS	rainwater management systems
ROI	return on investment
RWH	rainwater harvesting

SAGCOT	Southern Agricultural Growth Corridor of Tanzania
SAIPRO	Same Agriculture Improvement Project
SARI	Selian Agriculture Research Institute
SCAPA	Soil Conservation and Agroforestry Programme
SCTD	Schumancher Centre for Technology and Development
SEI	Stockholm Environment Institute
SIMLESA	Sustainable Intensification of Maize-Legume Cropping System for Food Security in Eastern and Southern Africa
SIWI	Stockholm International Water Institute
SLF	Sustainable Livelihoods Framework
SLM	Sustainable Land Management
SMU	Sorghum for Multiple Use Project
SNNPR	Southern Nations, Nationalities, and Peoples' Region
SPSS	Statistical Package for the Social Sciences
SRI	system of rice intensification
SS	stainless steel
SSA	sub-Saharan Africa
SSC	suspended sediment concentration
SSY	suspended sediment yield
SUA	Sokoine University of Agriculture
SWC	soil and water conservation
T	transpiration
T&V	Train and Visit
t/ha	tons per hectare
TAFSIP	Tanzania Agriculture and Food Security Investment Plan
TIP	Traditional Irrigation Project
Tsh	Tanzanian shilling
TT	traditional tillage
TXD	Tanzania Cross Dakawa
UBOS	Uganda Bureau of Statistics
UGX	Ugandan shilling
UMADEP	Uluguru Mountain Agricultural Development Project
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
URT	United Republic of Tanzania
US$	United States dollar
USAID	United States Agency for International Development
UWA	Uganda Wildlife Authority
VADP	village agricultural development plan
WAP	Water Action Plan
WaSA	Water Smart Agriculture
WASH	water supply, sanitation and hygiene
WaTER	Water Sanitation and Hygiene Transformations for Enhanced Resilience project
WCP	water cost of production
WEMA	Water-efficient Maize for Africa
WFP	World Food Programme
WHaTeR	Water Harvesting Technologies
WLE	CGIAR Research Program on Water, Land and Ecosystems
WOCAT	World Overview of Conservation Approaches and Technologies
WP	water productivity
WPrain	rainwater productivity
WSI	water system innovations
WUAs	water user associations
WWF	Worldwide Fund for Nature
yr	year
ZARDI	Zonal Agricultural Research Development Institute

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Foreword

In May 2014, researchers, practitioners and policy makers came together in Addis Ababa under the auspices of an event co-convened by the Cooperative for Assistance and Relief Everywhere (CARE), the International Water Management Institute (IWMI) and the Water, Land and Ecosystems programme of the CG system. The event drew inspiration from two preceding meetings, one convened by CARE in Morogoro, Tanzania, in August 2013 at which a 'regional charter on investing in water for smallholder farmers' was launched and an event in Addis Ababa to mark World Food Day convened by IWMI in October of the same year. Both events noted the serious challenges farmers in East Africa face given uncertain rainfall and a host of other pressures on agroecological systems.

More widely, this also reflected a growing sense amongst water scientists, governments and all the players and consumers in private sector food supply chains that farmers play the major role in managing water and land on behalf of society. For this reason farmers need to be able to operate in circumstances which enable them to meet the food needs of society, and to steward the ecosystems of water, biodiversity and the atmosphere, they need infrastructure and the facility to operate effectively in markets for local to global levels.

Bearing these concerns in mind, the May 2014 meeting launched a process of developing this sourcebook after agreement that there was a pressing need for greater regional consolidation of knowledge on improving water management for smallholder farmers. The meeting allowed participants the opportunity to explore how an emerging concept of Water-Smart Agriculture (WaSA) could support future policy attention to and investment in this critical area. Developed further by participants at the meeting, WaSA provides the organizing framework for this volume, in particular drawing attention to the need for better packaging of support across a range of agroecologies in order to build interventions that are more effective in delivering sustainable benefits to farmers in the water, land and ecosystems in which they are situated.

Above all, WaSA recognizes that there is no simple solution in East Africa—or anywhere else—to the many challenges facing the smallholders. However, the approach argues that much can be achieved by using specific, tried and tested technologies and practices and learning about the costs and benefits of use in conjunction with farmers themselves. Many of these technologies and practices are already well-known and the key challenge lies in enabling wider uptake, including triggering 'early adoption' across communities through demonstration by farmers at a local level. In addition, there is a need to match these approaches with incentives and policies (including those related to markets, value chains and financial services) that support and encourage future farmer efforts.

This collection of articles develops further the WaSA approach in East Africa and is aimed at a distinct group of users: development managers, educators, local administrators and policy makers. These are people in a position to utilize practical research outputs and to encourage and enable future impact at scale at both local and national levels.

It is important to note that this sourcebook is not meant as a definitive collection, but rather a starting point for thinking and inspiring future efforts. In this regard, the editors hope that as the global community moves forward in 2015 towards agreeing a set of Sustainable Development Goals (SDGs) (in a year designated the International Year of Soils), WaSA can play some role in influencing the implementation of the SDGs and can contribute to ensuring that farmers in East Africa achieve greater productivity, food security, climate resilience, and ecosystem sustainability in the face of mounting development challenges.

Divided into five sections comprising key issue areas, the sourcebook adopts a simple system of tagging cross-cutting themes that supports the reading in linking between case study examples. The editors welcome feedback and suggestions on material that could complement existing examples.

As a critical contribution to the global challenge of agricultural water management for smallholder farmers, I commend this sourcebook to you and encourage its uptake and use.

Yours sincerely,

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15 March 2015

Introduction

Challenges facing farmers in the East Africa region

The value of farming is on the rise again. After years of neglect, smallholder farmers—the lynchpin of rural production—are resuming their position as a major focus for development (World Bank, 2013). In part, this reflects a broad international consensus[1] that land, soil, and water are part of an emerging 'critical nexus'[2] of issues facing the world's population. By mid-century, around 9 billion people will require food security and much of this will still be derived from rural production systems, placing these systems at the heart of the sustainable development agenda.[3] The high demand side driven by population growth is accompanied by uncertainty on the supply side: climate variability and associated rainfall extremes are changing farming practices, including those in East Africa (Kristjanson et al., 2012); already there are signs that future risk – and perception of risk – is shaping the current actions and decisions of rural populations. As atmospheric warming alters the boundaries of agroecologies and shifts the hydrological cycle, these impacts will intersect further with a range of other factors, including the spread of pests and vectors of human and livestock diseases. Political-institutional environments will, in turn, respond through policy in a range of sectors, shaping the ways in which future generations perceive and experience farming as a livelihood system.

Other secondary impacts that are part of this critical nexus and that may cause additional impacts on farm productivity include demand for biomass energy. Many East African landscapes are already severely denuded, with loss of tree cover to fuel household demand for energy to cook and heat rendering soils increasingly vulnerable to extreme weather events. A critical nexus of energy, water, food, and land issues is now at the hub of global policy debates and represents a form of 'wicked' problem requiring multidirectional and multilevel solutions (Allouche et al., 2014). Simple solutions will not work and context will be all-important, including the wider policy and support environment that can encourage greater gender equality, address rights issues and access to resources, and ensure that decision making at a local level is grounded in effective knowledge systems.

Currently, much global policy—including at a regional level in East Africa—emphasizes irrigation development to meet food demand. Whilst this is an important approach in some contexts, there are recognized limits to how far this can expand in many parts of the world.[4] By a large margin, most farming in East Africa and in many parts of the world is rainfed. Better management of rainfed agriculture and/or use of supplementary irrigation at an appropriate scale can achieve significant long-term impacts. This understanding is at the heart of the water-smart agriculture (WaSA) concept and forms the backbone of this sourcebook.[5] In its simplest sense, WaSA is an approach to farming that balances water availability, access, and use across the range of water sources, according to principles of socioeconomic, environmental, and technical sustainability. It seeks to maximize returns for farmers while protecting ecosystems and ensuring more equal outcomes within farming communities. Central to the concept is continuous learning through which farmer experience is increasingly part of action research approaches that feed back into decision making at local and national levels.

A core focus of WaSA is the crucial impact that women farmers in particular can have within learning-based approaches. This gendered dimension is central to WaSA. A recent report by the World Bank (2014) shows that a key hindrance to agricultural development and broader growth is the wide and pervasive gender gap in agricultural productivity. While women comprise nearly half of the labor force in Africa's agriculture sector, and more than half in several countries, on the whole, they produce less per hectare than men (World Bank 2014).

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[1] 2014 was the FAO International Year of Family Farming; the African Union Year of Agriculture and Food Security; and 2015 is the International Year of Soils.
[2] The idea of a 'critical nexus' emerges out of the related concepts of the water-food-energy nexus and 'nexus development'.
[3] http://www.ifad.org/events/gc/38/doc/conceptnote_e_web.pdf
[4] http://www.fao.org/fileadmin/user_upload/esag/docs/AT2050_revision_summary.pdf
[5] http://www.gwieastafrica.org/water-smart-agriculture-podcast/

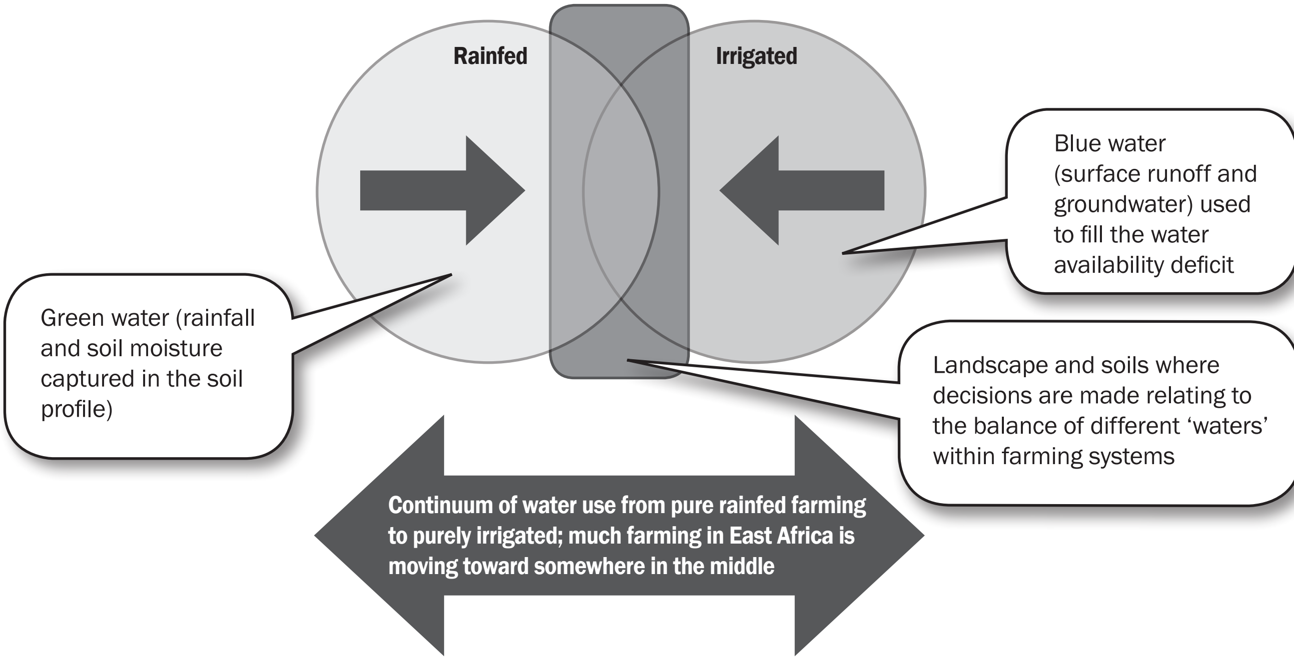

Fig. 1. *Water-smart agriculture conceptual model*

Water-smart agriculture *theory of change*

As a set of theoretical and practical approaches broadly nested under the term 'water-smart agriculture' (WaSA), this sourcebook complements materials on climate-smart agriculture but addresses the specific challenges and uncertainties surrounding water availability, access, and use, particularly within systems reliant on rainfall. In that sense it presents WaSA as a subset of CSA—and in some ways a more practical and tangible starting point to implementation. Many of the challenges facing farmers to adapt and increase resilience to a changing climate within landscapes either directly or indirectly are water-related, from capturing and storing uncertain rainfall and managing declining aquifers to supporting better soil moisture retention and crop use efficiency. Many choices relate to the range of storage and use options presented in Figure 2.

At the same time, these are not new challenges. Farmers in East Africa have been dealing with rainfall uncertainly for hundreds if not thousands of years. A crucial difference now is that institutional, policy, and communication environments have markedly changed in recent years and are now sufficient to enable substantial uptake and dissemination of new ideas and approaches, including across shorter time scales. Markets are now more accessible, information more readily acquired and shared—through mobile networks and the internet—and labor mobility is greater than ever. This provides opportunities for farmers to become more productive, generate greater returns from farming, and become advocates of new farming approaches – including WaSA. Within this more dynamic environment the sourcebook seeks to make a major difference by strengthening the environment of support for water management within smallholder farming systems.

The term 'water-smart agriculture' was coined by CARE during action research undertaken in the period 2013-2014. This was built on the undertakings included within a regional charter on *Investing in Water for Smallholder Agriculture* signed in Morogoro, Tanzania, in August 2013 by more than 40 government decision makers, civil society practitioners, journalists, and academic researchers—including the International Water Management Institute (IWMI) and Food and Agriculture Organization (FAO)[6]. These undertakings included 'enhancing the exchange of knowledge and evidence on best practices in agricultural water management

[6] http://www.gwieastafrica.org/media/GWI_RegionalCharter.pdf

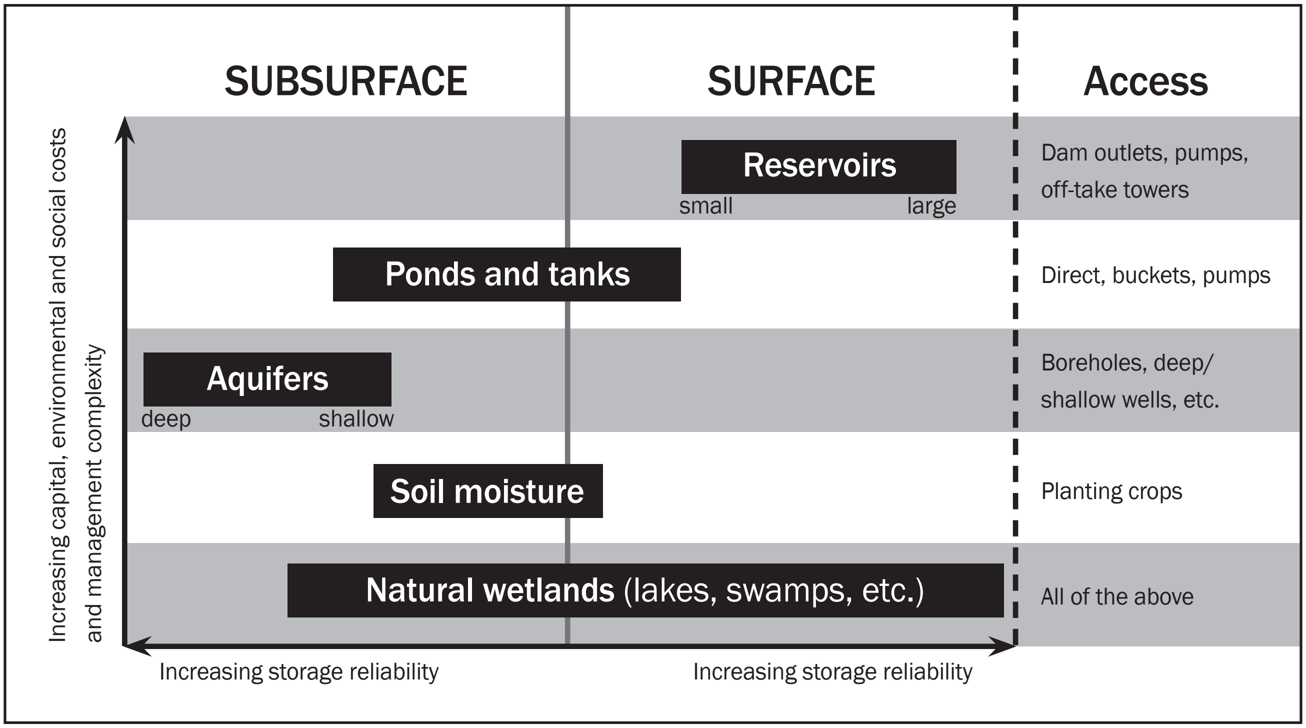

Fig. 2. *A continuum of water storage options. (Source: McCartney and Smakhtin)*

with a specific focus on the role of women farmers and empowering farmers as the ultimate decision makers through improving their knowledge, practices, skills, and potential to invest in their own futures.' Based on these undertakings, CARE with IWMI and Water, Land and Ecosystems (WLE) developed further the WaSA concept at a regional meeting in May 2014 and agreed to make it the centerpiece of this sourcebook. Ultimately, 'water-smart agriculture' is about packaging the right choices effectively and helping farmers to help themselves through farmer-to-farmer uptake and dissemination. The theory of change presented here helps to highlight key features of the approach.

Effective packaging of inputs to agriculture is central to the theory of change. Different packages will seek a sustainable balance between rainfed and irrigated farming across agroecological contexts. In all cases, this is to be based on informed understanding of physical, social, and economic barriers and opportunities, including rainfall, soils, markets, technologies, methods of financing, and the capacities of individuals and institutions. The second core idea is that nothing should remain static. Learning (and through learning, disseminating best practice) should be a constant process. This sourcebook provides a starting point, drawing on good practices across different country and regional contexts, but is not an end point. While the material presented is based on practices drawn together at three writeshops held in Ethiopia, Tanzania, and Uganda and additional regional-level harvesting of the literature, the intention is to make this volume a way of kickstarting future consolidation of more best practice and experience that can be refined over time via a regional knowledge platform.

To date and based on the experiencing of developing WaSA, the following emerging 'WaSA principles' provide guidance on using the material within this book:

1. Maximizing outcomes that are owned locally: WaSA involves assisting farmers to identify and apply 'best fit' water management regimes that improve water capture, storage, and use in given socioeconomic, technical, and agroecological environments. A central feature is ensuring that the ultimate water delivery vehicle – the soil system – is continually enhanced and supported to nourish crops, support livestock, and cater for other domestic and broader societal needs.

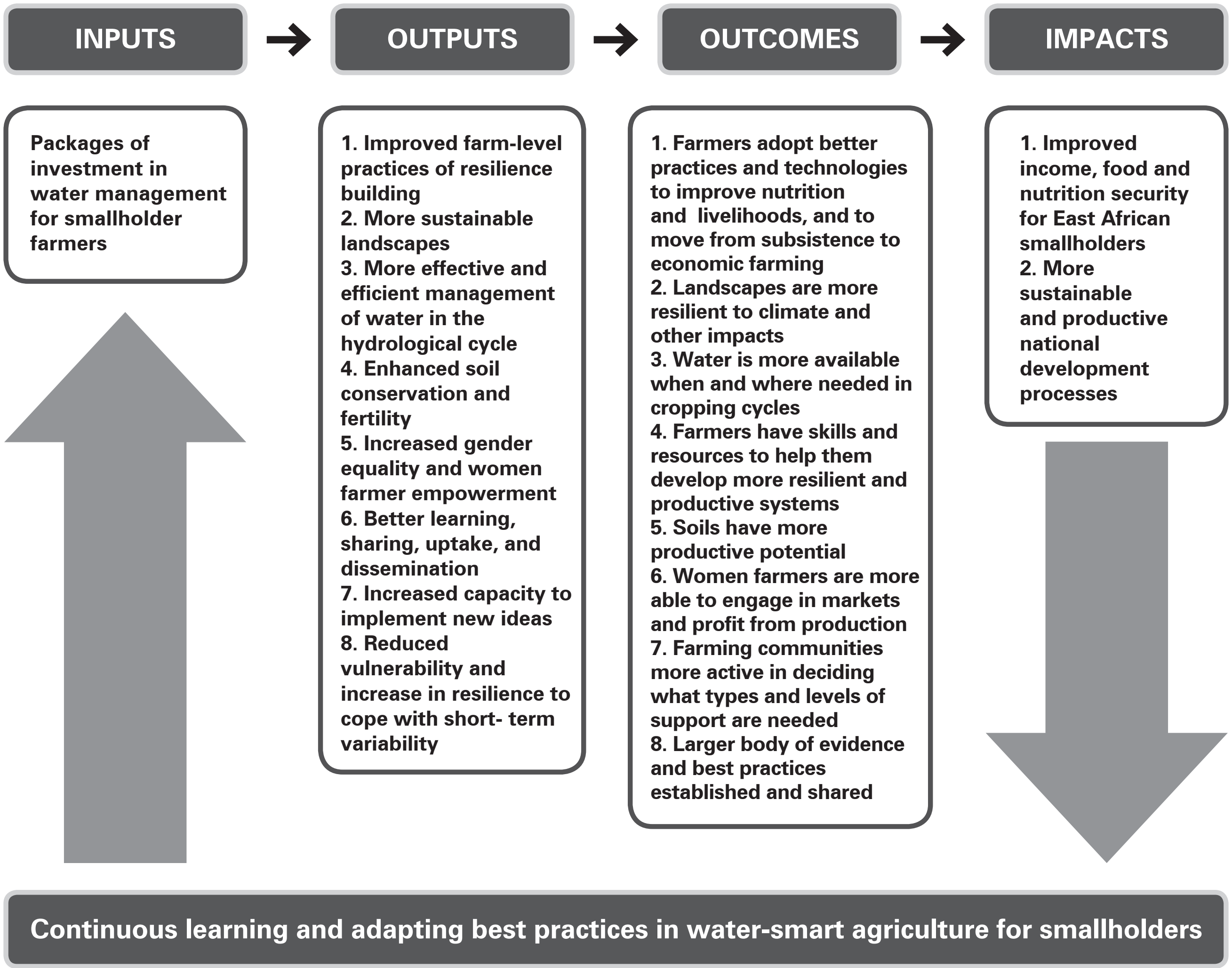

Fig. 3. *Water-smart agriculture theory of change*

2. Ensuring sustainability of resources: Water conservation and efficient use is central to WaSA, but so is bringing more water into farming systems in order to capture opportunities for value enhancement, including in dry seasons. Sustainability at scale means ensuring that resource utilization does not have a negative impact on other users and uses (e.g., household supplies and ecosystem flows). Importantly, it also recognizes the interactions of supply and demand at a landscape level recognizing water as a common pooled resource in many agricultural communities.

3. Transitioning to prosperity: WaSA is about using water more effectively and equitably to reduce risk and enhance farmer resilience. But it is also about enabling transitions through seizing opportunities to shift from low input-output (and frequently subsistence-based) farming to more profitable and food-secure systems that generate increased net returns to farm households. A central core of WaSA is the conviction that better water management now provides a key to unlocking future farmer prosperity.

4. Building in learning and sharing: A key part of the 'smart' in WaSA is shared learning on what works within and between different farming contexts. Learning based on action research with farmers, nested within learning and practice alliances, farmer field schools, and/or other forms of institutional innovation, is critical to precipitating the changes described above and to ensuring the continual refining of different WaSA 'package' approaches. With the advent of smart phone technology and rapid uptake in rural areas of East Africa, major advances in sharing practice can take place at relatively low cost. This will help to create, maintain, and evolve best practice, inform policy and continually meet evolving needs in East Africa and further afield.

Toward the practice of WaSA in East Africa

Above all, this sourcebook is about supporting the practical uptake of WaSA in East Africa. For clarity, the sourcebook is divided into five sections: Building Resilience, Sustaining Landscapes, Managing Water, Conserving Soils, and Addressing Learning and Complexity. This subdivision is based on the materials produced at three writeshops supplemented by selected supporting literature that is more regional in outlook and provides a broader context to the case study material. While there is no one model presented of what to do, the following outcomes can help shape choices made in moving to the practice of WaSA in East Africa:

- **empower farmers**—and those working with them—to address water-related risks, capture opportunities for dry-season production, strengthen and share new knowledge, skills, and other capacities, and instill stronger governance of water (and soils) in each local context, leading, in the long-term, to the wider public good of enhanced water availability for all watershed and ecosystem users;
- **accelerate gains in production** based on principles of sustainable intensification, producing more but at the same time ensuring more efficient utilization of rainfall (e.g., higher production from available rainfall) before seeking additional water from other sources;
- **improve soil health** by applying principles of good soil 'governance,' including soil and water conservation and landscape management in order to benefit from enhanced water storage, greater soil fertility, and, ultimately, more nutritional value from crop production;
- **support collective action at the watershed scale and establish good water governance** so that water savings made in agriculture can be allocated in ways that will strengthen water security for all, including reducing potential conflict between upstream and downstream users within shared watersheds; and, in addition, conserve and enhance the services provided by ecosystems that support food security and underpin future sustainable agriculture.

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Building Resilience

1

Climate Change, Water, and Food Security

The food price crisis of 2008 has led to the reemergence of debates about global food security (Wiggins, 2008) and its impact on prospects for achieving the first millennium development goal (MDG): to end poverty and hunger. On top of a number of shorter term triggers leading to volatile food prices, the longer term negative impacts of climate change need to be taken very seriously.

Smallholder agriculture, water, and climate change

Smallholder farmers (including herders and fishers) make up the majority of the world's poor people. The International Fund for Agricultural Development (IFAD) estimates that there are 1.2 billion people who cannot meet their most basic needs for sufficient food every day (IFAD, n.d.). Of these, the largest segment comprises the 800 million poor women, men and children, often belonging to indigenous populations, who live in rural environments and try to make a living as subsistence farmers and herders, fishers, migrant workers, or artisans. They often occupy marginal lands and depend heavily on rainfed production systems that are particularly susceptible to droughts, floods, and shifts in markets and prices. Hence, strategies to reduce rural poverty will depend largely on improved water management in agriculture.

For both rainfed and irrigated agriculture, the spatial and temporal variation of precipitation is key. The short-term variability of rainfall is a major risk factor. Soil moisture deficits, crop damage, and crop disease are all driven by rainfall and associated humidity. The variability in rainfall intensity and duration makes the performance of agricultural systems in relation to long–term climate trends very difficult to anticipate. This is particularly the case for rainfed production.

Although the different climate change models are not clear with respect to rainfall and periods of drought, temperature projections are generally more reliable. Increased evaporation and evapotranspiration with associated soil-moisture deficits will have impact on rainfed agriculture (Bates *et al.,* 2008). Recent estimates show that for each 1°C rise in average temperature, dryland farm profits in Africa will drop by nearly 10% (FAO, 2008b). In addition, increased evaporation of open water storage can be expected to reduce water availability for irrigation and hydropower generation.

Despite considerable uncertainty related to the impacts of climate change in Africa, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPPC) predicts decreasing rainfall in northern and southern Africa, increasing rainfall over the Ethiopian/East African highlands, and a considerable increase in frequency of floods and drought.

Food security concerns

The Food and Agriculture Organization of the United Nations (FAO) defines food security as the situation when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO, 2002). Food security is not narrowly defined as whether food is available, but whether the monetary and nonmonetary resources at the disposal of the population are sufficient to allow everyone access to adequate quantities and qualities of food (Schmidhuber and Tubiello, 2007). All dimensions of food security are likely to be affected by climate change (Box 1). Importantly, food security will depend not only on climate and socioeconomic impacts on food production, but also (and critically so) on economic growth, changes to trade flows, stocks, and food aid policy.

Water, food security, and livelihoods

A number of countries in sub-Saharan Africa (SSA) already experience considerable water stress as a result of insufficient and unreliable rainfall, changing rainfall patterns, or flooding. The impacts of climate change—including predicted increases in extremes—are likely to add to this stress, leading to additional pressure on water availability, accessibility, supply, and demand. For Africa, it is estimated that 25% of the population (approximately 200 million people) currently experience water stress, with more countries expected to face high risks in the future. This may, in turn, lead to increased food and water insecurity for at-risk populations, undermining growth.

It is estimated that the net balance of changes in the cereal production potential of SSA resulting from climate change will be negative, with net losses of up to 12%. Overall, approximately 40% of SSA countries will be at risk of significant declines in crop and pasture production due to climate change (Fischer *et al.,* 2005; Shah *et al.,* 2008).

FAO (2008a) estimates that, in 2007, almost 850 million people were undernourished. Climate change is expected to increase the number of undernourished people by between 35 and 170 million people in 2080, depending on projected development paths (Shah *et al.,* 2008).

In addition to farming areas, many of the world's rangelands are in semiarid areas and susceptible to water deficits; any further decline in water resources will greatly impact carrying capacity. As a result, increased climate variability and droughts may lead to significant livestock loss.

Food security and rural livelihoods are intrinsically linked to water availability and use. Food security is determined by the options people have to secure access to own agricultural production and exchange opportunities. These opportunities are influenced by access to water.

Making these water-livelihood linkages is important for a more complete understanding of the nature of vulnerability of households to climate-related hazards such as drought, and the multifaceted impacts that water security has on food and livelihood security.

Box 1. *Climate change affects all four dimensions of food security*

Food production and availability: Climate affects food production directly through changes in agro-ecological conditions and indirectly by affecting growth and distribution of incomes, and thus demand for agricultural produce. Changes in land suitability, potential yields (e.g., CO_2 fertilization) and production of current cultivars are likely. Shifts in land suitability are likely to lead to increases in suitable cropland in higher latitudes and declines of potential cropland in lower latitudes.

Stability of food supplies: Weather conditions are expected to become more variable than at present, with increasing frequency and severity of extreme events. Greater fluctuation in crop yields and local food supplies can adversely affect the stability of food supplies and food security. Climatic fluctuations will be most pronounced in semiarid and subhumid regions and are likely to reduce crop yields and livestock numbers and productivity. As these areas are mostly in sub-Saharan Africa and South Asia, the poorest regions with the highest levels of chronic undernourishment will be exposed to the highest degree of instability.

Access to food: Access to food refers to the ability of individuals, communities, and countries to purchase food in sufficient quantity and quality. Falling real prices for food and rising real incomes over the last 30 years have led to substantial improvements in access to food in many developing countries. Possible food price increases and declining rates of income growth resulting from climate change may reverse this trend.

Food utilization: Climate change may initiate a vicious circle where infectious diseases, including water-borne diseases, cause or compound hunger, which, in turn, makes the affected population more susceptible to those diseases. Results may include declines in labor productivity and an increase in poverty, morbidity, and mortality.

Source: Schmidhuber and Tubiello (2007).

In order to highlight such linkages, there has been a move in recent years toward looking at water issues through sustainable livelihood frameworks (Calow, 2002; Nicol and Slaymaker, 2003).

One main feature of climate change adaptation at the local level is its attempt to increase the resilience of populations to climate-related hazards. This means assessing the populations at risk of water and food insecurity. Risk is determined by, first, the external hazard and, second, the characteristics of the population that increase or decrease their susceptibility to the harm caused by the hazard.

Vulnerability is dependent on the nature of the hazard. Vulnerability is not the same thing as poverty, nor is poverty the same as vulnerability. Similarly, risks overlap with poverty, but they are not synonymous. All people face risks—the point is how people, especially the poor, are able to deal with them (Ludi and Bird, 2007).

Identifying populations that are vulnerable to current and future climatic hazards and conditions requires an understanding, therefore, of the climatic hazards that populations will most likely face, as well as an understanding of the specific livelihood capitals (or 'entitlements') that determine the 'internal' characteristics of the population.

Increasing the understanding of water use and livelihood strategies is key in the assessment of water stress and drought impacts and, as such, will be key in the assessment of climate change impacts. The concept of 'water security' is increasingly used to describe the outcome of the relationship between the availability of water, its accessibility, and use. Water security is defined as 'availability of, and access to, water in sufficient quantity and quality to meet livelihood needs of all households throughout the year, without prejudicing the needs of other users' (Calow *et al.,* n.d.).

Calow *et al.* (n.d.) distinguish three links between water, health, production, and household income. First, lack of access to adequate water supply, both in quality and quantity, for domestic uses can be a major cause of declining nutritional status and of disease and morbidity. Second, domestic water is often a production input. Such production is essential for direct household consumption and/or income generation. Third, the amount of time used to collect water, and related health hazards, can be immense, especially for women and girls, and has been well documented (e.g., Magrath and Tesfu, 2006).

Climate change adaptation to enhance food and water security

Adaptation to climate change impacts should not be approached as a separate activity, isolated from other environmental and socioeconomic concerns that also impact on the development opportunities of poor people (OECD, 2003). In countries where the majority of poor people depend on agricultural income, proposed climate change adaptation strategies center around increasing agricultural productivity and making agriculture, including livestock, fishery, and forestry, less vulnerable to climate stress and shocks.

Water management for agricultural production is a critical component that needs to adapt in the face of both climate and socioeconomic pressures in the coming decades. Changes in water use will be driven by the combined effects of (i) changes in water availability, (ii) changes in water demand for agriculture, as well as from competing sectors including urban development and industrialization, and (iii) changes in water management.

With regard to agricultural production and water, climate change adaptation may include (Bates *et al.*, 2008):

- adoption of varieties and species of crops with increased resistance to heat stress, shock, and drought. For example, a private-public partnership under the leadership of the African Agricultural Technology Foundation called Water–Efficient Maize for Africa (WEMA) intends to develop drought-tolerant African maize. This initiative, though, is not uncontested as it uses biotechnology besides conventional breeding and marker-assisted breeding techniques (www.aatf-africa.org);
- modification of irrigation techniques, including amount, timing, or technology (e.g., drip irrigation systems);
- adoption of water-efficient technologies to 'harvest' water, conserve soil moisture (e.g., crop residue retention, zero-tillage), and reduce siltation and saltwater intrusion;
- improved water management to prevent waterlogging, erosion, and nutrient leaching;
- modification of crop calendars, i.e., timing or location of cropping activities;
- integration of the crop, livestock, forestry, and fishery sectors at farm and catchment -levels;
- implementation of seasonal climate forecasting;
- additional adaptation strategies may involve land–use changes that take advantage of modified agroclimatic conditions.

Water-related adaptation strategies will also affect the livestock subsector. Adaptation strategies include improved rotation of pastures, modification of times of grazing, changing animal species and breeds, integration of crop and livestock systems, including the use of adapted forage crops, and provision of adequate water supplies.

Land users and rural communities already adapt autonomously their land management practices to a number of political, economic, social, environmental, and climatic changes. Depending on perceived or real changes in climate, they will continue to do so. Part of this adaptation, however, is likely to be maladaptation such as clearing forest land to gain additional arable land; increasing the cultivation of marginal land such as steep slopes leading to increased soil erosion; adoption of unsustainable cultivation practices as a result of dropping yields; introduction of new (exotic) plant and animal species; or more intensive use of chemical inputs leading to pollution. All of these may increase land degradation and endanger biodiversity, possibly reducing the ability to respond to increasing climate risk in the future. It is widely believed and many climate change national adaptation plans (NAPAs) emphasize that irrigation will be a major adaptation approach in the agricultural sector. The problem with this strategy, however, is that adaptation practices that involve increased irrigation water use may place additional stress on water and environmental resources on the one hand, and may be influenced by changes in water availability resulting from climate change on the other.

The IPCC (Bates *et al.*, 2008) concludes that, if widely adopted, adaptation strategies in agricultural production systems have a substantial potential to offset negative climate change impacts and can even take advantage of positive ones. At the same time, they can contribute to an increase in agricultural production sustainably.

They further conclude, however, that not much is known about how effective and widely adopted the different adaptation strategies really are. Reasons for this include complex decision making processes; the diversity of responses across regions; time lags in implementation; and possible economic, institutional, and cultural barriers to change. Government support that would help poor smallholders to adapt is very limited. On top of this, developing countries have received less than 10% of the money promised by rich countries to help them adapt to global warming (Vidal, 2009).

Policy attention by national governments and transnational bodies will, increasingly, have to focus on the coordination of water uses across transboundary riverbasins and across different sectors and arbitration in increasing conflicts over water.

If precipitation decreases and the demand for additional irrigation water is to be satisfied, then other demands (e.g., manufacturing, industry, urban consumption, etc.) will become much more difficult to satisfy. Climate change and increased water demand for agriculture in future decades are anticipated to be an added challenge to transboundary framework agreements, increasing the potential for conflict.

Unilateral measures for adapting to climate change-related water shortages by, for example, increasing storage capacity upstream, increasing investment in irrigation infrastructure and efficient water-use technologies, or revising land tenure and land use arrangements, can lead to increased competition for water resources. Regulation at both national and transnational levels must therefore be enhanced to deal with increased upstream water use that deprives downstream users of the water they depend on for their livelihoods.

Conclusions

A number of adaptation options in agriculture face a dilemma. Increasing water availability and increasing the reliability of water in agriculture, (i.e., through irrigation) is one of the preferred options to increase productivity and contribute to poverty reduction. However, as a result of the predicted climate change, semiarid and subhumid tropical areas that would greatly benefit from increased irrigation may see water availability changing temporally and spatially and rainfall not only declining, but also being more erratic and unfavorably distributed over the growing season, so that irrigation in the long term might not be a viable option.

In addition, the interrelations between adaptation and mitigation need to be carefully considered (Bates *et al.*, 2008). At best, adaptation and mitigation strategies exhibit synergies. Positive examples include many carbon-sequestration practices involving reduced tillage, increased crop cover, including agroforestry, and use of improved rotation systems. These lead to production systems that are more resilient to climate variability, thus providing good adaptation in view of increased pressure on water and soil resources. In the worst case, they are counterproductive. In relation to water, examples of adaptation strategies that run counter to mitigation are those that depend on energy to deliver water and, therefore, produce additional greenhouse gas emissions. On the other hand, some mitigation strategies may have negative adaptation consequences, such as increasing the dependence on biofuel crops, which may compete for water and land resources, reduce biodiversity, and increase monocropping, increasing vulnerability to climatic extremes.

Short-term plans to address food insecurity, provide access to water resources, or encourage economic growth must be placed in the context of future climate change to ensure that short-term activities in a particular area do not increase vulnerability to climate change in the long term. Policy attention is needed in the following areas.

1. Developing long-term water policies and related strategies, taking into account country-specific legal, institutional, economic, social, physical, and environmental conditions (FAO, 2008c). Policies and strategies will also need to integrate the different sectors depending on water—rainfed and irrigated agriculture, livestock, fisheries, forestry, nature and biodiversity protection, manufacturing and industry, and municipal water use. Water policies need to address such issues as upstream-downstream competition over water resources and equitable allocation of water across regions and generations;
2. Increasing water productivity by promoting efficient irrigation and drainage systems;
3. Improved watershed and resource management, integrating the different natural resources—water,

soil, flora, and fauna—through, for example, the promotion of integrated water resource management processes;

4. Enhancing water availability through better use of groundwater storage, enhancing groundwater recharge where feasible, and increasing surface water storage. Given the current economic situation of many water-stressed countries, however, managing demand is equally important: reducing water consumption and improving water use efficiency;
5. Institutional and governance reforms that balance demand and supply across sectors and that mainstream climate change adaptation;
6. Enhancing stakeholder participation in water development and climate change adaptation;
7. Improve information and early warning systems to provide land and water users with timely and adequate information and knowledge about availability and suitability of resources to promote sustainable agriculture and prevent further environmental degradation. Information exchange and dialogue between the agriculture, water, and climate communities is vital (FAO, 2008c), not only at national levels but also at transboundary river basin levels;
8. Human resource, capacity, and skills development of policymakers and endusers to help them deal with new challenges;
9. Increase investments in agriculture and rural development. The 2003 Maputo Declaration called for African governments to target 10% of their national budget to the agricultural and rural development sector. This is clearly justified, given the overwhelming environmental, economic, and social importance of agriculture in SSA, the anticipated impacts of climate change on agriculture (especially in semiarid and sub-humid areas), and the role agriculture has to play in climate change adaptation and mitigation.

Source

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Mitigation and Adaptation Options in Relation to the Millennium Development Goals

Societies in developing countries are strongly vulnerable to climate changes because of their dependence on natural resources and agriculture and their limited adaptive capacity. Climate change may therefore aggravate persistent problems such as poverty. Agriculture is the most important economic sector in sub-Saharan Africa, accounting for about 20–30% of GDP and 55% of the total value of exports. Rainfed agriculture is highly sensitive to climate change if more frequent droughts but also floods occur. Also, it is expected that temperature rise will have negative effects on highly valued commodities such as coffee. Forestry and agriculture are often weakly developed, highly dependent on each other, and vulnerable to climate change. Generally, policies and measures are developed and implemented without thorough consideration of their relation to climate change.

Ethiopia expects a 2 to 4 degree increase in temperature and the Horn of Africa a 10–30% increase in precipitation by the end of the century.

Projections from global circulation models on climate change are generally consistent in predicting temperature rise across Africa but show large uncertainty about the magnitude and directions of changes in precipitation. The current climate in Ethiopia is highly variable and climate change projections predict large regional differences in both temperature and precipitation. The highlands will suffer the most from a temperature increase of about 4 degrees, while the lowlands expect a 2-3 degree increase. Predictions on future precipitation levels are difficult to make and various models predict inconsistent results. Most models, however, predict a 10–30% increase in precipitation, although projections on changes in the timing of this rainfall over the year are still unknown. Short–term climate change projections for the coming decades, however, are highly uncertain.

The National Adaptation Program of Action (NAPA) of Ethiopia

The adaptation strategies developed in the NAPA of Ethiopia mostly focus on agricultural landuse. Adaptation of water and other natural resource management is seen as the most urgent subject to anticipate climate change. Diversification of farm activities and off-farm extension may be candidates for adaptive measures. Mitigation strategies include projects such as community-based carbon sequestration and promotion of on-farm and homestead forestry and agroforestry practices.

Hot spot areas are those most sensitive to climate change. An example is Ethiopia's Central Rift Valley where climate change threatens both coffee production and pastoralism.

The Central Rift Valley is an important area that provides many commercially important natural resources, but land degradation has resulted in profound erosion problems and loss of biodiversity. Rehabilitation of *Acacia* forests will improve the provision of essential ecosystem goods and services. Coffee is considered to be relatively sensitive to future temperature change and adaptation strategies will need to be developed for coffee farming in Ethiopia. Many native tree species play an important role in nitrogen fixation in soils. Harvesting these trees without replanting or replanting with non-native tree species will lead to soil degradation and loss of productivity. The project will assess strategies for the provision of various ecosystem services from a climate adaptation and mitigation perspective.

Mitigation and adaptation options

According to the UN, poverty rates in developing countries are estimated to have fallen from 52% in 1981, 42% in 1990 to 26% in 2005. Over a 25-year period, the poverty rate in East Asia fell from nearly 80% to under 20%. In sub-Saharan Africa, however, the poverty rate remained constant at around 50% (UN MDG factsheet). Although many developing regions, between 1990 and 2006, were successful in halving the proportion of underweight children, sub-Saharan Africa is still making least progress in reducing child malnutrition. In Ethiopia, 23% of the population had less than one dollar per day for consumption and 47% of the children under 5 are severely underweight (UN MDG website).

Climate change is likely to further inhibit any development in Africa. Food production and agricultural practices may be threatened by more extreme climate events such as frequent droughts and floods. Access to safe drinking water can also be affected by such developments. The proportion of people with access to improved drinking water in Ethiopia has increased from 13% in 1990 to 42% in 2006, but this MDG target may also be jeopardized by climate change in the future.

The framework presented in this report is focused on land-use adaptation and mitigation strategies on climate change. Natural resource management and land-use change are crucial factors for sustainable development in a region and their contribution to the millennium goals. For example, the rate of deforestation has been fastest in some of the world's most biologically diverse regions and old–growth forest ecosystems, including sub-Saharan Africa. In Ethiopia, the forest area has been reduced from a 13.8% cover in 1990 to 11.9% in 2003 (UN MDG website). Forests play a crucial role in combating desertification and water and nutrient losses. Therefore, forest management is taken central in the development of both adaptation and mitigation options. Among others, actions suggested by the UN include ensuring effective conservation and management to reverse the loss of natural resources and significantly reduce biodiversity loss. This may be achieved by introducing measures or mechanisms to reduce global greenhouse gas emissions by assisting developing countries—especially in sub-Saharan Africa—to transform subsistence agriculture in order to ensure long-term, sustainable production and developing a more diversified economic base. This can be done by supporting research and development in yield-enhancing agricultural and climate change technologies and enhancing climate adaptation programs to reduce the negative impact of climate change.

Climate change and sustainable development

Numerous definitions of sustainable development exist and the 6th EU framework project LUPIS, from which parts of the framework are adopted, adjusted the definition of Brundtland's report 'Our common future' into the definition of sustainable development as 'the elimination of poverty of present and future generations through management of land and natural resources which avoids the risk of radical ecosystem change' (e.g., Verburg *et al.*, 2008).

Sustainable development in developing countries mainly includes social aspects such as equity, while in rich countries, environmental issues play a prominent role. The agricultural sector and rural areas in East Africa will be strongly affected by climate change. In the long run, environmental issues such as droughts, floods, and temperature rise will severely affect developments in equity and poverty reduction. Diversification of agricultural activities may help reduce vulnerability of rural societies to climate change, on one hand, by the production of different agricultural commodities with various demands for natural resources, like water, and on the other hand, by diversification of income.

Uncertainty and the science-policy interface

Climate change adaptation in the context of sustainable development must be understood through the perspective of systems thinking and complexity. The development of a framework that we attempt to offer in this paper tries to capture much of the systems involved. At the same time, we acknowledge the high levels of uncertainty in this system. On the one hand, these uncertainties include the poor predictability of climate change and its impact as shown in uncertainties of projections. On the other hand, there are uncertainties in the dynamics of the human systems involved.

The development of NAPAs or any other adaptation strategy or plan is driven by different institutions, including stakeholders ranging from government departments, research institutes, donors to civil society. These are understood to belong to multiple, evolving systems with unpredictable relationships, including informal and intangible dimensions in which power and politics play important roles.

Policymakers involved in the development of climate change adaptation strategies have to deal with these uncertainties. Science can assist policymakers to understand the complexities of climate change and the unknowns. However, the interface between science and policy is a challenging one. Policymakers often want to get quick and straightforward answers to problems, while researchers would want time to thoroughly investigate options to meet high scientific standards. Investing in the mutual understanding of both sides of the science-policy interface will help to decrease the challenges.

Source

This article was drawn from discussion and summary section of a wider report entitled *Climate change in East Africa. Towards a methodological framework on adaptation and mitigation strategies of natural resources.* By René Verburg, Eric Arets, Jan Verhagen, Catharien Terwisscha van Scheltinga, Fulco Ludwig, René Schils, and Jouwert van Geene. Alterra-report 2018. e-mail: info.alterra@wur.nl

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Vulnerabilities of Key Agriculture Sectors to Climate Change

Economic development, in particular poverty alleviation, is a major issue for many African countries, which may consider climate change as a negligible problem compared with the huge challenge of hunger and poverty. But, in recent years, it has become evident that climate change impacts might hinder the achievement of development goals in developing countries.

Several arguments for integrating climate change issues into development policies and thus reducing vulnerabilities have been framed by Davidson *et al.* (2003):

- Food production needs to double to meet the needs of an additional 3 billion people in the next 30 years. Climate change is projected to decrease agricultural productivity in the tropics and subtropics for almost any amount of warming.
- One-third of the world's population is now susceptible to water scarcity. Populations facing water scarcity will more than double over the next 30 years. Climate change is projected to decrease water availability in many (semi)arid regions.

- Wood fuel is the main source of fuel for one-third of the world's population. Wood demand is expected to double in the next 50 years. Climate change will make forest management more difficult due to increases in pests and fires.
- Today, 1,6 billion people are without electricity. Electricity demand in developing countries will increase three to five times over the next 30 years. Fuel-based electricity production will exacerbate climate change.

The following sections try to give an overview of possible vulnerabilities of economic sectors in East Africa to climate change.

Primary production

Agriculture, crop production, and food security

Various assessments of climate change impacts on agriculture in Africa state that certain agricultural areas might undergo negative changes (Mendelsohn *et al.*, 2000b).

The UNFCCC states with respect to food security in Africa that, due to climate change, yields from rainfed crops could be halved by 2020 in some countries. Net revenues from crops could fall by 90% by 2100 (UNFCCC, 2007).

Detailed scientific research on potential crop losses due to climate change in East Africa is still lacking. However, East Africa's strong dependence on rainfed agriculture and the resulting vulnerability to climate change makes crop impact assessment a top priority.

In East Africa, the link between climate and livelihood is very strong. As East Africa depends heavily on rainfed agriculture, rural livelihoods are highly vulnerable to climate variability such as shifts in growing season conditions (WWF, 2006; IPCC, 2001). Furthermore, agriculture contributes 40% of the region's GDP and provides a living for 80% of East Africans (IFPRI, 2004). Due to temperature increase in the region and precipitation decrease in some areas, impacts can already be observed. For instance, from 1996 to 2003, a decline in rainfall of 50-150 mm per season (March to May) led to a corresponding decline in long–cycle crops (e.g., slowly maturing varieties of sorghum and maize) across most of eastern Africa (Funk *et al.*, 2005). Long-cycle crops depend upon rain during this typically wet season and progressive moisture deficit results in low crop yields in the fall, thereby impacting the available food supply (WWF, 2006).

According to the FAO State of Food Insecurity Report (2004), all East African countries suffered from weather-related food emergencies in 2003-2004, and can therefore be considered as vulnerable to the impact of climate change on their agriculture. Uganda also had to face the same challenge, but the food insecurity in Uganda was caused more by conflicts than by weather events (FAO, 2004; Funk *et al.*, 2005).

Some specific studies and analysis on potential impacts of climate change on crops in East Africa are available.

It is reported for Tanzania that, in the same farming system, positive and negative impacts may occur on different crops. It is suggested that impacts on maize, the main food crop, will be strongly negative for the Tanzanian smallholder, while impacts on coffee and cotton, significant cash crops, may be positive (Agrawala *et al.*, 2003).

In Kenya, a 1-m sea-level rise would cause losses of almost US$500 million for three crops (mangoes, cashew nuts, and coconuts) (Republic of Kenya, 2002). In the tea-producing regions of Kenya, a small temperature increase of 1.2°C and the resulting changes in precipitation, soil moisture, and water irrigation could cause large areas of land that now support tea cultivation to be largely unusable. As Kenya is the world's second largest exporter of tea, accounting for roughly 25% of export earnings and employing about 3 million people (10% of the population), the economic impact could be tremendous (Simms, 2005; WWF, 2006).

The Ugandan National Adaptation Program for Action demonstrates the dramatic impact that a 2°C temperature rise might have on coffee-growing areas in Uganda. The analysis indicates that most areas could become unsuitable for coffee growing.

Livestock production

Research on the impact of climate change on livestock farming in Africa has recently been conducted by Seo and Mendelsohn (2006a,b as cited in IPCC, 2007).

These are their results:

- In case of a 2.5 C° temperature rise, the income of small livestock farms could increase by 26% (+US$1.4 billion), in particular due to stock expansion.
- Further increases in temperature, however, would then lead to a gradual fall in net revenue per animal.
- A warming of 5°C would probably increase the income of small livestock farms by about 58% (+US$3.2 billion), largely as a result of stock increases.
- However, a warming of 2.5°C would be likely to decrease the income of large livestock farms by 22%(–US$13 billion).
- A warming of 5°C would probably reduce income by as much as 35% (–US$20 billion), resulting both from a decline in the number of stock and a reduction in the net revenue per animal.
- Increased precipitation of 14% would likely reduce the income of small livestock farms by 10%(–US$ 0.6 billion), mostly due to a reduction in the number of animals kept.
- The same reduction in precipitation would be likely to reduce the income of large livestock farms by about 9% (–US$5 billion) due to a reduction both in stock numbers and in net revenue per animal.

The study by Seo and Mendelsohn (2006a) also indicates that higher temperatures are beneficial to small farms that keep goats and sheep because it is easy to substitute animals that are heat-tolerant. Large farms, however, are more dependent on species such as cattle, which are not heat-tolerant. Increased precipitation is likely to be harmful to grazing animals because it implies a shift from grassland to forests, an increase in harmful disease vectors, and also a shift from livestock to crops (IPCC, 2007).

Detailed research on livestock vulnerability in East Africa is lacking and impact assessments should be carried out.

An example of impact of climate change on livestock in East Africa is given in the NAPA of Uganda. The subdivision of the Ugandan climate is reflected in the distribution of natural resources such as water, forest, and vegetation. The so-called cattle corridor lies in the semiarid climate zone and is predominantly a pastoral area, although rainfall is sufficient to support the growing of food for consumption in the area and neighboring regions.

The cattle corridor, stretching from the northeast to the southwest of Uganda, is a fragile ecosystem and depends on rainwater for human consumption and production. The prolonged and severe drought of 1999–2000 and the resulting water shortage led to loss of animals, low production of milk, food insecurity, increased food prices, and generally negative effects on the economy (NAPA Uganda, 2007).

Fisheries

Fisheries represent a significant source of revenue, employment, and proteins for all East African countries. Climate change may have an impact on fisheries as has been demonstrated for Lake Tanganyika by O'Reilly *et al.* (2003). They conclude that primary productivity in Lake Tanganyika may have decreased by as much as 20% over the past 200 years. Recent declines in fish abundance in East African Rift Valley lakes have also been linked to climatic impact on lake ecosystems (O'Reilly, 2007).

As many tropical fish have a critical thermal maxima beyond which they are unable to survive, climate change may also impact fisheries in East Africa (WWF, 2006). Many tropical fish can indeed endure temperatures that are close to their temperature threshold. A 1 to 2°C increase, however, may exceed these limits, in particular for populations that currently exist in thermally marginal habitats (Roessig *et al.*, 2004). However, because there are little data on the ability of these species to adjust their tolerance for water temperature, their response to climate change is largely unknown (WWF, 2006).

Although the impact of climate change on fisheries is likely to be significant, it clearly needs to be assessed together with other human activities, including impacts that may arise from governance of fresh and marine waters (AMCEN/UNEP, 2002). Furthermore, other factors depleting fish resources should be taken into account, such as pollution and overfishing.

Source

This article is drawn from a wider discussion in *Economic Impact of Climate Change in the East African Community (EAC)* by Josef Seitz, Global21 Consulting Toulouse/France and Dr. Wilfred Nyangena, School of Economics. Nairobi, Kenya. Final Report, 14 August 2009. Global 21 Consulting.

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Ecosystem Services and Resilience

Rising demand for food and upward trends in resource-intensive consumption are intensifying pressure on the world's food production systems (Garnett *et al.,* 2013; Bommarco *et al.,* 2013). Agriculture now accounts for 38% of the global land area (FAO 2011a) and provides employment for 31% of the world's employed people (World Bank 2014). Yet, an estimated 842 million people worldwide suffered from chronic hunger (FAO 2013), which means that they do not have enough food to lead an active life.

Industrial methods of agriculture have significantly increased crop yields per unit area (Bommarco *et al*., 2013). This has helped to meet the world's food needs, but has led to severe environmental impacts, including global biodiversity loss, and water and land degradation (Foley *et al*., 2011). As pressure on land, water and energy increases, the expansion of industrial agriculture becomes a less viable option. At the same time, less-intensive, smallholder agriculture alone cannot produce the yields that are needed to satisfy the world's growing demand for food. In order to feed the growing human population, changes are needed to the way in which we produce, distribute and consume food.

Sustainable intensification of agriculture has emerged as one promising response to these challenges, where discussions focus on increasing food production in ways that do not undermine the natural resource base upon which this production depends. There have been recent attempts to define, more precisely, what sustainable intensification means (see, for example, Garnett *et al*., 2013) and understand how it might be achieved (Poppy *et al*., 2014). It is also recognized that increasing production will not, on its own, be sufficient to increase food security (Loos *et al*., 2014), and must be combined with efforts to achieve more equitable distribution of food and improve consumption patterns. Indeed, as much as one-third of the food produced may be lost or wasted, globally, through inefficient harvesting, storage and processing of food, as well as market and consumer behavior (FAO 2011b).

WLE proposes efforts to intensify agriculture shift to focus on increasing food and livelihood security through the creation of resilient socio-ecological systems that secure the sustainable provision and equitable distribution of ecosystem services. Our priority is to increase food and livelihood security for the world's poor by enhancing the sustainability and equity in the provision of ecosystem services – and securing the natural resource base that underpins these services – that flow to and from agriculture and provide monetary, health, and well-being benefits to people. There are potentially substantial benefits to people from the improved management of ecosystem service flows; as an indication, between 1997 and 2011, the losses to ecosystem services due to land-use change are estimated to be between USD 4.3 and USD 20.2 trillion per year (Costanza *et al*., 2014). WLE seeks to understand how, when and where selected ecosystem services can be sustainably harnessed in agricultural systems and landscapes to unleash their potential and deliver positive outcomes for development. Our rationale for producing this ESR Framework is to specify the ESR core theme's research priorities and to provide a conceptual framework to WLE and its partners for applying ecosystem service and resilience science to achieve development outcomes.

Goals and objectives

The main goal of this ESR Framework is to help WLE achieve its Intermediate Development Outcomes (IDOs) and CGIAR's System-Level Outcomes (Table 1) by demonstrating how ecosystem services and resilience serve as key research for development themes.

The central hypothesis of this ESR Framework is that ecosystem service stocks and flows in agricultural landscapes can be managed to contribute to these development outcomes, and resilience concepts can help guide this process. While the concept of ecosystem services is in itself a topic of debate (Schröter *et al*., 2014), in section 3 on Applying ecosystem services and resilience concepts to achieve development outcomes, we discuss the mounting evidence indicating that good management of ecosystem service flows to and from agriculture can improve human well-being in agricultural landscapes, increasing food and livelihood security. In this way, we seek to meet our objective of providing a conceptual framework and presenting the existing evidence base for applying ecosystem service and resilience science to achieve development outcomes.

Table 1. *CGIAR System-Level Outcomes (SLOs) and WLE Intermediate Development Outcomes (IDO).*

CGIAR System-Level Outcomes (SLO)	WLE Intermediate Development Outcomes (IDO)
A. Reducing rural poverty	1. **Productivity:** Improve land, water and energy productivity in rainfed and irrigated agroecosystems.
B. Increasing food security	2. **Income:** Generate increased and more equitable income from agricultural and natural resource management, and ecosystem services in rural and peri-urban areas.
C. Improving human nutrition and health	3. **Gender and equity:** Enhance the decision-making power of women and marginalized groups, and increase the benefits derived from agricultural and natural resources.
D. Sustainable management of natural resources	4. **Adaptation:** Increase the ability of low-income communities to adapt to environmental and economic variability, demographic shifts, shocks and long-term changes.
	5. **Environment:** Increase the resilience of communities through enhanced ecosystem services in agricultural landscapes.

Applying ecosystem service and resilience concepts to achieve development outcomes

The ESR core theme's vision is for ecosystem service management interventions that deliver multifunctional agricultural landscapes, where communities are supported by the multiple ecosystem services and associated benefits provided by natural and agricultural systems in these landscapes. To achieve this vision, we ask: how, when and where can ecosystem service management be used to create and sustain resilient socio-ecological systems and deliver positive impacts on food and livelihood security?

The ESR Framework is centered on the notion that people can manage ecosystem service flows through agricultural systems and landscapes in ways that achieve positive outcomes for human well-being, notably poverty reduction and increased food and livelihood security. WLE suggests that resilience be used as a guide for studying the stability of agricultural systems and the ecosystem services on which communities depend. In this document, we refer to this notion of ecosystem service management guided by resilience thinking as the ESR approach.

Ecosystem condition and the stock and flow of ecosystem services impact directly on human well-being. Scientists are working to better understand which factors determine the type and severity of these impacts, such as whether changes to the supply of one ecosystem service – notably food - has more significant impacts on human well-being than changes to another; whether timelags mask the impact of ecosystem service decline on human well-being; and whether technological and social advances can improve use efficiency and provide substitutes to ecosystem services to the extent that ecosystem degradation and human well-being are decoupled (Raudsepp-Hearne *et al*., 2010).

To achieve positive impacts on human well-being, WLE scientists research the: (i) ecosystem structures and functions that underpin service provision; (ii) threats and critical thresholds affecting this ecosystem service supply; (iii) type and distribution of and trade-offs between ecosystem services across and between landscapes under different management regimes; (iv) the effect of different governance mechanisms and institutional structures on the availability of ecosystem services and their benefits to different beneficiary groups; (v) indicators and metrics for monitoring the impacts and outcomes of changes to ecosystem service flows on ecosystems and people.

WLE seeks to inform large-scale intervention decisions that have cross-scale and cross-level impacts on ecosystem service flows to and from agriculture. This includes large-scale decisions in planning (e.g. development allocations), energy (e.g. design and location of hydropower systems), agriculture (e.g. investment in irrigation infrastructure), conservation (e.g. habitat restoration and protection) and hazard mitigation (e.g. flood control). WLE engages with decision stakeholders to understand their information needs and the constraints to ecosystem service management, where decision-stakeholders typically include national and local governance institutes and their policy advisors, investors, community groups, farmer representatives, and conservation and development NGOs. Engaging these stakeholders is critical for ensuring ESR research is demand-driven and focused on closing knowledge and method gaps in all phases of decision-making.

Conceptual basis

CBD (1992) defines an ecosystem as "a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit." Biophysical structures and processes in an ecosystem can have functions that provide a service – something that is useful - to people (Haines-Young and Potschin, 2010). We use the definition of ecosystem services advanced by Walker and Salt (2006), with our additions shown in parenthesis: "the combined actions of the species [and physical processes] in an ecosystem that perform functions of value to society." This definition highlights that ecosystem services are about the benefits that ecosystems provide to people, and captures the notion that the biological and physical characteristics of a system underpin the delivery of ecosystem services. Similar to TEEB (2010), we classify ecosystem services as provisioning, regulating, habitat and cultural services, where:

- PROVISIONING services refer mainly to goods that can be directly consumed, and include food, water, raw materials, such as fibre and biofuel, and genetic, medicinal and ornamental resources.

- REGULATING services comprise regulation of climate, air quality, nutrient cycles and water flows; moderation of extreme events; treatment of waste – including water purification; preventing erosion; maintaining soil fertility; pollination; and biological controls, such as pests and diseases.
- HABITAT services are those that maintain the life cycles of species or maintain genetic diversity, through quality and quantity of suitable habitat, e.g., natural vegetation that enables the natural selection of species to maintain a diverse gene-pool or which service as a source of pollinator and pest control agents. These types of habitats benefit people primarily by maintaining stocks and flows of biodiversity, which underpin and ensure the resilience of many of the provisioning, regulating and cultural services provided by ecosystems.
- CULTURAL services refer to the aesthetic, recreational and tourism, inspirational, spiritual, cognitive development and mental health services provided by ecosystems. Figure 1 illustrates some of the ecosystem services provided by different landuse and management choices in an agricultural landscape.

The complex relationship between ecological processes, functions and ecosystem service delivery is gradually becoming clearer, although research

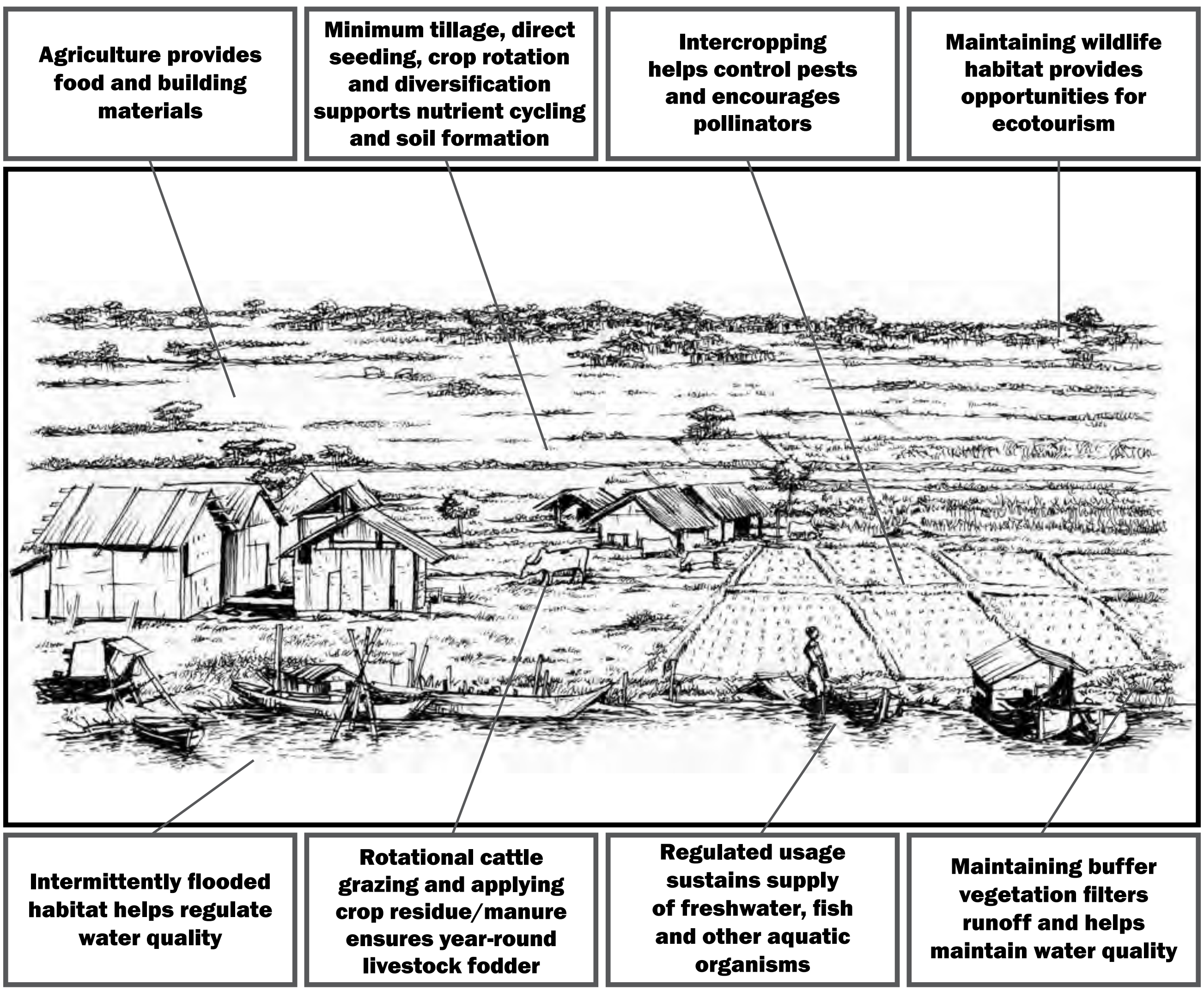

Fig. 1. Examples of ecosystem services that should be valued and bolstered in an agricultural landscape of Kampong Chhnang, Cambodia. WLE's vision for agricultural intensification include interventions that enhance these services to increase food quantity, quality and accessibility, and improve livelihood security. Source: WorldFish/E. Baran.

still needs to be carried out to strengthen this understanding. For example, soil biota in ecological systems are often disregarded, and yet they play fundamental roles in driving ecological processes that lead to ecosystem goods and services, upon which human civilization totally depends on (Lavelle *et al*., 2006). The array of ecosystem processes to which soil invertebrates make fundamental contributions include: i) increased soil porosity → water infiltration → water availability for agriculture; and ii) decomposition and humification → nutrient cycling → nutrient availability for crop and pasture growth (Lavelle *et al*., 2006; Bottinelli *et al*., 2014). However, while the linkages between soil biological diversity and ecosystem services are generally accepted, the task of attributing particular ecological functions to particular species, assemblages or even ecosystems remains a difficult one. In light of the ongoing work needed to disentangle the structures, processes and functions underpinning the provision of ecosystem services, mimicking the structure of natural ecosystems in managed agricultural systems seems likely to be the surest route to securing sustainable and resilient systems.

WLE considers agricultural systems to include the cultivation of crops and livestock production on land (agriculture) and in water (aquaculture), as well as fisheries and forestry. While the notion of ecosystems may conjure images of pristine natural landscapes, we explicitly include agricultural systems within the ecosystem concept as “novel”, or human-modified, ecosystems (Hobbs *et al*., 2006). There is ample evidence that these managed ecosystems provide ecosystem services (Power 2010; Zhang *et al.,* 2007). Indeed, ecosystem services are very important in agricultural landscapes because of their critical role in achieving food security, human health and well-being. Farmers are generally considered ‘providers’ of provisioning ecosystem services, using inputs and practices to provide a range of goods on which we depend, such as food, fiber and biofuel. However, good agricultural management practices impact and can enhance the flow and provision of many other ecosystem services, such as pollination, biological pest control, maintenance of soil fertility and structure, supply of habitat for wildlife, sustaining the aesthetic value of a landscape and regulating water supply (Tscharntke *et al.,* 2005, Power 2010; Zhang *et al.,* 2007). Conversely, poorly planned or badly managed agricultural systems can negatively impact the flow and provision of ecosystem services due to nutrient runoff, unintentional pesticide poisoning of some species and habitat loss (Zhang *et al.,* 2007). This inclusion of agroecosystems within the ecosystem service concept has fuelled discussions around ecosystem service-based approaches to agriculture (Bommarco *et al.,* 2013; Kremen and Miles 2012) and generated a much more interdisciplinary view of agricultural systems. Notably, conservation biologists have given greater consideration to the benefits that humans derive from ecosystems, even though their more traditional focus is on the conservation of species (Kareiva and Marvier 2007); it has also been incorporated into environmental economics, creating a surge in discussions on the externalities involved in the consumption of services, and the complexities in equitably distributing economic costs and benefits of the use and management of ecosystem services. The role of economics in the valuation of ecosystem services has also conjured fierce debate on the commodification of nature (e.g., The Guardian 2012a, 2012b).

WLE defines an ecosystem service-based approach to sustainable intensification as deliberately harnessing or restoring ecosystem services for production goals (e.g., increased yields, higher crop-per-drop ratios) or in ways that support these goals (e.g., pest control, seed dispersal, protection from storm damage), while reducing the negative impacts on the natural resource base that underpins these ecosystem services. In essence, an ecosystem service-based approach aims to facilitate an overall net positive effect on the provision of ecosystem services, both to and from agriculture. In this way, it aims to manage natural resources sustainably while maintaining or increasing food production and other ecosystem services. This might include, for example, the conservation of habitat for predatory arthropods to facilitate natural pest control (Rusch *et al.,* 2013), landscape management of barriers to reduce the flow of agricultural pests (Avelino *et al.,* 2012) or coordinating and incentivizing collective soil conservation in agricultural landscapes to increase the efficiency of hydropower (Estrada-Carmona and DeClerck 2011). We note that an ecosystem service-based approach is not devoid of technology or solely based on biological processes; rather, the development of technologies, tools and management practices that complement and increase the efficiency and impact of ecosystem services remain a critical line of inquiry and development. In our view, human-dominated landscapes present better opportunities for ecosystem service management than natural systems or protected areas because of the greater feasibility to manage landscape composition and configuration in the function of priorities. Agricultural landscapes are particularly amenable to such management due to their tremendous dependence on, and capacity to provide, ecosystem services, as well as the potential to develop industrial approaches to agriculture to achieve desired production, landscape and development goals. For example, Garbach *et al.,* (In Review) found that, amongst five systems of agroecological intensification, precision agriculture showed the strongest potential to increase yields and ecosystem service provision).

Ecosystem services interact with, and are intrinsically linked to, social structures and processes. As described by Levin *et al.,* (2009), humans can be considered an "integral part of the ecosystem, since humans derive a portfolio of services from the ecosystem and also act as a driver influencing ecosystem processes." Consideration of the coupling between social and environmental systems has given rise to the notion of **socio-ecological systems**. There is a wealth of literature on the theory of socio-ecological systems (see, for example, Berkes *et al.,* 2003; Becker and Jahn 2006; Ostrom *et al.,* 1999; Ostrom 2009). WLE's understanding of socio-ecological systems is guided by Walker and Salt (2006), who highlight that: (1) social systems are embedded in and interlocked with ecological systems (dynamics in one system affect the other); (2) socio-ecological systems can change in unpredictable, non-linear and transformative ways; (3) they are complex adaptive systems; (4) socioecological systems have varying degrees of 'resilience', and biological, physical and social factors can enhance (or reduce) this resilience. Resilience, as we apply it here, means the ability of a socioecological system to undergo change and retain sufficient functionality to continue to support livelihoods through, for example, the sustained provision of ecosystem services, including the quantity, quality, access and utilization of food supply (Park *et al.,* 2010).

Resilience is emerging as an important concept for understanding the stability and trajectory of the complex socio-ecological systems where ecosystem services are provided and consumed (Gordon *et al.,* 2008, Scheffer *et al.,* 2001). Resilience is not a static notion, rather it is focused on temporal change and on the role of internal and external drivers in transforming societies for better or for worse. These include drivers such as extreme weather events, spread of invasive species, shifts or failure in economic markets, or the introduction of new governance structures. Within development and, specifically, the WLE context, the focus is on positive transformative change—improved conditions for the poor—when shocks occur. Resilience is not necessarily an inherent component of ecosystem service-based approaches; optimizing the delivery of a bundle of ecosystem services for a selected management goal may increase the vulnerability of other ecosystem service flows to changes in the future with potentially negative outcomes on system resilience. Consideration of resilience in the design of ecosystem service-based approaches adds another dimension to the consideration of trade-offs, whereby some amount of redundancy in service delivery and access is desirable (LaLiberte *et al.,* 2010). Principles of socioecological resilience (Biggs *et al.,* 2012) are largely derived from the natural sciences. However, we hypothesize that the complex adaptive nature of ecosystems and the services they provide inherently includes greater resilience than static technological fixes. This is a critical line of inquiry for WLE. The challenge lies in designing ecosystem service management approaches that build system resilience and prevent crossing undesirable change thresholds (TEEB 2010).

Box 1*. Five Core Principles Underpinning WLE's ESR Framework.*

1. People: Meeting the needs of poor people is fundamental.
2. People and nature: People use, modify, and care for nature which provides material and immaterial benefits to their livelihoods.
3. Scale: Cross-scale and cross-level interactions of ecosystem services in agricultural landscapes can be managed to positively impact development outcomes.
4. Governance: Governance mechanisms are vital tools for achieving equitable access to, and provision of ecosystem services.
5. Resilience: Building resilience is about enhancing the capacity of communities to sustainably develop in an uncertain world.

Five core principles

The ESR Framework is grounded in five core principles (see Box 1) that we identify as being vital for the effective use of ecosystem service-based approaches and resilience thinking in the development context. These principles guide our ESR work in agricultural landscapes to help achieve development goals, including WLE's Intermediate Development Outcomes (IDOs).

WLE's ESR Framework

WLE's conceptual framework for using ecosystem service management to achieve development outcomes is presented in Figure 2.

WLE's work on ecosystem services and resilience is grounded in the idea that ecosystem services provide benefits to people that support livelihoods and human well-being, such as by generating income or providing nutritional diversity in diets (see Core principle 1). The quality and type of benefits received from ecosystem services depend on biological processes, creating tightly coupled socio-ecological systems (see Core principle 2), but also on whether the services and their benefits are equitably accessible and available for use.

As illustrated in Figure 2, ecosystem services in agricultural landscapes includes the following:

- services from agricultural systems, such as food (caloric, nutritional and cultural dimensions), water, fiber, biofuel and medicinal resources that flow directly to people;
- services to agricultural systems that support production, such as pollination, regulation of water supplies and genetic resources; and
- services that flow through, and are mediated by, agricultural systems to people in other ways, such as by moderating extreme climatic events, erosion control, regulation of air and water quality, and providing opportunities for recreation and ecotourism.

These service categories necessitate a matrix view of agricultural landscapes as including farmed fields, field margins, embedded semi-natural land uses, such as agro-forests, and natural land uses, such as wetlands and forests. Agriculture is frequently discussed in terms of its negative impacts on the environment, contributing to biodiversity loss, land degradation, water pollution and climate change (Foley *et al.,* 2011). Indeed, agricultural systems often negatively impact ecosystem service flows (and ultimately food production) in agricultural

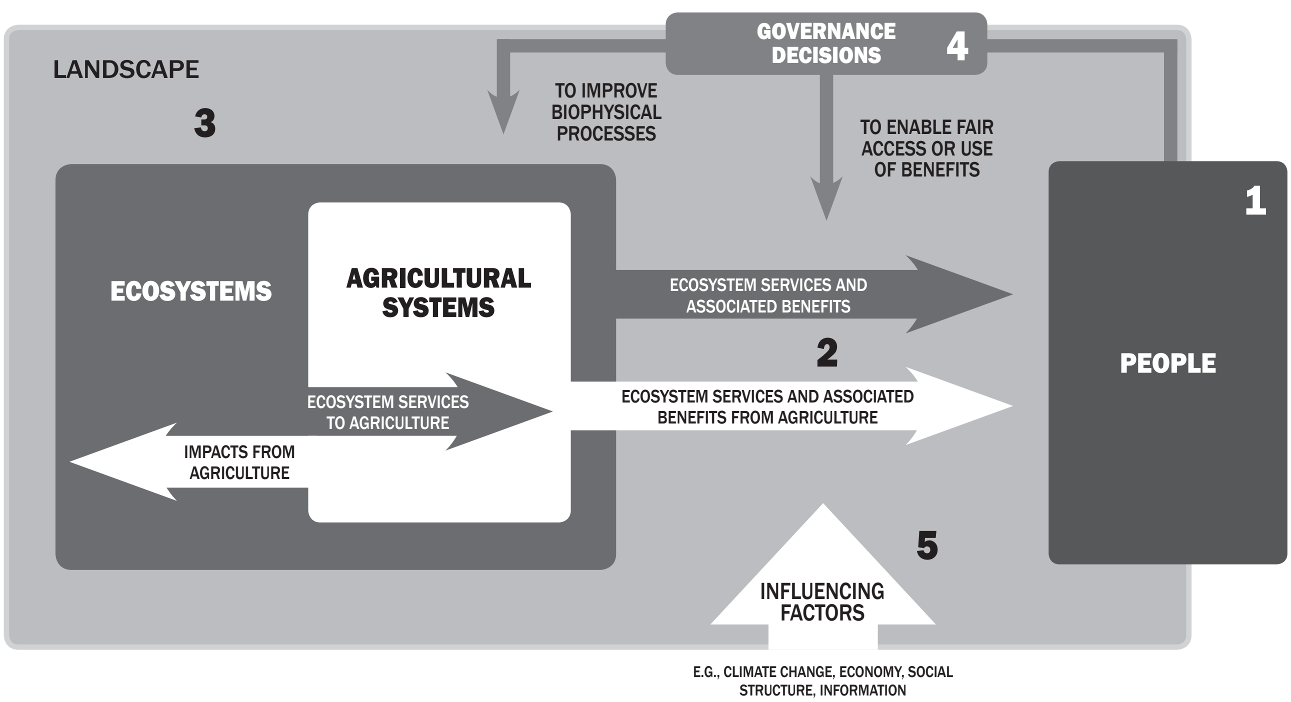

Fig. 2. *WLE's ESR Framework showing how management of ecosystem service flowing through an agricultural landscape can improve the health, security and economic status of people.*

landscapes, for example, by polluting water and soil with nutrient runoff or by degrading natural habitat (Zhang *et al.,* 2007), increasing sedimentation in rivers and streams, and increasing greenhouse gas emissions (Power 2010). One of the important insights that arises from studying ecosystem services is the understanding that agricultural systems can be better managed across and within scales to lessen, reduce and even produce positive impacts on the environment, and improve the flow of ecosystem services to people (Core principle 3). For example, production is one component of agricultural systems, and is dependent on a plethora of regulating and supporting ecosystem services that are provided to agricultural systems and benefit people in other ways (Zhang *et al.,* 2007). Many of the ecosystem services that are critical to agricultural production can be enhanced on agricultural lands themselves, through in-field management and are included in agroecological fields of study. Others are best suited to landscape-level interventions, which consider the management, composition and configuration of agricultural, semi-natural and natural land uses within agricultural landscapes. However, it is vital to understanding the trade-offs at multiple management levels involved in increasing agricultural productivity (Fremier *et al.,* 2013); if increased yield is achieved at the expense of clean drinking water, productive fisheries or renewable energy generation then increasing agricultural productivity is unlikely to ultimately improve human well-being or alleviate poverty.

People (e.g., individuals, farmers, communities, institutions) can make conscious choices to improve the flow of ecosystem services and maximize benefits through better governance of ecosystem service flows (see Core principle 4). Our hypothesis is that selective ecosystem service use and management enhances the biophysical structures and processes that produce these services. These decisions can enable more equitable access to and use of benefits from these ecosystem services.

Ecosystem service flows are influenced, and constrained by, internal and external drivers, such as climate characteristics, social structures, including societal demand for different services (underpinned by social needs, norms, perceptions and values [Cowling *et al.,* 2008]), status of knowledge and information availability, and economic conditions. These factors can constrain governance options and create shocks that impact the flow of ecosystem services. Resilience thinking provides a foundation for securing resilience in socio-ecological systems (Core principle 5) and resilience of ecosystem service flows – providing increased security for livelihoods that depend on the benefits from ecosystem services and potentially increasing the capacity of communities to develop.

Conclusion

This summarized version of the ecosystem services and resilience framework presents an approach to agricultural intensification that we believe can contribute substantially to the challenge of meeting the food requirements of the world's growing population without irreversibly damaging the ecosystems on which this production depends.

Source

For a complete discussion of the ESR framework, please refer to the original complete source: *CGIAR Research Program on Water, Land and Ecosystems (WLE) Ecosystem services and resilience framework*. 2014. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and and Ecosystems (WLE). 46p. doi: 10.5337/2014.229

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Vulnerability Assessment Methodologies for Adapting African Agriculture to Climate Change

The agriculture sector is one of the most important economic drivers for majority of the countries in Africa, contributing, on average, 30% of the continent's GDP and providing a livelihood to more than 70% of its people. Yet, agriculture in sub-Saharan Africa faces a number of difficult challenges. At a time when population increases require the world's farmers to produce more food, rising income levels lead to higher per capita consumption, and rapid urbanization pushes more fertile arable land out of production, researchers are struggling to identify ways to increase productivity per hectare. These challenges are further compounded by climate-related stresses, as farming becomes less predictable due to increased variability in rains, higher overall temperatures, and storm events that are more frequent and/or more intense.

According to the Intergovernmental Panel on Climate Change (IPCC), the future impacts of climate change on African agriculture include:

- 75-250 million people facing severe water stress by 2020 this number swelling to 350-600 million people by 2050

- Severely compromised agricultural production due to loss of land, shorter growing seasons, and more uncertainty about what and when to plant
- A possible 50% reduction in yields from rain-fed crops by 2020 in some north African countries, and crop net revenues likely to fall by as much as 90% by 2100 in South Africa

These projected impacts, if realized, could lead to the worsening of food insecurity in Africa and an increase in the number of people at risk of hunger, some of them chronically. In other words, vulnerability will increase. In the context of adaptation to climate change, vulnerability depends on the sensitivity of the system to changes in climate and the adaptive capacity of the population.

The way forward

Continental impacts vary significantly due to the diversity of environments across Africa, and there are many places and people with a high degree of adaptability and resilience to a range of climatic conditions. The differing impacts result from a variety of interconnected factors, including socio-economic conditions, agricultural technologies, and the natural resource base. Therefore, a variety of options and opportunities exists for countries to increase their resilience.

Meeting the challenges posed by climate change requires a holistic response comprising assessment, use of appropriate technologies and interventions, diversified livelihoods, and sustainable policies. This response involves a spectrum of activities, including those implemented at these levels:

- Field and farm level—such as protecting existing livelihood systems, diversifying sources of income, changing livelihood strategies, and providing an enabling environment for migration, when all other options are impossible in a particular area
- Extension and research level—including effective use of genetic resources; promotion of integrated farming systems; research and dissemination of crop varieties and breeds adapted to changing climatic conditions; improved infrastructure for small-scale water capture, storage, and use; and improved soil management practices
- Policy level—proactive, fiscal responses that include strategic interventions for high–probability impacts, implementation of insurance schemes where appropriate, and efforts to strengthen governance systems and their ability to facilitate adaptation interventions

A critical step in choosing among response options is to identify areas where constraints may be magnified by climate change and where opportunities lie to reduce these effects. Vulnerability assessments are a useful tool for understanding and effectively responding to the kinds of adjustments and changes required at community, national, and international scales.

Until recently, few assessments offered decisionmakers the information they needed, when they needed it, at relevant spatial and temporal scales. It is even more difficult to conduct these assessments in Africa because of scarcity of data, weak or dysfunctional institutions, limited capacity, and existence of multiple stressors (including those unrelated to climate change, such as HIV and AIDS, weak economic conditions, high population growth rates, etc.). Therefore, more practical approaches to using information gained from vulnerability assessments are necessary.

Vulnerability analysis approaches

Understanding who and what is at risk is the foundation of vulnerability analyses and indicates the strategies and measures that may be taken to reduce risk or to increase capacity to adapt. Choosing an appropriate approach for conducting a vulnerability assessment is important because each approach can reveal different vulnerabilities and identify different courses of actions. Several approaches are presented in the table, classified under five objectives that reflect increasing demands on available data, use of results from climate models, technical expertise, and resource capacity of the analysts.

The examples illustrate that no vulnerability approach can meet the needs of all adaptation activities and that there are advantages and drawbacks to each approach. Planners and program designers must choose the approach that best fits the particular situation. A few concepts that may guide the choice of approaches to vulnerability analysis can help

Comparison of vulnerability assessment approaches, by objective, context, strengths, and weaknesses (Zermoglio 2011).

Objective of assessment	Context for agriculture	Strengths	Weaknesses
Reduce impacts of disasters	Disaster risk reduction and humanitarian assistance	• Uses information from various sources and databases • Can be updated as new data become available • Comparability possible where data are available	• Spatial and technical expertise required • Differential vulnerability not addressed • Focus solely on disaster hazards
Mainstream adaptation into development activities	Input to development planning and adaptation policy Often part of related strategy documents such as national communications, national adaptation programs of action, and poverty reduction strategies	• Highlights processes underlying successful adaptation • Guidance and tools available to facilitate application • Basic data readily available and varies with respect to other inputs • Direct link to options and modifications in activities	• Can be data- and time-intensive to implement • Existing guidance and tools may need to be modified based on local needs
Estimate costs of adaptation	Estimate the impacts in terms of costs to agriculture resulting from climate change Can also be used to understand the costs of not adapting and supports resource allocation for adaptation	• Only approach that informs financial priority-setting • Useful in adaptation planning by identifying trade-offs • Offers insights on potential costs of inaction	• Difficult to conduct - requires significant training and expertise (e.g., economics, integrated assessment modeling) • High uncertainty in projections
Improve effectiveness of responses	Offers insights into the differential impacts on the vulnerable and helps to identify targeted options that respond to risks Inform better interventions by including vulnerable groups as analysis participants	• Encourage local agency and ownership • Increases potential success of interventions • Offers insights on potential “maladaptation”	• Time- and expertise-intensive • Site-specific and difficult to scale • Provides little detail on the structure of the hazard’s causal sequence – including the nested scales of interaction
Prioritize activities and monitor progress	Comparative approaches that specifically address targeting, program monitoring policy needs	• Allows comparisons across space and time (where data are available) • Can offer single value of vulnerability based on meaningful criteria, which can be considered by donor countries and organizations when taking decisions regarding the allocation of financial and technical assistance • Easy to update	• Requires subjective identification of indicators (no single one) • Are only snapshots in time and may disguise ongoing evolutions of certain dimensions • Scales of available indicators often mismatched and used anyway • Limited data-intensive applications and no site specificity • Difficult to validate by cause-effect processes

ensure that the assessment is appropriate for the given program, including that climate impacts differ and therefore responses must also vary

- for different people (individuals, households, communities)
- for different sectors (health, industry, agriculture fisheries, natural resources)
- in different places (villages, towns, cities, districts, ecosystems)
- at different times (present, next year, next 10 years, several decades on or longer)

because

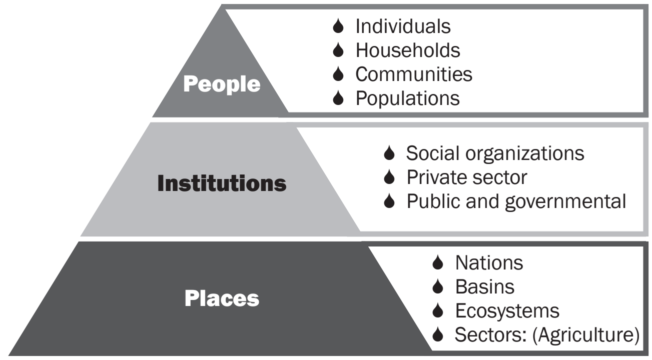
- specific climatic stresses and shocks vary by type, frequency, intensity, predictability, etc.
- environmental, economic and social factors vary (e.g., highland/lowland, coastal/inland, rich/poor, urban/rural, majority/minority religion or ethnicity, etc.
- in a specific area, some livelihoods and systems will be affected while others might not be
- the capacity to adapt differs and responses must incorporate these different capacities.

It is therefore critical that a vulnerability assessment answer questions such as

- Who (or what) is vulnerable ⟶ *System*
- To what are they vulnerable ⟶ *Exposure*
- Why are they vulnerable ⟶ *Sensitivity*
- What can be done to lessen this vulnerability ⟶ *Adaptive capacity*

Vulnerability assessment is widely used by organizations and programs involved with environmental change, human health, food insecurity, poverty reduction, conflict, sustainable development, and humanitarian aid. The uses of the information gained from vulnerability assessments for adaptation programming decisions can depend on a wide variety of factors, including:

- Scale of risks, in probability or magnitude
- Unit of analysis (see figure)
- Type of adaptation considered
- Time frame of the assessment;
- Availability of technical capacity to conduct the analysis



General units of analysis for vulnerability assessment.

It is important to note that the approaches themselves are not mutually exclusive and often overlap. Some methods are better placed than others to meet the specific needs of different adaptation projects.

Summary

A number of analytic approaches can inform efforts to understand vulnerability. This document describes vulnerability approaches by categorizing their role in supporting adaptation planning.

No vulnerability approach, regardless of its link to direct/indirect data, scale of analysis, and observed/hypothesized relationships, can meet the needs of all adaptation projects. Clearly, there are advantages and drawbacks to each, and the task is to choose an approach that corresponds best with the objective of the analysis and its intended application, time available for conducting the analysis, the scale and unit of analysis, and the resources and expertise of the team. The relative strengths and weaknesses of each approach need to be carefully considered before deciding on the methodology to be used for evaluating risks and identifying response measures.

Source

Vulnerability Assessment Methodologies for Adapting African Agriculture to Climate Change Factsheet by Feed the Future-Agrilinks under Climate-smart Agriculture Program Design Workshop (CAADP). November 10, 2011. Nairobi, Kenya.

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Farm-scale Management Practices to Improve Productivity and Resilience

Meeting the dual challenges of achieving food security and responding to climate variability and change will require significant changes in agricultural practice in coming years. Climate-smart agriculture takes an ecosystem approach, working at the landscape level to increase productivity, enhance resilience to changing temperatures and rainfall patterns, and reduce the greenhouse gas emissions that contribute to climate change.

A number of factors threaten agricultural productivity of African farmers. Many of Africa's soils are highly weathered and low in nutrients and soil carbon. As a result, they have limited capacity to retain the nutrients and soil moisture necessary for high yields. Climate variability and change pose additional challenges for producers. Some farmers are experiencing more frequent and intense storms that cause erosion, rainwater runoff, and crop damage, while others experience more frequent droughts. At the same time, rainfall patterns are becoming more variable with delayed onset and length of the rainy season and, in some cases, drought. These unpredictable patterns make it difficult for farmers to plan and manage their crops. Fortunately, there is a range of management practices and technologies that can be applied on-farm to increase agricultural resilience to climate stress.

Key issues

In sub-Saharan Africa, 250 million people went hungry in 2010. Hunger is particularly prevalent in arid and semiarid lands, where soil quality has been decreasing for years. Poor crop performance and high risk of crop failure in these systems, combined with low levels of rural development, have discouraged farmers from investing in soil fertility improvements. From 1945 to 1990, soil nutrient removal (without replenishment with fertilizer or manure) and other forms of soil degradation reduced agricultural productivity in Africa by an estimated 25% (UNEP, 1990).

Some of the causes of soil fertility depletion in Africa include limited adoption of fertilizer replenishment strategies and soil and water conservation measures; decline in the use and length of fallow periods; expansion of agricultural production into marginal and fragile areas; and the removal of vegetation through overgrazing, logging, development, and domestic use. An overall decline in farm input investment, including fertilizers, seeds, and technology adoption exacerbates soil degradation. Trade policies that increase fertilizer prices relative to commodity prices and inefficient input markets that fail to provide timely delivery of high–quality fertilizer prove to be disincentives for fertilizer use. There is growing evidence that, where soil carbon content is low, the yield response from fertilizer application is not profitable for the farmer (Marenya and Barrett, 2009).

Water management is another key constraint to agricultural productivity. Ninety-five percent of the food in sub-Saharan Africa is grown under rainfed agriculture (Rockstrom and Falkenmark, 2000), which is highly vulnerable to adverse weather conditions. The largest threat to rainfed agriculture is not overall water scarcity but extreme rainfall variability. This leads to more intensive rainfall events provoking runoff and erosion, while reducing infiltration rates. Variability can also cause longer intervals between rains, drying the root zone at critical points in the growing season, as well as more frequent and severe droughts resulting in crop failure. In the dry areas, water, not land, is the limiting factor in improving agricultural production. Maximizing water productivity, and not yield per unit of land, is therefore a better strategy for on-farm water management under such conditions. When water is scarce, higher farm income may be obtained by maximizing water productivity than by maximizing land productivity.

Other challenges to achieving food security include rapid population growth, limited access to agriculture-related technical assistance, and lack of knowledge about profitable soil fertility management practices leading to expansion into less favorable land.

Sustainable practices

A range of well-established restoration and management options can improve human livelihoods, repair ecosystems, and increase the resilience of both people and landscapes to climate change. The FAO (2010) highlights key components of climate-smart production systems that are relevant to farm-scale management, including

- *Soil and nutrient management.* Enhancing the availability of soil nutrients can be achieved by increasing soil organic matter (conservation agriculture, reduced tillage, continuous soil cover, composting); improved application of fertilizers (micro-dosing, controlled–release or deep–placement fertilizer technologies); and increasing fertility by integrating legumes into farming systems (grain-legume crop rotation, cover crops, relay crops, integration of leguminous trees on-farm). Improved land preparation practices that minimize soil disturbance and ensure that fields are ready to plant at the start of the rains can also significantly increase productivity. On-time planting allows crops to benefit from a nitrogen flush with the first rains. In Zambia, total maize production is reduced by 1.5% for each day planting is delayed (Garrity, 2009).

- *Water harvesting and use*. Capturing rainwater where it falls (ridge tillage, planting pits/zai holes and catchment ponds), retention of soil moisture (mulching, permanent soil cover) and increasing water productivity through irrigation and counter-season production can enhance overall yield. High runoff and low infiltration rates mean that only 15-30% of rainfall is available for crop production. However, water–harvesting technologies can reverse this trend. In Mali, adoption of improved ridge tillage increased water infiltration rates, allowing the soil profile to hold 17% more water while increasing soil carbon by an average of 8% per year. The result was a 30–50% increase in yield (Kablan *et al.*, 2008).

- *Integrated pest and disease management.* National-level monitoring and tracking the shifting distribution and strains of diseases and pests due to changing climate regimes should be linked to on-farm practices such as integrated pest management and adopting resistant varieties to limit crop damage.

- *Resilient ecosystems*. Improving ecosystem management and sustaining biodiversity support pest management, micro-climate regulation, pollination, and nutrient cycling. While achieving ecosystem resilience requires action at the landscape scale, farm management practices that reduce erosion and rainwater runoff; increase on-farm habitat for beneficial insects, pollinators and wildlife; sequester carbon; and reduce conversion of natural habitat to agriculture support ecosystem resilience across the landscape.
- *Genetic resources*. Developing improved varieties and preserving genetic resources of crops and their wild relatives are critical at the national level to ensure that appropriate climate–resilient varieties are developed and accessible to producers.
- *Harvesting, processing, and supply chains*. Efficient harvesting and early transformation of agricultural produce can reduce postharvest losses and preserve quantity, quality, and nutritional value of food products. Farm-scale interventions, including enhancing the ability to meet market grades and standards and improving harvesting, storage, and primary processing, can ensure profitability while reducing postharvest loss.
- *Diversification can increase the efficiency of farming systems and build their resilience to climate change*. It can spread risk, increasing economic resilience at the farm and at the local levels. Diversified rotations, including crop varieties and species with different thermal/temperature requirements, better water use efficiency, resistance to pest/disease, and lower yield variability are effective ways to reduce risks and increase efficiency.

Farming systems consistent with climate-smart agriculture

A number of farming systems/approaches compatible with climate-smart agriculture are being adopted at a significant scale in Africa. These include the following:

Conservation agriculture (CA)

This is defined as having three key components: (1) minimal soil disturbance (no-till/low-till), permanent soil cover (mulch or cover crops), and crop rotation (Hobbs, 2007). According to the FAO, CA aims to conserve, improve, and make more efficient use of natural resources through integrated management of available soil, water, and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production.

Evergreen agriculture (EA)

This is the integration of particular tree species into annual food crop systems (Garrity *et al.*, 2010). The World Agroforestry Center introduced the concept of EA by highlighting experiences with farmer-managed natural regeneration of trees in the Sahelian Parklands and integrating agroforestry species into CA in Zambia and Malawi. Research indicates that the potential for significant productivity increases when trees are integrated into cropland.

Sustainable agricultural intensification

The process entails increasing agricultural production from the same area of land while reducing negative environmental impacts and increasing contributions to natural capital and the flow of environmental services.

Ecoagriculture

This is a landscape approach that supports rural communities to achieve three core goals: enhance rural livelihood, conserve or enhance biodiversity and ecosystem services, and develop more sustainable and productive agricultural systems. It recognizes farmers and communities as key stewards of ecosystems and biodiversity and the need for collective management of the landscape by a range of stakeholders (EcoAgriculture Partners, 2011).

Considerations for program design

The design of climate-smart agriculture programs should pay close attention to the obstacles identified by FAO and other organizations and scientists working on climate–resilient agriculture programs.

Key design issues include:

- Adopting an ecosystem approach with cross-sectoral coordination and collaboration at the landscape scale is essential to adapt to climate stresses.
- A range of effective climate-smart practices already exists and could be introduced and scaled in developing country contexts.
- Institutional, technical, and financial support may be required to support smallholder transition to climate-smart agriculture.
- Data, knowledge, and technology gaps exist and should be addressed to support improved technologies, methodologies, and climate resilient varieties.
- Harmonization of climate change, agricultural, and food security policies is required at the national, regional, and international levels.

Source

Farm-Scale Management Practices to Improve Productivity and Resilience Factsheet by Feed the Future-Agrilinks under Climate-smart Agriculture Program Design Workshop (CAADP). November 11, 2011. Nairobi, Kenya.

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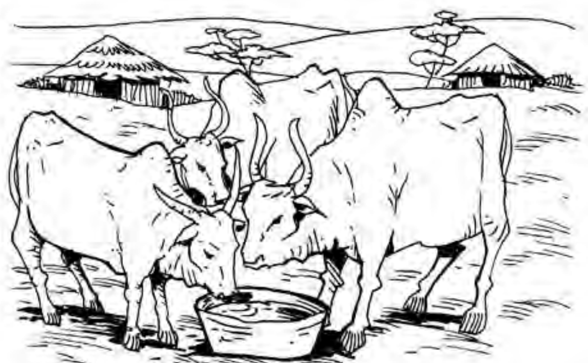
Web-based resource

EcoAgriculture Partners. 2011. What is Ecoagriculture? http://www.ecoagriculture.org/page.php?id=47.

Improving Water Productivity and Efficiency



Rainfall variability has adverse impacts on agricultural production. Rainfall variability experienced in sub-Saharan Africa already has detrimental impacts on crop production. Indeed, too much or too little water due to erratic rainfall and insufficient storage capacity wields adverse impacts on food security. Climate change is widely predicted to increase rainfall variability in sub-Saharan Africa, with the effect of increasing droughts and floods. For many millions of smallholder farmers, reliable access to water is the difference between plenty and famine. It is therefore essential to find ways to cope with existing and increasing variability in rainfall, as well as other effects of climate change like changes in temperature patterns.

Water storage is the basis for ensuring water productivity in the face of climate change. Water storage spurs economic growth and helps alleviate poverty by making water available when and where it is needed. Today, many developing countries, even those with abundant water, have insufficient water storage capacity. Inadequate storage leaves farmers vulnerable to the vagaries of climate. Ethiopia is one such example. Ethiopian farmers are heavily reliant on rainfed subsistence agriculture. The lack of storage infrastructure means farmers have limited ability to cope with droughts and floods. These limitations are estimated to cost the economy one-third of its growth potential. The Ethiopian case is a good illustration of the urgent need for appropriate investments in water storage to increase agricultural productivity and to ensure that farmers have options for adjusting to the coming climate changes (IWMI, 2009).

Many technologies are available to enhance water productivity. Improving water productivity constitutes another method to adapt to climate change. Increasing water productivity enables greater crop production per unit of water consumed, thereby decreasing reliance on erratic rainfall. There are numerous ways to increase water productivity, some of which are described below.

Response strategies

Storage as basis of improved water productivity

When most people think about water storage, the first thing that comes to mind is large dams. More than 45,000 large dams (more than 15 m high) have been built throughout the world. However, many effective methods for storing water are also relatively simple and cheap, bearing in mind that in some regions such as Ethiopia, even simple ponds and tanks are beyond the financial means of the poorest. Ponds and tanks built by individual households or communities can store water collected from microcatchments and rooftops. Individual ponds and tanks may be small in volume, but in some places this water is vital to supplement domestic water supplies, household gardens, rainfed crops, and livestock. Many different storage options exist (McCartney and Smakhtin, 2010):

Natural wetlands. Lakes, swamps, and other wetland types have provided water for agriculture for millennia, both directly as sources of surface water and shallow groundwater and indirectly through soil moisture. Consequently, wetlands span the surface/subsurface interface and provide water in many different ways. As a result of their important role in the provision of water, wetlands are increasingly perceived as “natural infrastructure.”

Soil moisture. Globally, the total volumes of water stored within the soil are huge, but at any given locality, they are relatively small and quickly depleted through evapotranspiration. Because of this, in recent decades, there has been increased interest in various in situ rainwater management techniques that enhance infiltration and water retention in the soil profile. Widely referred to as soil and water conservation (SWC) measures, examples vary from place to place but the most promising include deep tillage, reduced tillage, zero tillage, and various types of planting basin.

Groundwater. Groundwater is water stored beneath the surface of the Earth in aquifers. A major advantage of groundwater is that there is little or no evaporation and total volumes are often much greater than annual recharge. The amount of water that can be abstracted from a well in an aquifer is a function of the characteristics (particularly the permeability) of the rock. Some aquifers will yield only a few liters per day, while others can yield as much as several million liters. Methods for increasing groundwater recharge include pumping surface water directly into an aquifer and/or enhancing infiltration by spreading water in infiltration basins.

Ponds and tanks. Ponds and tanks are cisterns or cavities (covered or uncovered, lined or unlined) built by individuals or communities to store water. They are often linked with rainwater harvesting and store relatively small (but often vitally important) volumes of water. Ponds and tanks fill either by surface runoff or through groundwater and differ from reservoirs by the absence of a dam. A common limitation is that they are usually shallow, with a relatively large surface area, so that often a significant proportion of the water is “lost” through evaporation.

Reservoirs. Reservoirs consist of water impounded behind small and large dams constructed across streams and rivers. Small dams (often built simply by mounding earth) store relatively small amounts of water (a few hundred to a few thousand cubic meters) and often empty every year. Many small dams do not have outlets and water is simply removed by livestock drinking, pumping, and as a consequence of spilling and evaporation. They tend to be shallow with relatively large surface areas so that, in common with many ponds/tanks, a significant proportion (sometimes more than 90%) of the water may be lost through evaporation.

Direct improvements in water productivity

The selection of a particular technology for a given set of conditions is not always evident. As

Different technologies for improving water productivity.

Technology	Description	Advantages	Disadvantages	Typical cost (US$)
Large schemes	Typically river diversion with or without storage reservoir	Potentially large acreage, high potential for improving food security	Management problems, high cost of maintenance	3750–4000/ha
Small schemes	Typically up to 200 ha, may or may not involve storage	May be farmer–managed	Typically less secure water source	450–540/ha
Drip kits	20–L bucket with lengths of drip kit and larger sizes	Versatile, may be used for kitchen garden with excess production marketed	Limited in size, requires nearby water source	20–200 per kit
Drip irrigation systems	Commercially made drip tape, filter, water source	Water-efficient, delivers measured amount of water to root zone	Drip tape generally has a life less than 5 years	High cost
Greenhouses	Plastic or glass enclosure for intensive, controlled agriculture	Water efficient, good potential control of diseases and pests	Plastic may have life less than 5 years, subject to hail damage	High cost
Rainfall harvesting	Constructed reservoir for capture of rainfall for irrigation purposes	Provides supplemental irrigation to rainfed crops or allow production of irrigated crops	May be water–short during drought	Can be constructed by local labor
Treadle or other manual pumps	Lifts water from shallow well, capable of irrigating up to 0.5 ha	Provides a low-cost water source	Requires shallow aquifer within 9 m of surface	35–120
Power pumps	Provides pressurized water from surface or groundwater source	Provides a reliable water supply	Requires electric, gas or diesel power and maintenance	Dependent on power source, lift, and volume
Photo-voltaic pumps	Provides pressurized water from surface or groundwater source	Provides a reliable water supply, no operating costs	May require maintenance, typically small-scale application	High investment cost

can be seen in the table, there is a wide range of technologies available. Some will be more appropriate than others, according to local farmer preferences and local conditions. Farmers would benefit from technical assistance to evaluate and recommend technologies for their particular situations. For irrigation schemes, as opposed to individual enterprises, assistance may be needed in establishing farmer organizations and assuring that they can effectively manage and maintain irrigation systems. The table provides information on some of the major approaches and technologies, along with some of their advantages, disadvantages, and costs.

Source

Improving Water Productivity and Efficiency Factsheet by Feed the Future-Agrilinks under Climate-smart Agriculture Program Design Workshop (CAADP). November 10, 2011. Nairobi, Kenya.

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The Relevance of Small-scale Irrigation in the Pastoral Regions of the Horn of Africa

Pastoralism in the Horn of Africa is currently experiencing intensifying pressures resulting from human and herd demographics, environmental change, contested natural resources, livelihood impoverishment and political marginalization. Some of these changes may threaten the very future of pastoralism in modern economies, at least for the poor. On the other hand, new adaptive responses to the challenges facing pastoralists are taking place, particularly with respect to markets. Furthermore, mobile pastoralism is an efficient system of natural resource management in the arid grasslands. How should governments and civil society (including donors and the voluntary sector) respond to the bad and the good news? They face priority choices that involve major trade-offs between economic activities. Among these constantly shifting and competing choices, and especially relevant to organizations seeking to intervene through poverty-reducing projects, is a strategy to promote crop farming, small-scale irrigation in particular. This may offer a form of productive diversification for pastoral peoples, especially those who find that their livestock-based production system is no longer viable.

The Oxfam-led Regional Learning and Advocacy Project (REGLAP) is a consortium project that aims to promote resilience among vulnerable dryland communities in Uganda, Ethiopia, and Kenya through policy change and practice. The project is currently funded by the European Commission's Humanitarian Office's Drought Risk Reduction Action Plan (DRRAP). REGLAP has been in existence since 2008, funded by ECHO, first as the Regional Pastoral Livelihood Program, to strengthen the evidence base for support for pastoral populations, and later as the regional learning and advocacy program for vulnerable dryland communities.

This study, commissioned by REGLAP, aimed to review available evidence concerning the potential for expansion of crop agriculture, as an alternative or complementary strategy to pastoralism, in arid and semiarid areas of Kenya, Ethiopia, and Uganda (large- and small-scale irrigated and rainfed), in order to promote sustainable and resilient livelihood. These were to be weighed against other livelihood support options in order to inform REGLAP's own advocacy position as well as those of Oxfam and other NGOs, especially around the IGAD-led Ending Drought Emergency plans. Research gaps and means of filling them were to be suggested. Recommendations for advocacy and practice in promoting crop agriculture in relation to other investment priorities would be made.

This article, through an overview of literature and experience gives, government, NGOs, private sector partners and REGLAP the evidence base for policy and practice on development in pastoral regions of the Horn of Africa, with particular reference to small-scale irrigation. The 'pastoralist's dilemma,' whereby the amount of rangeland that is available is considered to be insufficient to support enough livestock to provide livelihoods for a fast-growing population, is being exacerbated by the loss of rangeland (especially valuable riverine pastures) to appropriations for commercial farming and especially irrigated plantations. Many severe droughts have caused high mortality and the intervals between them have not permitted herd reconstitution. There are increasing numbers of destitute pastoralists with few or no surviving livestock.

This is a complex system dynamics containing many elements. Singled out among environmental variables are scarcity and variability of rainfall and water resources, which are at the root of uncertainty experienced by human communities, themselves growing rapidly in number (with accompanying migration and urbanization). Far-reaching land use change reflects unprecedented pressures on the land from livestock, farmers, corporations, and governments, transforming ecosystems and driving degradation in many areas. However, urbanization and international trade are encouraging increasing participation in markets: those for inputs, outputs, land and labor, resulting in the diversification of household livelihoods. Consequently, the investment landscape is changing rapidly as dryland resources are revalued upward and external actors increase their involvement. The dynamics of the human and biological systems thus pose a threat but also offer opportunities, one of which is irrigation for the markets.

The droughts of the past decade have helped to focus policy directions in the region, both at the international level and in national policymaking. In general, there is some movement toward a coherent policy toward pastoralism that recognizes the value of the systems rather than seeking to replace them. This is apparent in the African Union's Policy Framework for Pastoralism in Africa and COMESA's Policy Framework for Food Security in Pastoral Areas under Pillar III of the CAADP. IGAD's drought disaster and sustainability initiative supported country planning papers for Ethiopia, Uganda, and Kenya. These statements, which sit within an existing structure of national policies and institutions relating to the agricultural and water sectors, climate and food security programs, vary in tone from more centralized (Ethiopia) to decentralized (Kenya). Kenya has recently enacted its National Policy for the Sustainable Development of Northern Kenya and other Arid Lands. Development is the ultimate answer to poverty and hunger in the drylands, but many issues of local ownership, participation, and empowerment remain to be addressed.

Three policy pathways are available to governments and development agencies in the drylands of the Horn of Africa:

1. Promotion of crop agriculture, especially small-scale irrigation;

2. Continued support for pastoralism, albeit in new forms; and

3. Facilitating income diversification (including migration).

This article is drawn from a wider analysis of the strengths, weaknesses, opportunities and constraints of these three options. The first (which is the main focus of this study) offers increased value per hectare under irrigation. Ex-pastoralists take up irrigation, retaining secondary livestock interests. These agropastoral systems reap the advantages of diversification and a reduced risk of food insecurity. However, constrained by few animals, small holdings and shortages of capital, they may have exchanged one poverty trap only to enter another in the longer term. Much irrigable land remains. However, irrigation needs considerable investment, including inputs, technologies, services, and markets. Expansion, though certain to occur (spontaneously even if not promoted by policy), will need investment and adaptation. The situation varies from country to country. Technologies are available, models for investment and cost recovery have been tried, and attention given to agropastoral transitions. Ethiopia prioritizes large-scale schemes, whereas Kenya has favored decentralized solutions, with public-private partnerships and other innovative financial approaches. There is urgent need for more data and for economic studies of comparative advantage, cost effectiveness, and mitigating the potential negative social and environmental consequences of these attempts.

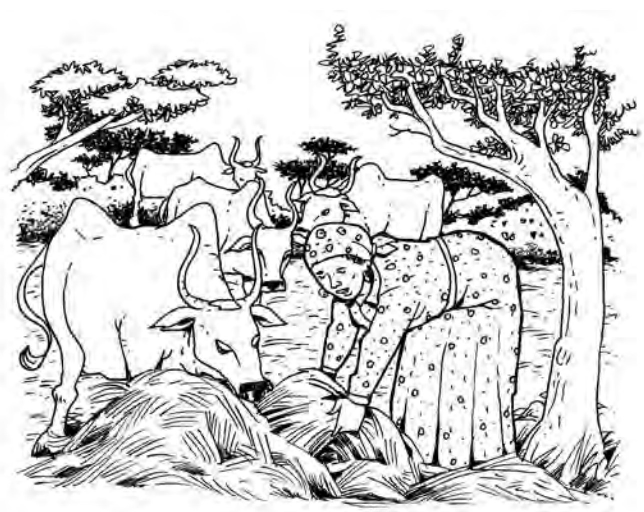
Small-scale irrigation

From the evidence so far reviewed, it is clear, in so far as we may generalize across the huge diversity of East Africa, that among crop agriculture options, only that of small-scale irrigation offers some scope for a transformation of mobile pastoralism, as an alternative to, or complementary with, livestock production. However, while there are considerable potentials for expanding irrigation, these potentials may still not be equal to the task of providing livelihoods for large ex-pastoral populations at improved living standards. The patchy success of many schemes shows that additional investments besides irrigation infrastructure are required, including access to improved seeds (for high-value cultivars), fertilizer and other inputs, training, maintenance services and farmers' marketing organizations (You *et al.,* 2011 Headey *et al.,* 2011).

Two key questions need asking with respect to small-scale irrigation as a solution to the "pastoralists' dilemma:" first, is there scope for expansion of the irrigated area? second, what can be learned from project experience about the economic costs and benefits of small-scale irrigation? At the country level, it suffices to say that abundant potential exists, even in Kenya where 85% of the land area is arid. But, at the ecological level, can this potential meet the needs of pastoral populations? According to calculations, 2.2 million ha of irrigable land, divided equally among a pastoral population of 19.3 million, could provide an average of 0.69 ha per pastoralist household in the Horn of Africa (Sandford, 2013). However, this average hides huge differences between countries (1.25 ha for Ethiopia and 0.23 ha for Kenya). The assumptions must be that the 'pastoral population' will continue to grow, if more slowly, and, if riverine pastures are brought entirely under irrigation, mobile pastoralism as we know it will be mortally wounded.

Answering the second question is equally ambivalent, as few analyses have been carried out. Sandford (2013) reports on three 'pastoralist-related' irrigation schemes in Kenya and Ethiopia, with widely divergent cost levels and output values. He concludes that (excluding the Kenya example, which is in Turkana) 'the level of net benefits that can be achieved on pastoralist-related schemes is broadly compatible with the level of capital costs actually incurred in installing the irrigation systems', provided that any opportunity costs of land and labor are ignored. This may be justified because of the low returns to alternative land uses (i.e., grazing) and non-agricultural use of labor.

That small-scale irrigation makes economic sense is confirmed by the vitality of the private sector in such areas as the Wabi Shabelle River and the Mandera Triangle. It is estimated that only 2.4% of irrigable land is under irrigation in the Somali Region of Ethiopia, of which about 70% is under 'traditional'



irrigation technologies such as spate irrigation, controlled or uncontrolled flooding, lift irrigation using buckets, and gravity-fed canals.

In Kenya, a strong demand for horticultural products (including exports) is driving a ‘new frontier’ in small-scale irrigation, based on the use of low-cost technologies, wholly or partly made in the country. The technologies include rainwater harvesting, bucket irrigation, gravity’ fed sprinkler and drip, treadle and pedal pumps, rope and washer, motorized pumps, wind power, and small earth dams. Purcell (n.d.). Small-scale irrigation uses an estimated 50,000 ha; the total irrigated area is 80,000 ha of a potential area of more than 300,000 ha. The Ministry of Agriculture has a target of 1.2 million acres over 5 years (Daily Nation).

Significantly, small-scale irrigators in Kenya raise their own capital from private savings, attracted by good profits. Compared with farm incomes from rainfed land, which average less than US$750/ha, irrigated land can produce two-three crops a year worth US$1,400 (snow peas, French beans), US$450 (kale) or US$600 (onions). Such opportunism among farmers is not new and accords with the findings of local district studies in semiarid Machakos and Makueni districts (Tiffer *et al.,* 1994). It may be noted that the Akamba menfolk were themselves semi-mobile pastoralists before the colonial period. Farming, which consisted of hand-hoeing and shifting cultivation, was undertaken by women.

Very little attention is given in macro-scale planning proposals to the legion of issues surrounding small-scale farmers’ participation in irrigation schemes. Studies at the project level are infrequent. One exception, a study of crop farming along the Wabe Shebelle River in the Somali Regional State, investigated three of some 18 ‘asset-building groups’ that were set up in an earlier project (USAID, FIC, TU 2010). Each had about 50 farmers with shared pumps. From an examination of scheme performance and intended or actual benefits, it was concluded (disappointingly) that, when compared with pastoralism, small-scale irrigation may not remove risk. Beneficiaries had reverted to individualized operations and preferred the indigenous land-sharing and pump-renting agreements. Instead of helping destitute widows, the scheme was supporting experienced irrigators who had benefited from earlier projects. A great many technical issues were found to impact on performance. Diversity of situations and weak ‘ownership’ indicate that irrigation should be planned on a case-by-case basis and with full stakeholder participation from design to implementation.

Given such complexity, it is unlikely that small-scale irrigation can be effectively expanded by a blue-print at a macro-scale. A guide to planning and managing small-scale irrigation schemes has been provided by FARM-Africa (Carter and Danert, 2006).

But where interventions fail, private enterprise seems to flourish. In some major river valleys of the Somali Region, irrigation is already considered to exploit most of the potentially irrigable land, based on small holdings, diesel pumps, hand labor and sub-optimal fertilizer treatments—on a ‘low input – low output’ basis (Devereux, n.d.). Pastoralists are said to be driven into farming by their declining livestock holdings and by shortages of grazing land. They tend to accord low status to farming. The labor requirements of year-round irrigated farming are not compatible with the needs of mobile pastoralism, except for large families. But many Somalis, nevertheless, have recently negotiated access to irrigable land and water adjacent to the pre existing schemes on the Shebelle River, and the privatization of land for irrigation has led to disputes (Gomes, 2006). Its rising value also attracts speculators and entrepreneurs from the towns. The cultivated area in the state increased threefold between 1973 and 2010. Security of land tenure is an urgent issue for (ex-) pastoralists, many of whom do not expect to return to mobile pastoralism.

Crop agriculture, to reduce vulnerability to drought, must be rooted in sustainable resource management and generate a level of production that satisfies the material and social needs of each family. Being sedentary automatically extends the pastoralist’s agenda from livestock into farming, education, health, and market access for income diversification. Two schemes for Kereyu agropastoralists in Fentale (in the Awash River Basin, Ethiopia) make use of irrigation water on the margins of the Metehara sugar plantation (Akloweg, 2013). They accommodate 600–700 beneficiaries on land, formerly communal rangeland, allocated by the elders at 0.75 ha for a family. While their diminishing herd are grazed collectively on rangeland at 2 days’ distance, the communities occupy new housing in settlements with a school, administration, and unsurfaced road to market (at about 15 km). New income streams and especially the ability to sell two or three crops at different times of the year are seen as advantages. However, an annual fee is payable to offset the capital costs of the schemes. Besides the management of land and water resources (managed by water users' associations), issues of market demand and linkages (motor transport for produce), fertilization (cost), technology (scarcity of capital funds), education (inability to sustain children's registration beyond primary level), health, and income diversification are concerns. Staff and skill shortages have affected efficiency (Flintan n.d.). Poverty still means a lack or shortage of livestock, but while irrigated farming has reduced the risk of food insecurity, the inability to acquire additional irrigable land has raised fears for the next generation, while the scope for income diversification is constrained by education and travel costs.

Schemes can also be adversely affected by power shifts and conflict. Pastoralists displaced by the Shifta rebellion in the 1960s took up irrigation in the Tana floodplain with government support, but when this was removed, the farms languished until renewed support was forthcoming. Many used farm incomes for restocking and went back to mobile pastoralism. The crucial difference was and still is marketing access and costs (Farah *et al.,* 2003). According to informants, sustainable irrigated cropping in the Garissa area depends on the removal of compulsory payments to the scheme revolving fund, better transport to market, resolving the competition for labor between farming and herding, giving equal opportunities to women (whose participation in farming is crucial), ending the inefficient underuse of field holdings, and improving efficiency and equity in water management.

Small-scale irrigation is not yet a panacea for the problems faced by pastoralism. But the values of snow beans, French beans, kale, and onions in Kenyan markets illustrate increasingly buoyant markets, and the 'boom' in small-scale irrigation where urban markets are within reach, suggest positive trends in contrast to the negatives of the "pastoralists' dilemma." However, small-scale irrigators may compute their business strategies (for example, by undervaluing family labor), the widespread success of farmers in gaining access to growing fruit and vegetable markets should eventually open the door to agro-pastoralists in more remote places. Even in a remote place—such as the Mandera triangle on the borders of Kenya, Ethiopia and Somalia—irrigated fodder production for the market, which is the local transborder traffic in livestock, is increasing incomes, if not necessarily those of the poorest (ELMT, 2009). Success also depends on maintaining water and seed supplies (ELMT n.d.).

Irrigation schemes need capital. Cost recovery problems have shadowed small-scale irrigation schemes supported by external donors or the government, with top-down management and unpopular land alienation. New models of capitalization are required. Experiments in new financial and management packages have begun to yield lessons in Kenya (Gikuchi, pers, commun.). A public-private partnership leases common or community trust land and shares capital costs between private investors and local farmers. A company manages the scheme. As profits accumulate, the leased plots are taken over by small-scale farmers, so the land stays with the community. Other innovative financial packages have been developed and experimented in Kenya (Grimm and Richter, n.d.).

Private investors may have local connections and be prepared to abandon profit maximization in favor of the social rewards of philanthropy. 'Impact investments' that aim at social as well as economic benefits - for reasons other than profit maximization - are gaining ground as a new class of financial assets (Morgan, 2010). If the ASALs are to achieve economic parity with more humid zones, new opportunities for investment are required (Pipal Ltd., 2011). This thrust has been underlined in a recent report on global drylands (EMG, 2011).

However, two caveats are in order (Avery, 2010). The first is that small-scale irrigation is necessarily located as close as possible to the water source. But in Kenya, where riverbank flood recession farming is traditional, cultivation disturbs soils and increases erosion, and the Water Act forbids 'tillage' within the riparian zone. The implications of water legislation are unclear, since it appears to be widely disregarded.

The second caveat is that conflicts may arise where schemes are set up in the territories of wildlife populations. Damage may be caused, crop losses incurred, and fencing proved prohibitively costly to smallholders.

Critical factors in the success of small-scale rainfed or irrigated agriculture include:

- secure rights of access to land

- high-value and innovative crops
- integrated livestock enterprise
- infrastructure in place
- accessible markets
- water harvesting, efficient management
- well-designed gravity systems (ILRI)

Conclusion

It is suggested that we may be on the cusp of a significant transition to growth in the small-scale irrigated sector. Enabling a transition will be the challenge for the promotion of good practice and for innovative research. Good practice in small-scale irrigation should include (1) planning that recognizes system interactions, reconciles contested claims to resources, and follows democratic principles; (2) freedom of choice in matters relating to household livelihood strategies; (3) recognizing and realizing the complementary benefits of livestock; (4) the conservation of soils and water; (5) educational enablement of individual life chances; fully participatory irrigation development and regulation; (6) allowance for multisectoral livelihood strategies; (7) exploitation of complementarities between production systems at the local level; (8) enhancing livelihoods and better life chances for individuals through education; (9) extension as a way of building human capital; (10) action research and innovation relevant to small-scale production units; and (11) provision of economic incentives for micro-investments. A framework for action is proposed with technical, economic/financial, and policy/institutional agendas.

Source

This article has been drawn from a section of a wider study. Refer to the following for the original full article: *The place of crop agriculture for resilience building in the drylands of the Horn of Africa: an opportunity or a threat?* By Michael Mortimore. June 2013. Regional Learning and Advocacy Programme for Vulnerable Dryland Communities. GROW. Food. Women. Planet. mike@mikemortimore.co.uk

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Impacts of Climate Change, Variability and Adaptation Strategies: The Case of Manyoni District in Singida Region, Tanzania

Climate change and variability (CC & V) is rapidly emerging as one of the most serious global problems affecting many sectors in the world. It is considered to be one of the most serious threats to sustainable development with adverse impact on environment, human health, food security, economic activities, natural resources, and physical infrastructure (IPCC, 2007; Huq *et al.*, 2006). Africa is one of the regions in the world most vulnerable to climate change. Previous assessments (IPCC, 1998; Hulme, 1996) concluded that Africa is particularly vulnerable to the impacts of climate change because of factors such as widespread poverty, recurrent droughts, inequitable land distribution, and overdependence on rain-fed agriculture. Devereux and Edward (2004) reported that countries in East Africa are already among the most food-insecure in the world and CC & V will aggravate falling harvests.

According to Tanzania NAPA (2006), agriculture has been identified to be the second most vulnerable sector to the impacts of climate change. A study on vulnerability and adaptation to climate change impacts on other sectors in Tanzania clearly indicated that forestry, water, coastal resources, livestock, and human health are also likely to be vulnerable to climate change.

These sectors are closely linked to agriculture and therefore effects of CC & V on such sectors will further negatively affect both crop and livestock production systems. The impacts of climate variability are manifested by floods, droughts, erratic rains, and extreme events. URT (2005) revealed that famine resulting from either floods or drought has become increasingly common since the mid-1990s and is undermining food security. CC & V are likely to intensify drought and increase potential vulnerability of the communities to future climate change especially in the semiarid regions (Hillel and Rosenzweig, 1989), where crop production and livestock are critically important to food security and rural livelihoods.

A number of studies conducted recently in Tanzania have recognized that CC & V is happening and is coupled with significant impact on various natural resources, including agriculture, which is the main source of livelihood in rural areas (Majule *et al.*, 2008; Majule, 2008; Agrawala *et al.*, 2003). Various climate-related impacts such as floods and droughts regularly have substantial effects on economic performance and livelihood of communities in rural areas that depend on rainfed agriculture.

A study by Ngana (1983) on drought and famine in Dodoma District indicated that the presence of dry spells in critical periods for most crops contributed considerably to crop failure and famine. Given the overdependence on rainfed agriculture by the majority of people living in rural areas, CC & V has been one of the major limiting factors in agriculture production, thus resulting in food insecurity and low income generation.

This study explored indigenous knowledge on perceptions, vulnerability, adaptations, and coping strategies, coupled with scientific analysis of the prevailing climatic regimes in the areas of study and established enhanced adaptations of the agricultural systems. The information derived from the study is expected to be used by stakeholders, including scientific communities and policymakers, to address issues related to CC & V in similar agro-climatic conditions. The overall aim of this study was to examine the impacts of CC & V on agricultural systems and establish how adaptation strategies could be enhanced to improve agricultural production under a changing climate. Specifically, the study

i) identified existing agricultural systems and factors influencing production in selected villages,

ii) established the patterns and trends of temperature and rainfall and assess their impacts on agriculture production, and

iii) established people's indigenous knowledge on CC & V and their adaptive capacity.

Research methodology

Description of study area

The study was carried out in Manyoni District in Singida Region, Tanzania. The district lies between 6°7'S and 34°35'E covering an area of 28,620 km^2, which is about 58% of the entire area of Singida Region.

Two villages, Kamenyanga and Kintinku, were selected for this study. They are located in two distinct local agroecological zones, the former being on a plateau (slightly high terrain), while the latter is located in the rift valley.

Data collection and processing

Both secondary and primary data were collected to address the objectives of this study. Secondary sources included published research papers and relevant reports, rainfall and temperature data kept at the Meteorological Department, internet search, and other relevant sources. Primary data were collected using multiple approaches, including both quantitative and qualitative. PRA methods were used to collect primary data from the study area. The methods used included key informant interviews, focus group discussion (20 participants per village), household interviews (10% of households per village), historical mapping of different climate-related events over the past years that could be remembered, wealth ranking of different social economic groups based on local criteria they use, and direct field observations through transect walks.

Climate characteristics

The climate of Manyoni District is basically an inland equatorial type modified by the effects of altitude and distance from the equator. The district forms part of the semiarid central zone of Tanzania, experiencing low rainfall and short rainy seasons, which are often erratic, with fairly widespread drought of 1 year in 4. Manyoni District has a unimodal rainfall regime, which is concentrated in a period of 6 months from

November to April. The long-term mean annual rainfall is 624 mm with a standard deviation of 179 mm and a coefficient of variation of 28.7%. The long-term mean number of rainy days is 49 with a standard deviation of 15 days and a coefficient of variation of 30.6%. Generally, rainfall in the district is low and unreliable.

Results and discussion

Major economic activities

Farming is the major economic activity for 61.8% of the respondents in Kamenyanga and 56.9% in Kintinku. Although livestock is the second major economic activity in Kamenyanga (35.3%) and Kintinku (25.0%), all livestock keepers were also farmers and none of the respondents was keeping livestock alone. Petty business ranked as the third economic activity. However, the activity appeared to be of less importance to Kamenyanga (2.9%) as compared with Kintinku (18.1%).

Given that, farming and livestock keeping were the main economic activities in both villages. This implies that CC & V will have a far-reaching effect on the livelihoods of these communities.

Other minor economic activities included selling of local brew, which was common in Kamenyanga and was mainly done by women. According to interviewees, this activity has recently increased.

In addition, there has been an increase in the number of women involved in the production of charcoal and the collection and selling of firewood.

Local perceptions on long-term changes in temperature and rainfall

Respondents in Kamenyanga village (63.8%) and in Kintinku village (73.8%) perceived that there was an increase in temperature over the last 10 years. It has been reported that during this period, from September to December, the area becomes extremely hot, especially in Kintinku, and during the night it is very cold.

Most of the respondents in both villages perceived changes in the onset of rains (35.8% and 36.2% in Kamenyanga and Kintinku, respectively) a decrease in precipitation (35.8% and 25%, respectively) and an increase in frequency of drought (24.7% and 29.8%, respectively). The majority declared that onset of rainfall has changed because they used to plant crops in October/November but, nowadays, they have to plant in December/January.

Temperature and rainfall trends based on empirical data

Local perceptions by farmers with respect to changes in temperature as well as increasing rainfall variability were closely related to empirical analysis of rainfall and temperature trends using the data obtained from the meteorological station. Trend analysis of rainfall data indicated that annual rainfall decreased from 1922 to 2007, having a more pronounced decrease from 1982 onward.

Generally, in the past, rainfall in Manyoni used to start fading away in May. Currently, this is not the case as indicated by decreases in rainfall amounts and patterns. The onset of rainfall has shifted from October to November and the rainy season is shorter, ending in March or April. What can be noted is that the area might be receiving the same amount of rain, but there are changes in the distribution, therefore leading to floods and/or droughts. Also, there were changes in rainfall peak.

For farmers, this implies increased risk of crop failure due to poor seed germination, washing away of seeds and crops, stunted growth, and drying of crops caused by changes in rainfall pattern and amount. Sometimes, this leads to replowing and replanting, thereby increasing production costs. For livestock, this implies decreased pasture and increased incidence of parasites and diseases due to decreased rainfall (drought) and increased rainfall (floods).

Temperature change and variability

The average annual temperature increased by 0.7 °C. The analysis of annual average temperature over a period of 20 years (1984–2004) showed an increase in average annual temperature by 0.7 unit. Such a change is not surprising, but it validates the observation that global warming can be revealed, even at the local scale.

According to IPCC (2007), this increase in average temperature will adversely affect crops, especially in semiarid regions, where already heat is a limiting factor of production. Increased temperature also increases evaporation rates of soil and water bodies as well as evapotranspiration rate of plants and increases the chances of severe drought. It means that, with warmer temperatures, plants require more water.

Factors affecting crop production

Based on household surveys in both villages, it is apparent that climate change—related factors were the most important constraints to crop production. Ranked in the order of their importance are:

i) Unpredictable rainfall (unclear onset and ending of rains)

ii) Increased pest and disease incidence linked to warming

iii) Declining soil fertility associated with frequent drought

Increasingly unpredictable rainfall

Respondents reported experiencing delays in rainfall, sometimes receiving rainfall earlier than normal, leading to poor germination of seeds. This forces farmers to do multiple sowing of seeds. Also, more frequently, farmer reported experiencing long dry spells and drought, leading to low yield or total crop failure.

Increased pests and diseases

Farmers perceived an increased incidence of pests and diseases due to warming. For instance, more stalk borers (*Calidea dregii*), locally called *Mpipi,* attack maize, sorghum and rice. Also, ants, locally known as *nkeki*, were reported to be a major problem in rice/paddy nurseries. In both villages, qualea birds came out as another major pest of sorghum and rice.

Declining soil fertility

A number of factors contribute to declining soil fertility (Majule, 1999). This occurs, for example, when the mining of soil nutrients exceeds their replenishment, resulting in a negative balance of nutrients. Poor agronomic practices such as frequent fires tend to reduce soil organic matter, which is vital for conserving nutrients.

In the study villages, the removal of soil nutrients was mainly done through harvests and burning of crop residues. Linked to climate change, drought might have contributed to low soil productivity as it tends to reduce water in the soil, consequently affecting nutrient mineralization and their availability to crops.

Impacts on management of major crops

Farmers have changed most of their cropping practices due to changes in rainfall pattern and amount (see table). Planting methods for some crops such as maize and sorghum have also changed from broadcasting on flat land to row planting on ridges. This is basically aimed to encourage moisture conservation and reduce competition because of many plants in the area. Another common practice is planting early- and late- maturing crop varieties on the same plot.

Adaptation strategies

In response to the impacts associated with climate change and variability, communities in study villagers are implementing different adaptation measures.

Soil fertility improvement and management practices

Farmers in Kamenyanga and Kintinku ensure proper timing of different farming activities. Preparation of land for planting (locally known as *kubelega*) starts early enough (middle of July) to avoid unnecessary competition for labor during the peak period, which normally occurs soon after the onset of rains. Some farmers bury crop residues in the field so as to replenish the fertility of the soil, while others burn the residue to enhance quick release of nutrients.

Also, burning of residue is done to ease cultivation and is a way of controlling crop pests such as stalk borers. There was a small proportion of farmers who allow livestock to graze on farmland after harvesting the crop. Adaptation to impacts of CC & V in farming systems requires resilience against both excess of water (due to high intensity rainfall) and lack of water (due to extended drought periods).

Soil tillage practices

Farmers classify soils locally by using color, natural fertility, depth, and moisture-holding capacity. Two

Impacts of changes in rainfall pattern on cropping practices in Kamenyanga and Kintinku villages.

Farming operation	Maize	Bulrush millet and sorghum	Sweet potatoes	Finger millet	Paddy	Sunflower	Groundnuts
Planting time	Shifted from Oct/Nov to Dec/Jan	Shifted from Oct/ Nov to Dec/Jan	Shifted from Feb to Mar/Apr	On onset of rainfall, shifted from Nov to Dec/ Jan	Shifted from Nov to Dec/Jan	Shifted from Jan to Feb	Shifted from Nov to Dec/ Jan
Planting method	Shifted from broadcasting to ridging	Shifted from broadcasting to ridging	No change	No change	No change	Spacing on flat or ridges	No change
Changes in crops or varieties	Use both local and short varieties	Long and short variety of sorghum is used, only local variety of millet used	Local and short variety (Mkombozi)	Maintained local variety	Local and short varieties	New crop – *Pana* variety preferred	Local (ngogo) and short (Mamboleo)
Pest and disease incidence	Increased damage by *Calidea dregii*	Increased pests and disease (e.g., *Calidea dregii* and birds)	No change	No change	Increased insect pests (e.g., *Calidea dregii)*	New crop noted to be attacked by birds, rodents	Increased rodents
Harvest time	May to Jun/ Jul	May to Jun/Jul	Mar to Aug	No change	May to Jun/Jul	May to Jun	May to Jun/ Jul
Harvest amount	Decreased (from 20 to 10 bags/ha	Decreased (from 22.5 to 17.5 bags/ha)	Mkombozi is high-yielding variety	Relatively decreased	Relatively decreased	Fair	Relatively decreased
Storage method	Local storage facility and bags	Local storage facility to bags	No change	Local storage facility to bags	Local storage facility to bags	Bags	Local storage facility to bags
Storage problems	Increased pests	Sorghum attacked but not millet	*Mkombozi* has long shelf life	No change	Increased pests (e.g., rats)	Rats	Rats
Marketing	Increased market	Increased 4000 Tsh/20 kg	Increased market	Increased market	5,000 Tsh/20 kg	Oil price 28,000 Tsh/20L	700 T/S/H/ kg
Utilization	Food and cash, pasture	Food, cash and local brew	Food and cash	Food and cash	Food and cash	Food and cash, livestock feed	Food and cash

major dominant soil types are *mbuga* and sandy (*kichanga*) soil. Mbuga soil is dark in color, sticky, fertile, and holds moisture for a long time. Sandy soil is not fertile and easily loses moisture. Based on this categorization, farmers select crops and determine planting dates to match the different soils. It was reported that farmers plant maize and cassava crops on contour ridges, whereas bulrush millet, bambara nuts and groundnuts are planted in flat beds.

Farmers use contour ridges as a strategy to minimize soil erosion to encourage better root penetration and enhance moisture conservation.

Staggered seed crop planting

In both villages, most of the farmers use more than one plot for crop production. To avert crop production risks due to rainfall variability and drought, staggered planting is commonly done by most farmers, whereby crops are planted before rain onset (dry land) on uncultivated land. Others were planted immediately after the rains, while still other plots were planted a few days after the first rains. Tilling begins in fields that were planted prior to cultivation on the third week after the onset of rain, which also the destroys the early-germinating weeds and reduces weeding. These were done purposely to distribute risk by ensuring that rainfall was utilized to the maximum by the crop planted in the dry field (Liwenga, 2003).

Mixed cropping

Mixed cropping involves growing two or more crops in proximity in the same field. The system is commonly practiced in both villages where cereals (maize, sorghum), legumes (beans), and nuts (groundnuts) are grown together. From discussions with farmers, it was noted that they have a wide field knowledge of the advantages of mixing crops with varying attributes in terms of maturity period (e.g., maize and beans), drought tolerance (maize and sorghum), input requirements (cereals and legumes), and end uses of the product (e.g., maize as food and sunflower for cash). The study revealed that farmers diversify crop types as a way of spreading risks on the farm (Orindi and Eriksen 2005; Adger *et al.*, 2003). Crop diversification can serve as an insurance against rainfall variability.

Conclusions

Crop production and livestock keeping are the major agricultural activities in the semiarid areas of Tanzania. The study has been able to establish that rainfall and temperature in the study area have been decreasing and increasing, respectively, negatively affecting production and management of different crops. Different forms of changes in rainfall have been identified, including shrinking of rain season by a month due to late onset of rainfall period—shifting from October to November and ending in April instead of May.

The analysis and perception of the local people indicated a shift in the onset of long rains from October/November to December/January with shortening of rainfall period and increased frequency of drought. They used a combination of strategies to adapt: proper timing of agricultural operations, crop diversification, use of different crop varieties, changing the planting dates, increased use of water and soil conservation techniques and diversifying from farm to nonfarm activities. However, this study recommends that such measures need to be strengthened.

Source

Impacts of climate change and variability and adaptation strategies: The Case of Manyoni District in Singida Region, Tanzania by A. L. Mary[1] and A. E. Majule[2] in the African Journal of Environmental Science and Technology Vol. 3 (8), pp. 206–218, August, 2009. Available online at http://www.academicjournals.org/AJEST.
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Climate Change Impacts on Freshwater Resources and Water-dependent Services

Water is predicted to be the primary medium through which early climate change impacts will be felt by people, ecosystems, and economies. Both observational records and climate projections provide strong evidence that freshwater resources are vulnerable and have the potential to be strongly impacted. However, impacts on water resources and water-dependent services have yet to be adequately addressed in either scientific analyses or water policy.

This study aims to fill in some of the gaps. No new research is presented; rather the aim is to pull together what we know about the links between climate change and water, drawing on both the scientific and nonscientific literature, for an informed but non-specialist audience. Commissioned by WaterAid in the UK, this report has two broad objectives:

- To summarize current understanding of climate change projections and scenarios, and the impacts climate change may have on water resources, and water supply, sanitation and hygiene (WASH) in sub-Saharan Africa (SSA) and South Asia.

- To discuss implications of the above for policy and practice at a range of different levels—from funding for climate change adaptation at an international level to the planning and implementation of WASH interventions at a community level.

It is important to note the marked absence of literature on climate change and sanitation. As such, this report has largely focused on water resources and water supply. A key conclusion is that more research is required to better understand the impacts of climate change on existing sanitation systems and to identify effective responses to current and future climate change.

The key messages of the report can be distilled into three main areas.

Climate change impacts on water variables and implications for WASH

- There is large uncertainty with respect to climate change predictions and impacts on future water availability and quality in SSA and South Asia. Global warming is projected to cause an intensification of present climatic and hydrological variability in Africa and South Asia and may cause extreme events, such as tropical storms, floods, and drought, to increase in frequency and intensity.
- In terms of water availability, projected effects include more seasonal and higher intensity rainfall, increasing seasonality of river flows, modification of groundwater recharge patterns, and risk of significant reduction in the volume of reliable surface water resources. Implications include reductions in the reliability of rainwater-harvesting schemes, greater need for and reliance on both natural and man-made water storage, the potential breaching of (and damage to) low-capacity sewage and drainage systems, and increased dependence on groundwater in Africa and South Asia to meet future water demand.
- In terms of water quality, climate change is likely to exacerbate existing problems. More intense rainfall events will result in increased turbidity of surface water as well as higher (seasonal) contaminant loading of shallow groundwater, possibly leading to an increase in water-borne diseases. Increased flooding may also overwhelm currently used sanitary protection measures leading to damage of infrastructure and water contamination. In coastal areas, there is likely to be significant incursion of saltwater into aquifers as sea levels rise.
- Climate change will put a premium on information about water resources, yet few countries know about the quantity, quality, distribution, and reliability of their water resources, about how they are being used, or which water sources are functional. Monitoring systems need to be strengthened as a matter of priority, particularly for groundwater resources.
- Climate change is one of a number of pressures on water and livelihoods. In many countries, there are multiple, interrelated pressures, including demographic shifts, urbanization, changing patterns and levels of consumption, and pollution-drivers of change that will affect the supply of water, the demand for water, or both. These other drivers may pose bigger threats to water resources and water-dependent services than climate change, at least over the short-medium term.
- Water scarcity is not physically determined; access, entitlements, and equity also matter. Conventional notions of scarcity that focus on water availability, privileged in current climate change debates, sideline crucial supply-side issues of rainfall variability and water distribution and, on the demand side, downplay the importance of access and equity. The water 'crisis' is a crisis for the poor, with its roots in politics and institutions, rather than water availability. Hence, extending access to reliable and affordable water and sanitation services remains key to strengthening livelihoods and building resilience to climate change.
- Refocusing the debate on water security offers a way forward, emphasizing the importance of resource access and entitlements as well as water availability, quality, distribution, and reliability. Water security can be defined as the availability of, and access to, water sufficient in quantity and quality to meet the production, livelihood, and health needs of populations, together with an acceptable level of water-related risk.

Policy responses and policy engagement

- Adaptation to the impacts of current and future climate change is unavoidable, whether planned or unplanned. Adaptation is now viewed as an essential component of any climate change policy. Arguments now focus on which countries need to adapt, which sectors/areas/groups are most vulnerable, how best to provide support, and the level and type of finance required.

- Adaptation aimed at enhancing the capacity of systems to respond and adapt to climate change will require greater efforts to address the underlying causes of vulnerability and longer term planning beyond 'immediate needs.' Promoting flexible forward-looking decisionmaking and governance is needed to reduce the risks of maladaptation.

- At a global level, the policy response to adaptation is primarily being carried out under the United Nations Framework Convention on Climate Change (UNFCCC). Planning focuses on three issue-areas: developing a shared vision on adaptation, identifying means to implement adaptation, and enhancing financial and technical support for adaptation.

- At a national level, government responses have centered on the creation of national adaptation programs of action (NAPAs) and reporting actions through national communications. NAPAs focus on assessing vulnerability to climate change, identifying adaptation strategies, and identifying means to implement adaptation strategies, typically project-based. While the process of NAPA preparation has generally been successful in raising awareness of climate change and encouraging dialogue, adaptation plans have not been mainstreamed into broader development policies, including poverty reduction strategies and water resource management. Nonetheless, most NAPAs identify water as a vulnerable 'sector' and attach importance to water-related adaptation.

- A number of approaches, including vulnerability assessment, scenario-based planning, adaptive management, mainstreaming, and community and ecosystem-based management, have been developed to facilitate the adaptation, planning, and implementation process. However, the value-added of 'new' approaches is sometimes questionable: the most effective form of adaptation will remain robust, climate-resilient development.

- Stakeholders can engage in the adaptation planning process at global, national, and local levels. Areas of engagement include feeding into vulnerability, hazard and adaptation assessments to fill existing knowledge gaps; disseminating climate-related knowledge (on impacts and adaptation options) to local and national levels to facilitate the decisionmaking process; and climate-proofing ongoing and future programs and projects.

Operational responses and pro-poor adaptation

- Both WASH and water resource management investments can be 'screened' for climate risks using the tool kits described in this report. Screening aims to ascertain the extent to which existing development projects consider climate risks, identify strategies for incorporating climate change into projects, and guide project managers toward risk-minimizing options. A major challenge is to ensure that a 'top-down' approach is combined with 'bottom-up' inputs. An aggravating circumstance in most countries is also the gap in knowledge in terms of both observational data and in understanding how climate change will affect the hydrological cycle and water-dependent services at the temporal and spatial scales relevant to decisionmaking.

- To promote pro-poor adaptation, existing approaches such as water safety planning could be extended to include screening for climate change risks and impacts. New frameworks have also been developed such as CRiSTAL, a community-based screening tool kit. Drawing on a Sustainable Livelihoods Framework (SLF), it aims to help users understand links between livelihoods and climate and to assess a project's impact on community adaptive capacity. This tool kit could potentially be applied to water resource management interventions, but further analysis and field-testing are required to determine its effectiveness. In view of the 'data gap' in most developing countries and difficulties in downscaling climate projections at the basin scale and below, scenario-based approaches that consider a range of different climate futures are recommended.

- Lessons have been learned from implementing community-level adaptation projects. These include the need for a wide-reaching communication strategy, the need for interventions that build on existing coping strategies, the importance of broad-based livelihood improvement and vulnerability reduction, and the importance of national and local 'political' support. Equity issues—the distribution of climate change costs and the benefits arising from planned adaptation interventions—have only been patchily integrated into project design thus far.

- Given the uncertainties surrounding the impacts of climate change on water, planning around technology choice should be 'robust of uncertainty' (i.e., appropriate to a range of different rainfall and runoff conditions). This implies a greater focus on the reliability of different sources, for example, siting boreholes and deeper wells in more productive aquifers, favoring development of larger springs, and the strengthening of sanitary protection measures. However, the use of more vulnerable sources, such as shallow wells, should not be ruled out completely, especially in combination with other technologies that, collectively, spread risk and provide water for different uses.

Source

Climate change, water resources and WASH: A scoping study by Roger Calow[1], Helen Bonsor[2], Lindsey Jones[1], Simon O'Meally[3], Alan MacDonald[2], Nanki Kaur[3]. ODI Working Papers Overseas, Development Institute,
[2] British Geological Survey,
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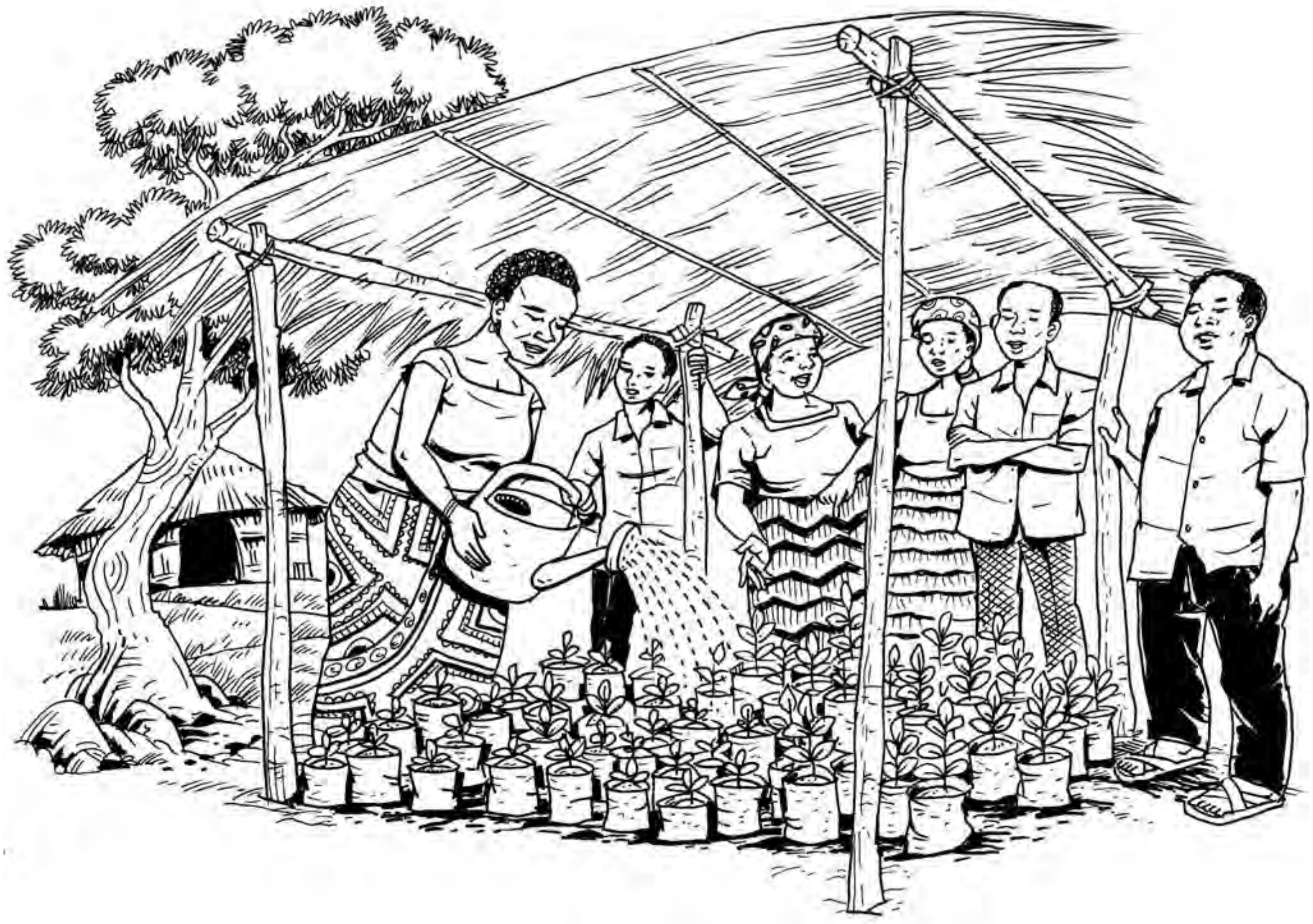
Building Community Resilience to Climate Change through Water-Smart Agriculture



KDWSP is a faith-based organization (FBO) that has been providing sustainable water and sanitation services to the rural poor, and water has stressed the communities of Kigezi Diocese since its inception in 1986.

Rubaya and Butanda subcounties in Kabale District, southwestern Uganda, are heavily cultivated hills that range from 1,219 m (3,999 ft) to 2,347 m (7,700 ft) above sea level. Mean annual rainfall is 1,092 mm. The rainy seasons are from March to May and from September to November, with intervening light rains. The June to August spell is the main dry season, while from December to February, the rains are usually light. About two million people live in the district, making it one of the most highly populated in the country.

The catchment area in the district comprises steep slopes, deeply narrow valleys of the Kigezi highlands, Lake Bunyonyi, River Ruhezagyende, and expansive swampy areas, 58% of which have been reclaimed for agriculture (NEMA, 2008).

In this area, pollution, urbanization, industrialization, and other challenges greatly affect water resources. Besides, low productivity, disease, malnutrition, slow economic growth, social instability, and conflicts over resources have made the communities more vulnerable to degradation of environmental resources.

The main challenge to the water sector was in developing platforms for disseminating information on technologies, best practices, knowledge and experiences on water resources. It took great efforts to ensure that all stakeholders benefit and feel they are part of the process. The government's response to the challenge was seen in the Water Action Plan (WAP) released in 1993–94 to provide a flexible and dynamic framework for developing and managing Uganda's water resources.

KDWSP employed an integrated water resource management approach in a successful pilot project, thereby reaching 408 households (2,448 beneficiaries) in the two subcounties. This project promoted and coordinated development and management of water, land, and related resources. It aimed at equitably maximizing the resultant economic and social welfare without compromising sustainability of vital ecosystems. The project started in June 2011 and ended in December 2013.

Agriculture is the backbone of Uganda's economy, constituting about 42% of the GDP, more than 90% of export earnings, and employing about 86% of the labor force. However, the contribution of agriculture to total GDP has decreased from 45.7% in 1995–96 to 41.5% in 1999–2000.

Problems

High population exerts lots of pressure on very scarce and fragmented land and its resources. This is so in the face of poor methods of farming, soil exhaustion due to destruction of soil structures, and deforestation for many economic and social reasons. The famous Kigezi terraces constructed during the colonial times have been heavily degraded and poorly maintained. As a result, landslides, floods, gullies, and erosion have brushed off fertile soils into lower streams.

Further, destruction, sedimentation, siltation, and pollution of water sources from floods and local gin effluents had compromised environmental and community health. More destruction of water projects such as gravity flow schemes of Kahungye and Muguli, gardens, homes, and latrines compounded the problem. Water sources were polluted by farmers spraying crops and vegetables because the rains would wash the chemicals into the soils, which would then percolate into water systems.

More so, the rate of vegetation destruction was increasingly high with the rising population pressure and high poverty levels amidst limited alternative means of livelihoods. There was also pollution from local gin production plants with effluent discharges into water sources.

The community lacked appropriate technologies, best practices, and knowledge on the relationship between water and land resources, and how mismanaging one of them compromises the other. This inevitably affects the humanity that survives on such vital ecosystems. They could not systemically appreciate their problems.

Implementation

To mitigate these problems, a participatory project analysis was conducted. This entailed resource mapping of vulnerabilities and assessing threats and severity of depletion from a cause-and-effect perspective. It also required capturing community attitudes and dynamics, re-engaging of traditional interventions and measures, and involving the concerned stakeholders. This approach helped in defining problems, setting priorities, action planning, capacity-building training and implementing the project.

KDWSP facilitated the formation and training of the catchment management organization and the resource user groups (charcoal burners, environmentalists, farmers, water user committees, and local gin producers). This strategically helped empower and put the community at the forefront of project implementation and sustainability.

Implementation involved the construction of conservation channels, energy-saving stoves, contour furrows and check dams, punctuated with soil-filled gunny bags constructed across formed gullies at intervals to trap the silt. All water resource banks were buffered with environment-friendly projects.

The communities were empowered to establish and manage nursery beds to improve green cover. Although replacing cut trees is good, it is not an effective method of recovering environmental benefits and, alternatively, an energy-saving stove was devised to check this gap. This stove, crafted with a heating unit, a cooling chamber, and a slug channel leading to a soak pit, became an effective facility adopted, promoted, and widely used in the community to check negative pollution of the environment.

As well, there was need to create awareness in the community. The project established information and knowledge-sharing platforms for dissemination, learning, and training. Thematic messages were packaged in a video documentary, reports and music, and dance and drama pieces from farmer field schools. This strongly appealed to a wider audience, including mandated institutions and civil society at community, subcounty, district, regional, and national levels.

KDWSP monitored and supported the implementation processes of resources, whereas user groups and the community worked together to deliver these projects with external support. This helped the project extend technical support and review practices and activities during implementation.

Methodology

The implementation was participatory as community members were involved in identifying and analyzing the problems, devising solutions, and training them how to implement and sustain the use of the technology.

The community mobilized locally available materials (resources) such as stones, sand, unskilled labor, and food contributions.

Equitably and inclusively, most interest groups, especially women, youth, and all institutions in the community participated, thereby bringing diverse stakeholders on board to capture wider interests and enhance project acceptability.

Results

Five soil and water conservation (SWC) channels and 135 check dams were buffered and excavated of average capacity 2-6 m^3 punctuated with soil-filled gunny bags and elephant grass. These have helped retain water for recharge and re-use and healed many gullies.

A functional and effective catchment network of stakeholders was established for learning and relearning. This involved the district level water resources management body, mandated institutions, opinion leaders, political leaders, and representatives of resource users to capture the interests of all stakeholders.

Contact farmers in the catchment area planted 1,200 sugar canes, 900 seedlings of different tree species, 1,500 passion fruit, 200 tomato trees, and 600 grafted avocados. Four community-managed nursery beds were established to improve on the green cover while boosting their livelihood.

Twenty-three households were supported with energy-saving stoves. Five local distillery industries also received improved energy-saving stoves, each accommodating 24 heating containers. Energy consumption was cut to a quarter from what it had been previously, and firewood that previously lasted for only a single day now lasts 4 days.

Members of six water user committees were trained and refreshed; 179 artisans trained in rainwater-harvesting technologies have constructed 200 rainwater-harvesting ferrocement tanks (4,000 liters) and six institutional tanks (20,000–50,000 liters) to increase access to clean water for consumption, agriculture and environmental benefit, and to check water runoff.

Challenges

The slow adaptation capacity and delayed shift in the mindset of farmers to help them move from traditional framing to conservation agriculture presented barriers to adoption.

Land fragmentation and scarcity were a challenge and a limitation to adaptation of best practices and resource bank protection.

Lessons

Community-led initiatives that address problems in the community have defined themselves; these have provided a reliable premise for sustainability. Interventions that may contravene some values or policies should be well-defined to minimize conflicts.

Proper identification of real hot spots and devising appropriate technologies for intervention and agreeing on interventions have contributed to acceptability of the project and community participation.

The success of the project depends on the degree of the problem being addressed with alternatives and minimal interruption in people's livelihoods.

Recommendations

Communities need participatory project analysis to achieve their full participation right from inception through implementation and sustainability of rolled-out project.

Conservation farming methods should be adapted to replace traditional means of farming to address issues of poverty as well.

Project commitments and promises must be made on realistic and sustainable interventions.

Local communities should be empowered to enable them to transform from being vulnerable beneficiaries to active stakeholders, who operate at the forefront of every intervention. This can bring multiplier effects to the community.

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Water-Smart Agriculture through Adoption of Drought-tolerant Crops

The primary goal of promoting water-smart agriculture (WaSA) is to support water management efforts in agriculture and increase crop productivity for every drop of water used. Similarly, there is a strong element of ensuring food security in promoting WaSA through drought-tolerant crops in Nakapiripirit, Karamoja Subregion by the Ecological Christian Organisation (ECO), a non-governmental organization with support from Cordaid. The practice also tries to build resilient communities in fragile ecosystems such as those Karamoja in to enhance sustainable management of resources, understanding the possible scenarios of climate change and disaster risk reduction measures with respect to livelihood.

The promotion of drought-tolerant crops started in 2012, targeting local agro-pastoral farmers in Lolachat and Nabilutuk subcounties as primary beneficiaries. ECO did a survey in October 2014 among the direct project beneficiaries to assess the effectiveness of growing drought-tolerant crops among other adaptation measures. In that survey, 78% of respondents strongly agreed that using drought-tolerant crops is a contextually effective and affordable measure. Other measures include weather information, early warning centers, drip irrigation, apiary, development of bye-laws and use of energy-saving stoves.

Nakapiripirit District

Nakapiripirit is one of the districts of Karamoja, a semiarid area located in northeastern Uganda that comprises six other districts: Kaabong, Kotido, Abim, Napak, Moroto, and Amudat. The district is home to about 26,870 people and economically, about 85.6% of the rural population live below the poverty line—less than 1 dollar/day (UBOS, 2012). The area is characterized by low and unreliable rainfall, a unimodal rainfall pattern with one planting season, vulnerability to frequent droughts and persisting food shortage. Mean annual rainfall ranges between 600 and 1,000 mm. The area is characterized by low groundwater recharge, high potential evaporation, and growing water demand (MWE, 2013).

There is a water challenge cycle in Karamoja as demonstrated by low inputs into the system and high output rates. Being an agro-pastoral setting, water is needed for crops, animals, domestic use, and environmental needs. This puts pressure on the limited water resources and thus requires smart practices that ensure sustainable use and effective mitigation of disasters. Drought is the major hydro-meteorological challenge in Nakapiripirit, which leads to crop failure and food shortage (UNDP, 2013).

Why drought-tolerant crops?

Drought-tolerant crops are being promoted as they are able to adapt to water-stressed situations. They also have low feeding habits and low nutrient needs, among other physiological advantages that drive the necessary management practices. Studies have shown that many areas with low and erratic rainfall, where crop water stress is common, are also deficient in nutrients. This deficiency is frequently the second most limiting soil factor. An interaction often occurs between soil water and nutrients, which means that soil water can influence the availability of nutrients, which availability can, in turn, affect the uptake of soil water and crop resistance to drought. Thus, reciprocally, both factors can influence each other. As a result, water deficiencies become more quickly apparent and damaging than nutrient shortages. This suggests that conserving water may often have priority and quicker benefit over attempting to conserve soil particles per se (FAO, 2014).

FAO Uganda in 2010 commissioned a study in the Karamoja subregion to ensure three adaptation strategies, namely: continuous agricultural production and development, water management, and ecosystem environmental protection. It identified drought-tolerant and early-maturing crops available for community uptake. Both traditional and improved varieties were identified and recommended.
Crops recommended include sorghum varieties (indigenous) such as Tinyitinyi, Akirikir, Naterekune, Tinyang, Ekabir, and Loyokou, and improved ones like Sekedo. Other crops include green gram, cowpea (*Vigna unguiculata*), K131 beans, Tepari beans, pigeon pea, cassava Katumani, pearl millet, and bulrush millet.

Growing drought-tolerant crops

Communities have long been cultivating some drought-tolerant crops such as sorghum, and millet. However, studies on the above crops have been carried out by various research institutions like the National Agricultural Research Organisation-Nakapiripirit ZARDI, and the National Agricultural Crop Research Institute Namulonge (NaCRRI). Local communities, through practical observation of varieties and practices in their fields, also contribute to experiential knowledge, thus making the practice adoptable.

Promotion is done through advocacy, sensitization, and direct support to agro-pastoralists by giving inputs such as seeds and gardening tools, teaching good agronomic practices, and providing training.

Awareness and advocacy as prerequisites

Essential is the community awareness of both indigenous and improved varieties, their sources and markets, handling and propagation procedures, importance of the practice and their overall contribution to soil health, agro-pastoralism, water resources and human well-being. The effectiveness of the practice to produce high-yielding and drought-tolerant crops largely depends on variety, environmental conditions, and management.

The sensitization helped build consensus, achieve

Table 1. Comparison of water uptake of various crops (FAO, 1996)

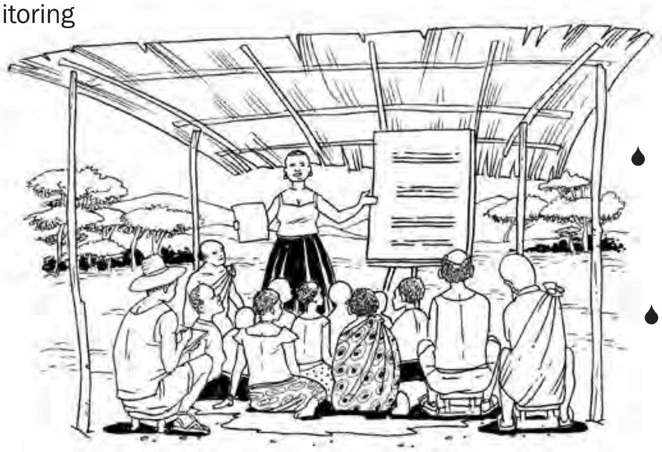
Food	Crop coefficient	Growth period (days)	Daily crop water requirement (mm/day)	Seasonal crop water requirement (mm/day)
Sim sim ground	0.8	120	3.3	396
Nuts	0.8	130	3.3	429
Sorghum	0.8	125	3.3	412.5
Green gram	0.875	90	3.6	324
Cowpea	0.875	100	3.6	360
Millet	0.6	105	2.5	262.5
Maize	0.825	120	3.4	408
Banana	0.75	365	3.1	1131.5
Beans	0.75	90	3.1	279
Sugar cane	0.95	365	3.9	1423.5

greater understanding of the practice, manage expectations, and facilitate wider adoption.

Drought-tolerant crop selection and cultivation

The community was given a number of alternatives to choose from and practice. ECO has directly supported 2,000 households by supplying seed of their chosen crops—these included green gram, simsim, groundnut, sorghum, and cowpea. Very few people were interested in millet. The beneficiaries have organized themselves into 78 groups since 2012, composed of women, men, the youth, and the elderly. ECO has reached other stakeholders through awareness campaigns and advocacy meetings at the local, district, and national levels. Households participated in both group gardens and private (own) gardens and the model was hailed for being able to spread risks, enable collective action, learning and sharing, and strengthen community cohesion. Monitoring of progress was easy because each group has a leadership structure. The leaders ensure communication, keep records, address conflicts, convene meetings, and facilitate management.

Most of the crops planted have been doing well though yield varies across communities due to a number of factors. Farmers are encouraged to plant various crops and varieties so that they can complement each other, and spread the risk. Drought-tolerant cropping in Nakapiripirit and areas with related environmental conditions is unique given the various benefits that accrue. For instance, they require attention to site-specific attributes, harmonization of efforts, and ability to strengthen linkages between research and policy to inform practice and vice versa, which are vital to WaSA. It promotes comparative advantages in agricultural production, supports food security, and mitigates overconsumption of resources like water, and enables producing within resource capacity means, among others. Beneficiaries have greatly endorsed the practice as effective for their local setting.



Key results

- Promotion of drought-tolerant crops has resulted in commendable acceptance of agriculture in a predominantly pastoral community, evidenced by the wide adoption of drought-tolerant crops.
- Local communities are more aware of and concerned about issues of climate change and how to adapt to climate and become water-smart. This has been achieved through

accompanying the provision of drought-tolerant crops by awareness and weather information dissemination.

- In a region characterized by one growing season, members are able to produce good and increasing crop yields out of their gardens through agricultural intensification. The recent survey by ECO established a qualitative increase in crop yields among agro-pastoralists and an increase in agro-land acreage since 2012. Evident in the survey, crop yields have risen from 43% to 48% among most beneficiaries who cultivated within acreage range of 1.5–2.5 ha compared with the time before the interventions. The increase varies according to group, community, individual, year, season, and agronomic practices used. For instance, people/groups and individuals who planted early at the onset of the rainy season usually reported better yields than those who planted late.
- Through proper agronomic training accompanying the practice, communities have learned new agricultural techniques and/ or reinforced the traditional agro-pastoral knowledge. Currently, the communities are ably intercropping, planting in rows, planting early following the onset of rains, seeking out guidance on crop varieties to plant, and deploying other soil and water conservation techniques that they had never used before such as mulching.
- Growing drought-tolerant crops has benefited the various households, development partners, government, private sector businesses dealing with agro-inputs, research institutions in the region, and ECO through the ability to realize their missions and objectives of sustainably improving the food situation.
- There is noticeable behavioral and attitude change, improved decisionmaking, reduced need for humanitarian intervention, informed agro-decision making by the implementing partners, and better research use/application for the related institutions in the project area compared with the past.
- Lastly, optimizing soil moisture is one other key result through the adoption of drought-tolerant crop. Most crops such as banana and sugarcane use large quantities of water, which under rainfed conditions come entirely from water in the soil. Thus, crops that are light feeders like sorghum tend not to overdrain the soils, making them fit for an already soil water-stressed area.

Key challenges

- High rural poverty levels are a key challenge in promoting related interventions and their sustainable uptake. Most community members cannot afford seeds, improved varieties, and on-site field studies of their soils.
- High levels of illiteracy where 86% of project beneficiaries could not write and read (ECO survey, 2014) constitute a barrier. This hinders farmer record keeping, reading, and research on interventions individually.
- While promotion of indigenous drought-tolerant crops is appreciated by many farmers, these farmers sometimes exhibit bias in the promotion of trial varieties. They are interested in new varieties that raise their expectations, and when their expectations are not quickly and easily met, they get demoralized.

Limitations

- Use of drought-tolerant crops alone is ‘no silver bullet’ to increase crop yield, and confront soil and water challenges in the area. They require packaging well with other supportive interventions, and understanding the technicalities involved, which are normally hard to comprehend locally.
- Climate change effects amidst other naturally existing challenges of aridity and low soil fertility also hinder the performance of these crops.
- Projects are unable to quantitatively establish the water smartness of crops in various fields.

Key lessons

- Beneficiaries mostly focus on output and impact rather than on practice/mode. ECO directly links the practice to the community needs and visions they developed, demonstrating how drought-tolerant crops contribute to the attainment of the Vision 2020 maps of the various communities developed and adapting technical terminologies to local understandable concepts.

- Drought-tolerant crops are water-smart, given their physiological makeup. Therefore, promoting them in drought-prone areas results in higher adoption.
- Also learned, the communities have long developed confidence and attachment to their indigenous varieties. If found worthy, they should be promoted more by re-cultivating confidence in the use of these varieties.

Conclusion

Substantive studies have been done on existing and new varieties of potential drought-tolerant crops that can be planted in semi-arid areas like Karamoja and other relatively dry environments. These crops are found to have mechanisms that are adaptable to water stress conditions and thus use available water effectively and efficiently. These studies inform our decision to promote drought-tolerant crops with the end in mind. The crops are worthwhile ventures to enable food security and are greatly endorsed by the local communities. However, drought-tolerant crops also require additional support of good agronomic practices, continuous monitoring of enabling factors, and also alternative exploration of livelihood options. Depending on available resources, ECO plans to scale up to other parts of Karamoja with related messages, continued evidence-based advocacy, and direct support. They intend to continue building linkages with research institutes and work with other players who support livelihood improvement in Karamoja as well.

Key recommendations

- WaSA should be promoted through comprehensive and informed communication about the available options fit for setting drought-tolerant crops in water-stressed areas.
- Continuous support to livelihood improvement interventions through use of drought-tolerant crops and other livelihood options is necessary to reduce overdependence on fields in the Karamoja subregion.
- Recognize soil and water as key and living components of the environment. To date, it has received far less attention in comparison with the aboveground components, which are more readily perceived, and should therefore be promoted.
- Usefulness of rainwater and organic matter should be promoted. By recycling through different biotic processes as many times as possible, adoption of multiple soil and water conservation techniques will support the natural elements of drought-tolerant crops.
- Focus should be on socio-environmental acceptability rather than on textbook philosophy. Research should bear a clear understanding of the people and their social-cultural perspectives, build consensus, and mobilize local support.
- There is a need for more research on indigenous varieties that can easily be adopted, are affordable, and can be replicated. Research finding must be disseminated to the people who need them in easy-to-comprehend terms.
- Continuous linking with research institutions to keep abreast of local and other site-specific agricultural requirements and knowledge should be encouraged and promoted to ease adoption of WaSA practices and technologies for development.

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Use of Drought-tolerant Crops as a Strategy for Efficient Use of Available Water: Sorghum in Same, Tanzania

Semiarid areas are characterized by low and erratic rainfall, accompanied by high evaporation rates that exceed the amount of rainfall occurring annually. There is general water scarcity, which is partly a result of climate changes and variability and partly a result of increased competition for limited water resources. Climate change and abstractions over the past decades have reduced in-stream flows. A good example is Pangani River Basin where in-stream flow has been reduced from several hundreds to less than 40 m^3/s (IUCN, 2003).

Same District in the Kilimanjaro region of Tanzania experiences semiarid condition in the western lowlands of Makanya, Hedaru, Same, Ruvu and Mwembe wards. Rainfall in these areas shows a high degree of variability and unpredictability, which seems to be increasing over time, with impact on both food and livelihood security. It is therefore apparent that water is essential for crop production and the single most important aspect of crop production that determines yield (Directorate for Agriculture, Irrigation and Cooperatives-SAME, 2013). However, the existing traditional irrigation system appears to be insufficient to serve the needs of the majority of the households and Same District thus faces frequent food shortages. The Same district council therefore decided to promote and encourage farmers to grow sorghum as an intervention to ensure food security (Deutscher Entwicklungsdienst Ded-SAME, 2010).

In Tanzania, sorghum is the third most important cereal after maize and rice. Sorghum is grown as a staple in the semi-arid areas of the Central Zone (Dodoma and Singida). In other areas of Tanzania, such as Mwanza, Shinyanga, Mara, Morogoro, Pwani, Mtwara, Lindi, Mbeya, Tabora, Manyara and Kilimanjaro, sorghum is grown mainly for food security. It is used and processed into traditional foods, fermented and unfermented flat and leavened breads, thin and thick porridges, steamed and boiled cooked products, snack foods, and alcoholic and nonalcoholic beverages. Tanzania annually produces around 600,000 tons of sorghum.

Sorghum production as a water-smart strategy

Water-smart agriculture includes promotion of, water-use-efficient techniques through selection of crop varieties with ability to survive drought. These drought-tolerant crops include sorghum, lablab, cassava, millet, and sweet potato. The paper focuses on sorghum production in Same District.

Sorghum *(Sorghum bicolor* [L.] Moench*)* is a crop indigenous to Africa; it is a relatively drought-tolerant crop that can be produced over a range of water availability levels (e.g., full irrigation to deficit irrigation or under rainfed conditions). The highly drought-tolerant sorghum usually yields better than maize on soils with poor fertility. It is often the feed grain of choice where irrigation capacity is limited. It requires about 350–600 mm of rainfall to mature and are therefore suitable in semiarid areas where rainfall ranges from 500 to 800 mm/annum, as in Same District. The crop performs much better when land is properly managed and soil and water- conserving and water-harvesting practices are done.

Sorghum tolerates drought better than most other grain crops. This trait can be attributed to:

- Its exceptionally well-developed and finely branched root system, which is very efficient in absorbing water.
- Its small leaf area, which limits transpiration.
- Its leaves folding up more efficiently during warm, dry conditions (compared with maize's).
- Its effective transpiration ratio of 1:310 (the plant uses only 310 parts of water to produce one part of dry matter) compared with maize's 1:400.
- Its leaf epidermis being corky and covered with a waxy layer, which prevents plant desiccation.
- Its stomata closing rapidly to limit water loss.
- Its ability to remain in a virtually dormant stage during dry periods, and then to resume growth as soon as conditions become favorable.
- The ability of side shoots can develop and form seed (even if the main stem dies), when water supply improves.

Farmers in many parts of Same (especially in the western lowlands) grow mainly maize under rainfed conditions. Maize yield has drastically declined in the last 15 years (DAICO–Same District, 2010)—from 0 to 1.5 tons per hectare, depending on variety, soil fertility, and management practice. This is in contrast to yields in other places such as Meru District in Arusha where they get as high as 7.5 tons per hectare (DAICO–Meru District, 2013). On the other hand, the yield of sorghum in Same ranges from 1.25 to 2.5 tons per hectare. Sorghum is more water-smart compared with maize and other cereals due to higher production from little available rainfall (Fig. 1).

This paper aims to discuss improvement of water use efficiency by planting sorghum, which has the ability to survive drought, in order to improve production and productivity and thus enhance food security and standard of living of people in semiarid areas.

Methodology

The methodology involved documenting field experience, observations, interviews, and literature review. From these, the Same district council, in collaboration with development partners, decided to start a sorghum development program. Implementation started by sensitizing village leaders on the importance of planting sorghum. This was followed by establishing demonstration plots and farmer field schools and training of champion farmers on improved methods of sorghum production. Improved seeds were supplied to these champion farmers for use in their demonstration plots.

Fig. 1. Maize is not a good option in semiarid conditions.

Participatory approaches and tools were used in the preparation of plans to implement a demand-driven program so as to promote self-employment and ensure sustainable projects. Through participatory approaches, village communities were enabled to prepare village agricultural development plans (VADPs). These VADPs later on became the basis of district agricultural development plans. The most frequently identified problem was poor crop performance due to erratic rainfall. This has led to shortages of food, progressively low income for farmers, poor contribution to development activities, and low standard of living.

The sorghum development program in Same District is being implemented in 10 villages, including Mwembe. The program started in 2012 in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Selian Agriculture Research Institute (SARI) through the Sorghum for Multiple Use Project (SMU).

Results and discussion

Key achievements

- The perceptions of smallholder farmers, especially women, toward the initiatives are positive. Morale is very high as they realize that, by planting sorghum, they can get more yield, more income, and more food.
- Farmer's knowledge of appropriate sorghum farming techniques has increased. About 1400 farmers grew sorghum in 600 acres in the 2013/2014 season.
- There was increasing demand for sorghum at Same, which has resulted in increased prices of up to Tsh 1500–2000 per kg.
- Increased food security among farmers—from 0 maize/acre to 8 bags of sorghum.

Key challenges

- The main challenge encountered is the inadequate knowledge among farmers about sorghum as a water-smart crop and its appropriate farming method. There is very little understanding of the drought tolerance ability of sorghum. Majority of the farmers do not know the proper agronomic practices for sorghum. This has caused reluctance among farmers to grow the crop.
- Sorghum is attacked by birds at the milking stage.

Solutions

- Capacity building of farmers. Several activities may be done to achieve this: establishment of farmer field schools (FFS), establishment

The champion farmer

Mrs. Walter Mjema lives in Mwembe village in Tanzania's Kilimanjaro region. This dry area receives less than 400 mm of rain each year. Climate change is affecting rainfall patterns. The traditionally rainy months of October and November have not brought steady rains for the last 2 years.

Mrs. Mjema is a champion farmer who participated in the implementation of the Care GWI II program. She has also been involved in the Small-scale Innovation Project as a researcher farmer. She practices and demonstrates soil and water conservation and water-harvesting techniques in her farm.

"I have been growing sorghum since 2011. Every year, I harvest not less than 10 bags (100 kg each) of sorghum from my small piece of land of 1.25 acres. Before sorghum, I used to grow maize on that land. Because of drought, production was very poor. I hardly get five bags of maize," says Mrs. Mjema.

Her family sold nine bags of sorghum last season and got Tsh 900,000. They used that money to buy 5 bags of maize (Tsh 250,000) and the rest was used to meet family needs like tuition. "I get food and money, so I am happy being food-secured".

Mrs. Mjema further explains, "I have experienced that, without any supplementary irrigation, sorghum performs well and yields are reasonable, meaning that growing sorghum is an efficient way of utilizing available little rainwater in the village. I therefore agree with agriculture extension officers who say that sorghum is a drought-tolerant crop. And as a champion farmer, I advise and encourage other farmers in the village to grow it. So far, more than 50 farmers at Mwembe Village followed my footsteps."

of demonstration plots, training of farmers on sorghum production and processing through seminars, workshops, and study visits.

- Encouraging farmers to use rainwater harvest technology and small-scale irrigation. Farmers are also motivated to cultivate drought-tolerant crops such as lablab, cassava, millet, and sweet potato.

Conclusions

In line with the 2013 national agricultural policy, adoption of water-smart sorghum is critical to achieve food security. The policy intends to promote rainwater use efficiency in order to enhance water productivity. This can be achieved through selection of crop varieties that are able to survive drought and applying small quantities of water at critical times. The crops chosen for dry farming should either be drought-evasive or drought-tolerant. Production of drought-tolerant crops such as sorghum can help farmers improve yield in semiarid areas, improve food security, and improve income. The use of sorghum can mitigate the effects of climate change on global food production.

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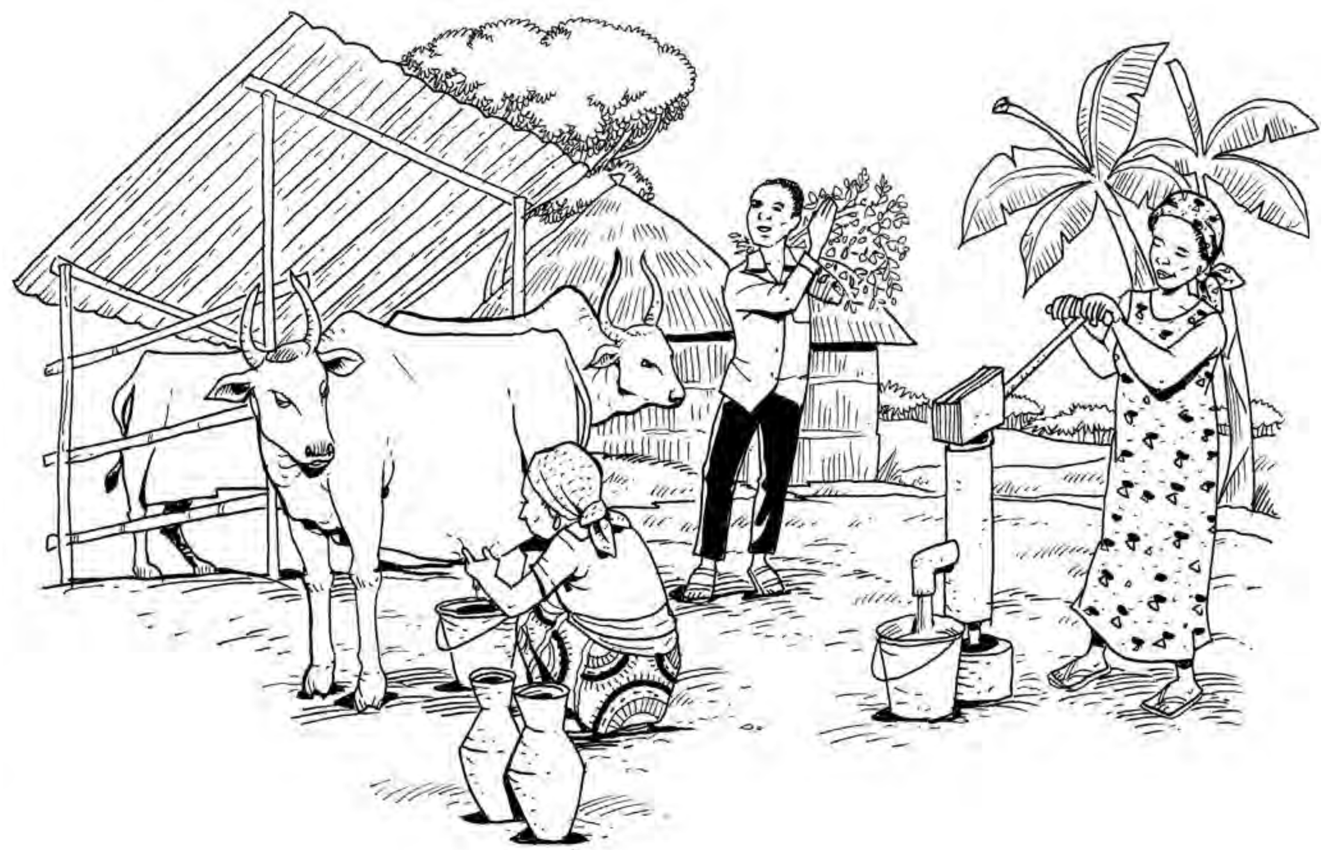
Improving Livestock Water Productivity:
Lessons from the Nile River Basin



Many criticisms regarding livestock keeping in recent years stem from the perception in developed countries that animal production consumes too much water, especially in a world where farmers' access to water resources is decreasing. Research conducted over the past 10 years confirms that excessive water use is common, especially for beef production in industrialized countries. However, understanding water use in small-scale livestock farming systems in many developing countries requires a different way of thinking. This article highlights key research findings from a project in the Nile River Basin (Awulachew *et al.*, 2012), along with their implications for agricultural water management in general and livestock keeping in particular. The results are drawn primarily from the Consultative Group on International Agricultural Research (CGIAR) Comprehensive Assessment of Water Management in Agriculture (2007) and the CGIAR Challenge Program on Water and Food.

Key research findings

- Rainfall is the ultimate agricultural water resource. Past research and development focused on management of blue-water resources, which include rivers, lakes and streams, particularly for irrigation. However, about 60% of global rainfall accumulates as soil water and evaporates or transpires directly to the atmosphere without passing through blue-water bodies. This is termed green water (Falkenmark and Rockstrom, 2006).

- The Nile River Basin receives about 1,900 billion m^3 of rainfall per year. About 4% (80 billion m^3) passes through the river and lakes of the Nile to reach Lake Nasser, Egypt. Of the Nile catchment area, 62% is used for livestock grazing and mixed crop-livestock systems, and it receives about 85% (1,600 billion m^3) of total basin rainfall (Peden *et al.*, 2009). Evapotranspiration (ET) from green water in these agricultural areas is 63% (1,200 billion m^3) of basin rainfall. Access to more rainfall and surface flow water and using it more productively and effectively for the benefit of people and nature offer the greatest opportunity for improved cropping and livestock production.

- Inappropriate management of both livestock grazing and mixed crop-livestock systems is a leading cause of land degradation or desertification in the Nile Basin. Loss of vegetative cover, biomass and production characterizes land degradation and results in sub-optimally high evaporation (E) and low transpiration (T) rates. Because T is a primary driver of plant production, conversion of nonproductive E to productive T is key to improving crop and livestock water productivity. Here, we focus on livestock water productivity (Anonymous 2009), but simultaneous consideration of cultivation practices and conservation of natural biodiversity remains necessary.

- Although drinking water is crucial to animal production, the amount of water required to produce animal feed may be 100 times greater than that for direct animal intake. By focusing on water use for feed production and the impacts of livestock-keeping on hydrology, increasing livestock water productivity (LWP) can help enhance beneficial goods and services derived from domestic animals while making more effective use of available water in rainfed agriculture.

Livestock water productivity

Within an agricultural system, rainfall is the primary source of water, but surface flow from upstream areas can be locally important. Depletion usually refers to the volume of water lost from an agroecosystem and includes transpiration, evaporation, and downstream discharge. LWP is a scale-dependent concept. For example, water depleted from a small upstream watershed may be available to downstream users.

LWP is the ratio of the total value of goods and services derived from domestic animals to the amount of water depleted as a cost of livestock-keeping (Fig. 1). Livestock provides multiple benefits and services such as meat, milk, hides, manure, farm power and a preferred means to accumulate wealth. To increase LWP, we must increase the benefits animals provide or reduce the amount of water depleted through livestock-keeping. To assess multiple benefits, we can monetize and use monetary equivalents such as US$ per cubic meter of water depleted. While non-monetary cultural benefits remain important, they were not addressed in this research. There are four basic LWP-enhancing strategies:

1. Feed sourcing and management strategies require procurement of feeds with a low water cost of production (WCP). A prime example is using food-feed crops in mixed crop-livestock systems. Growing 1 dry weight kg of a crop such as teff, maize or sorghum typically requires 2-3 m^3 of water. After harvest, crop residues used to sustain domestic animals constitute feed that requires no additional water. Notwithstanding farmers' potential use of crop residues for fuel, home construction and soil nutrient replenishment, effective use of food-feed crops reduces the WCP of both crop and animal products. In some cases, such as dryland pastures, forage may have a relatively lower WCP because available water cannot sustain competitive demands from cultivation. Within water-scarce areas, importation of feed for livestock creates no additional local demand for water, although it likely will do so elsewhere.

2. Production-enhancing strategies help maximize benefits derived from animal production per unit volume of water depleted. Water used to produce feed for sick and dying animals results in little or no benefit to producers. Thus, veterinary care, provision of appropriate nutrients and creation of a stress-free environment helps increase LWP, as can enhancing market opportunities for animal products.

3. Water-conserving strategies help increase LWP by shifting evaporation to transpiration. For example, overgrazing depletes vegetative

cover, resulting in high evaporation and low transpiration in rangelands. Better pasture management through seasonally varying and sustainable stocking rates and rehabilitation of degraded areas fosters higher transpiration rates by encouraging infiltration of rainwater, replenishing soil fertility and maintaining a critical mass of live plant biomass that can respond to the onset of rains. In addition, well-managed vegetative buffer strips around the edges of lakes, rivers and ponds limit degradation of water quality through sedimentation and contamination with pathogens. A 3-meter wide vegetative buffer can filter out >90% of sediments and zoonotic pathogens, helping to maintain down-slope water quality. In many countries, these buffer zones are protected by law, although enforcement is rare.

4. Strategically allocating spatial and temporal distributions of livestock, drinking water and feed resources will allow for sustainability in animal production. Under free-grazing systems, the LWP is low because the cattle concentrate around drinking water supplies, which results in overgrazing near water sources while undergrazing occurs elsewhere.

Rather than technical fixes, these strategies involve having access to and adopting an appropriate mix of technology, training and education, community participation, investment, marketing opportunities and coherent governance. This is especially true where livestock, land, water and market development depend on access to common-property natural resources managed through local institutions and various levels and branches of government. These strategies need integration with development priorities related to improving cultivation practices, adapting to climate change and promoting agricultural markets.

Integrating irrigation development with livestock keeping is important. Africa-wide, the highest livestock densities are associated with large-scale irrigation (Peden *et al.*, 2006). Large-scale irrigation, such as in Gezira (Sudan), often generates abundant crop residues and nutritional supplements that can sustain meat and dairy production and thus farm income. Yet planners often fail to provide access to safe and sustainable watering sites, veterinary services and corrals. In small-scale irrigation, water harvesting can also help to increase LWP and

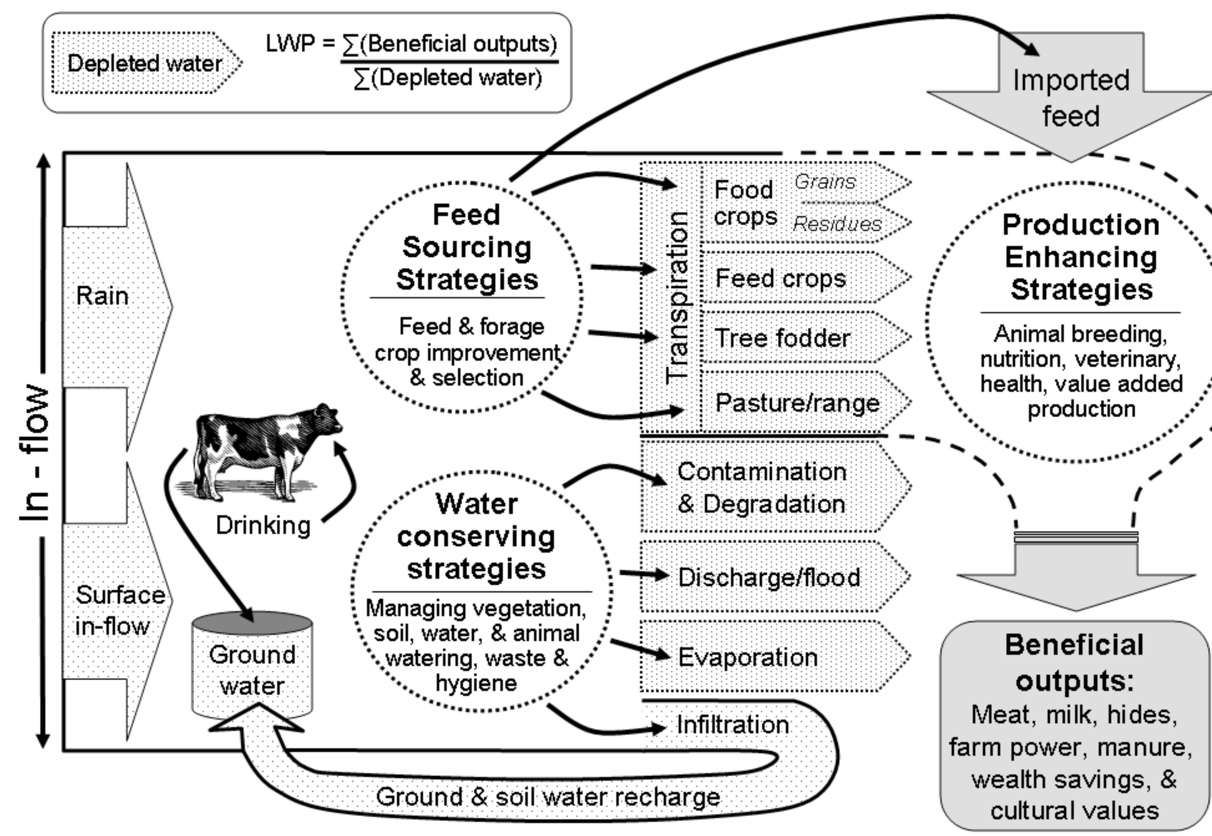


Fig. 1. LWP depends on water accounting principles and helps identify opportunities for more effective water use; (Peden et al. 2012)

farm income (see case 1 below). Ironically, much investment in African irrigation aims to reduce poverty. When successful, many farmers use the extra income to acquire livestock as a means to grow and secure wealth.

Rather than using a fixed set of recommendations, there is need to gain a better understanding of the local situation. An assessment of agricultural water use is necessary to identify appropriate intervention options, as shown in the two case studies which follow.

Case 1: Smallholder Ethiopian farming in Ethiopia (Fig. 2). In the Awash River Basin, a group of farmers with mean annual income of about US$300 were trapped in poverty. A few local cows and subsistence cultivation sustained them. Sasakawa-Global 2000 and the International Livestock Research Institute (ILRI) provided training and loans of about US$1,100 per household. This credit enabled construction of underground water tanks and establishment of supplemental irrigation of cash crops such as garlic and onions. Irrigation water was collected from household water catchments of about 2,500 m^2. The farmers also replaced local cows with hybrid cows that combined benefits of indigenous and Friesen breeds. Daily milk production rose from about one to almost 20 liters. Farmers converted milk into butter and procured feed resources. The stored water eliminated the need for children to trek long distances daily to the river to water their animals and enabled them to attend school. Farmers also introduced "cut-and-carry" feeding and use of crop residues. Within 3 years, family income rose more than 300%. Marketing of vegetables and milk represented 40% and 60% of their increased income, respectively. Loans were repaid over a 3-year period during which net farm income also rose. Marketing of dairy products and cash crops, along with improved productivity of crops and milk, generated increased beneficial income and, combined with decreasing non-productive water depletion (run-off), resulted in higher agricultural water productivity.

Case 2: Rehabilitating degraded rangelands in Uganda (Fig. 3). In Nakasongola District, Uganda, overgrazing and excessive charcoal production led to severe loss of vegetation and the feed and ecosystem services it provides, greatly increasing termite damage. Resultant land degradation forced herders to abandon their land and migrate to new areas. Uncontrolled animal access to drinking water led to bacterial contamination and loss of riparian buffer vegetation. Soil carried by runoff from upstream areas filled ponds or valley tanks with sediment, reducing water storage capacity. With loss of available drinking water, herders were forced to trek long distances to Nile riparian areas for drinking and grazing in the dry season. Stress associated with forced migration led to high rates of animal morbidity and mortality. Researchers from Makerere University and ILRI collaborated with livestock keepers to rehabilitate pastures and improve valley tank management. By restoring grass production, herders transformed excessive evaporation into transpiration, thereby increasing forage production and LWP. By providing vegetative buffers and separate drinking troughs, valley tanks retain greater storage capacity and water quality.

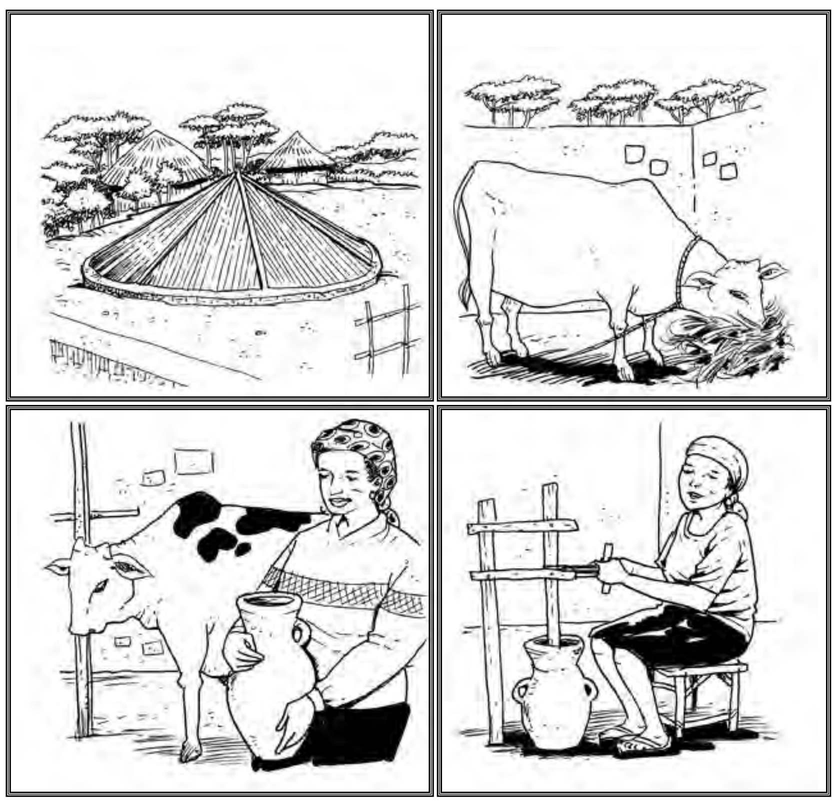


Fig. 2. *Water harvesting (top left) for supplemental irrigation for cash crops combined with cut-and-carry feeding (top right) of improved dairy cows (bottom left) and conversion of milk to butter (bottom right).*

Fig. 3. *Rehabilitating pastures (left) and improving water management (right) increased LWP, enabling more productive and sustainable animal production.*

Conclusion

LWP takes an interdisciplinary agroecosystem approach to achieve more effective, sustainable and productive use of agricultural water for animal production. It calls for better feed sourcing and management, adoption of best-bet animal production technology, and improved water conservation. Increasing LWP requires appropriate technology within the context of multi-stakeholder participation and enabling financial and governance systems. In African rainfed agriculture, the greatest opportunity for increasing LWP lies in capturing non-productive evaporation and converting it into productive transpiration, a strategy that can increase water availability and access without increasing competition for already scarce blue-water resources.

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Source

Improving Livestock Water Productivity: Lessons from the Nile River Basin by Don Peden. January 27, 2014. Ethiopia. Email: d.peden@cgiar.org

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Improving Water Productivity in Crop-livestock Systems of Drought-prone Regions

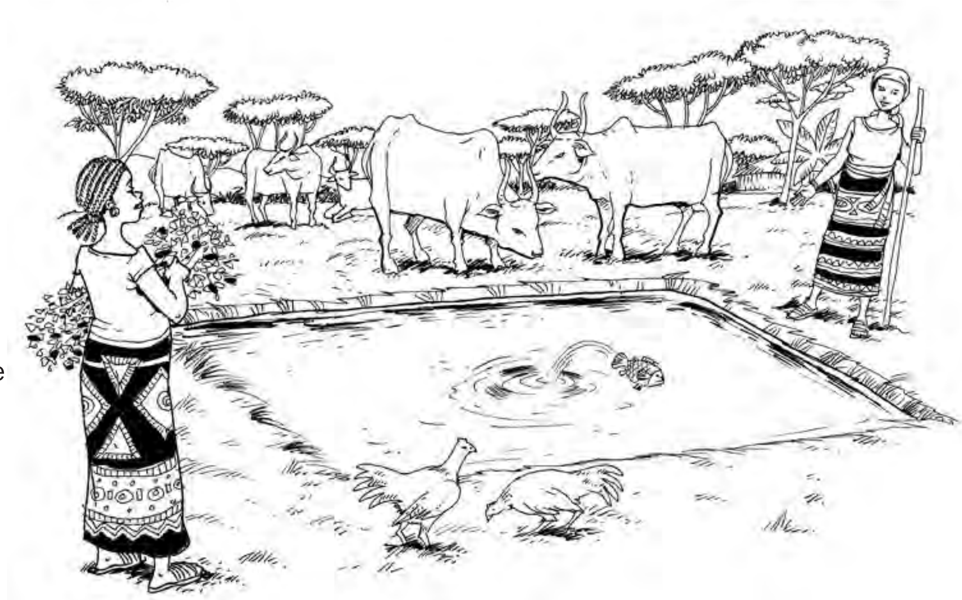
Crop-livestock systems in sub-Saharan Africa (SSA) are mostly rainfall-dependent and based on fragmented marginal lands that are vulnerable to soil erosion, drought and variable weather conditions. The threat of water scarcity in these systems is real due to expanding demand for food and feed, climate variability and inappropriate land use (Amede *et al.*, 2009). According to recent estimates, farming, industrial and urban needs in developing countries will increase water demand in 40% by 2030 (FAO, 2009). Water shortage is expected to be severe in areas where the amount of rainfall will decrease due to climate change. The lack of capacity of communities living in drought-prone regions to respond to market opportunities, climatic variability and associated water scarcity also result from very low water storage facilities, poverty and limited institutional capacities to efficiently manage the available water resources at local, national and basin scales. The spiral of watershed degradation causes a decline in water budgets (Awlachew and Ayana, 2011), decreases soil fertility, reduces farm incomes in SSA (Amede and Taboge, 2007) and reduces crop and livestock water productivity (Descheemaeker *et al.*, 2011). In areas where irrigated agriculture is feasible, there is an increasing demand for water and competition among different users and uses.

Strategies and policies to reduce rural poverty should not only target increasing food production but should also emphasize improving water productivity (WP) at farm, landscape, sub-basin and higher levels. In drought-prone rural areas, an increase of 1% in crop water productivity makes available at least an extra 24 liters of water a day per person (FAO, 2003). Moreover, farming systems with efficient use of water resources are commonly responsive to external and internal drivers of change. This paper presents evidence from Ethiopia, Zimbabwe and India and captures current understanding of strategies to improve water productivity in drought-prone crop-livestock systems.

Molden *et al.* (1997) defined water productivity as the ratio of beneficial outputs and services to water depleted in producing them, which could be expressed in terms of amount (e.g., kg grain per m^3 of water) or value (e.g., US$ per m^3 of water).Definitions of WP could vary based on the purpose, scale and domain of analysis. Water productivity enables assessment of interactions between different system elements (e.g., livestock and crop) and creates an enabling environment for a better understanding of system efficiency (Peden *et al.*, 2009; Haileslassie *et al.*, 2011). The volume of water depleted to produce a similar type of animal product also varies among systems (Haileslassie *et al.*, 2011) and is affected by the type of inputs and management practices used. For instance, WP of livestock is strongly linked to that of feeds (Descheemaeker *et al.*, 2011). In the crop-livestock systems of India, Haileslassie *et al.* (2011) noted that the largest component of total water consumption in livestock systems was the production of irrigated fodder while the smallest component was use of crop residues. In fact, the WP of livestock positively correlates with the percentage share of crop residues in the diet (Haileslassie *et al.*, 2011).Water productivity was also higher for intensive systems than extensive systems (Clement *et al.*, 2011).

There are proven interventions that would improve water productivity in these systems. Interventions focused on improving feed management, water management and livestock management had a positive effect on improving water productivity (Peden *et al.*, 2009) ranging from a potential 4 to 94% improvement (Descheemaeker *et al.*, 2011). Improved livestock health, leading to lower mortality rates, led to greater animal outputs from the same feed and water consumption. Reducing animal numbers also led to reductions in depleted water, land used and feed produced, but resulted in higher milk and meat production, due to savings in energy for non-productive activities and maintenance (Descheemaeker *et al.*, 2011). Descheemaeker *et al.* showed that combining several different interventions using integrated approaches across spatial and temporal scales led to greater improvement in water productivity as compared to any single intervention: the whole was greater than the sum of the parts. Creating fertile spots around houses is a common practice in SSA where farmers grow crops for food security and cash (Amede *et al.*, 2011). The homestead plots, which are favored for application of household refuse, manure and night soil, are also enriched by nutrients coming from the outfields in the form of feed and mulch (Amede and Taboge, 2007) and tend to have higher WP than the less fertile outfields. Introducing zai pits, which are small water harvesting holes dug during the dry season and then filled with handfuls of biomass, as an example of water conserving structures in these less fertile and sometimes degraded outfields increased potato yields five-fold and bean yields three-fold compared to the local practices, and WP was 300–700% higher (Amede *et al.*, 2011).

Irrigation is another important intervention to minimize drought effects and improve rural livelihoods of drought-prone regions. However, the return per irrigation investment in the region has been low to date. In an assessment of irrigation schemes in Ethiopia, Awlachew and Ayana (2011) reported that 87% of all schemes are operating, 74% of the command areas are cultivated but only 47% of the planned beneficiaries benefited from irrigation. Large-scale schemes using pumps show higher water use efficiency than simple gravity diversion types. Understanding the water budgets of the irrigation schemes and water distribution across the different uses is also a prerequisite to minimize water loss and encourage productive use of water. In an attempt to quantify water losses in small-scale irrigation schemes in Ethiopia (Demeku *et al.*, 2011) found that about 35% of the applied irrigation was lost as unproductive water with the water loss from the main, secondary and field canals being 26, 4.5 and 4%, respectively. These authors also found that incentives for farmers are critical to improve water management at farm and landscape scales. In situations where farmers were required to rent irrigation pumps, they have minimized unproductive water loss, increased productive water and got higher farm returns. However, financial capacity of farmers, which commonly enables them to gain access and control over water, is highly variable, location specific and dynamic even under a relatively homogenous biophysical and social context (Clement *et al.*, 2011). For instance, in India the better-off farmers who have their own water source and who only need to pay diesel costs to access irrigation water might be more willing to accept changes in water management or cropping practices. The inequities in water access are also commonly deep rooted in land ownership (physical accessibility to water harvesting structure or location relative to the irrigation canal), and are difficult to challenge. Interventions aimed at increasing water productivity do not always necessarily benefit the poorest members of rural communities or the women—rather these might favor the better-off farmers who have access to a wide range of resources and connections (Clement *et al.*, 2011). By excluding women from water users' and livestock producers' associations (e.g., in Zimbabwe), the community commonly loses out on a significant opportunity to increase water productivity and potentially higher returns from crop and livestock investments (Senda *et al.*, 2011). These systems could be more efficient and equitable through capacitating local institutions and improving governance of collectively managed irrigation schemes, grazing lands and hillside exclosures (Deneke *et al.*, 2011).



One of the major drivers in SSA affecting water management has been land use and land cover change as a result of human actions and enterprise choices that, in turn, alter the availability of water resources for various uses. In a detailed study in the Ethiopian highlands, Ali *et al.* (2011) reported that land use change was much faster in relatively water-rich regions compared to dry crop-livestock systems. For instance in Fogera, in the Northern Ethiopian wetlands, land which used to be allocated for livestock rearing up to the mid 1980s has been converted to an intensive rice-based system with the introduction of paddy rice. The consequence was an increased water depletion and intensification of crop-livestock systems, but also increased water productivity through producing food and cash crops three times in a year. On the other hand, a drier landscape, Lenche Dima, had undergone minimal change in the same period except for a shift of the livestock population towards small ruminants. Crop-livestock systems that are affected by rapid land use changes and associated decline in water budgets and nutrient depletion could be best managed through integrated rainwater management systems.

Rainwater management is an integrated strategy that enables crop-livestock systems to systematically capture, store and efficiently use water and nutrient resources on farms and watersheds in a sustainable way for both agricultural and domestic purposes. It focuses more on the institutions and policies than on the technologies and advocates increased water storage and WP at various scales; in the soils, farms, landscapes, reservoirs and basins. Rainwater management is an effective strategy to manage the consequences of climate change (e.g. floods and drought) by combining water management with land and vegetation management. This is particularly critical for Eastern and Southern Africa where the rate of land degradation is rapid and about 70% of the land falls within drought-prone regions (http://www.un.org/esa/sustdev/csd/csd16/rim/eca_bg3.pdf).

In general, several opportunities exist for increasing agricultural WP in SSA. Integrated research and development focused on improving WP across enterprises, scales and systems can enable communities to improve their capacity to adapt to and enhance their resilience to challenges such as climate change and food insecurity. An interdisciplinary and multi-institutional approach, which recognizes the complexity of water use and management and water governance,would provide strategies to produce more food, feed and income. An inclusive research for development approach, which places poor farmers and women at the center of water research, is needed. Three strategies came out of this project:

1. The most important strategy to improve water productivity is increasing productive water use (transpiration) over unproductive water depletion (evaporation and seepage) through adoption of soil and water conservation practices, appropriate choice of crop varieties, improved irrigation efficiency and integrated crop-livestock systems.

2. Adoption of interventions for improving water productivity is mostly governed by socio-economic situations of rural households. Understanding wealth and gender dynamics is a critical tool to target clients. Identifying incentive mechanisms for communities to invest in land and water management and empowering communities to make appropriate decisions in managing land, water and livestock resources would enhance the likelihood of adoption of interventions by farming communities.

3. Interventions for improving water productivity are diverse, ranging from selecting water-efficient crop and forage varieties to watershed management, which involves various disciplines and institutions. Achieving water productivity at farm and watershed scales demands closer interaction and linkages among various actors, which could be achieved through skillful facilitation and better communication.

Source

This article is drawn from *Improving water productivity in crop-livestock system of drought-prone regions*, by T. Amede, S. Tarawall, and D. Peden, Exp. Agric. 47: 1-5.

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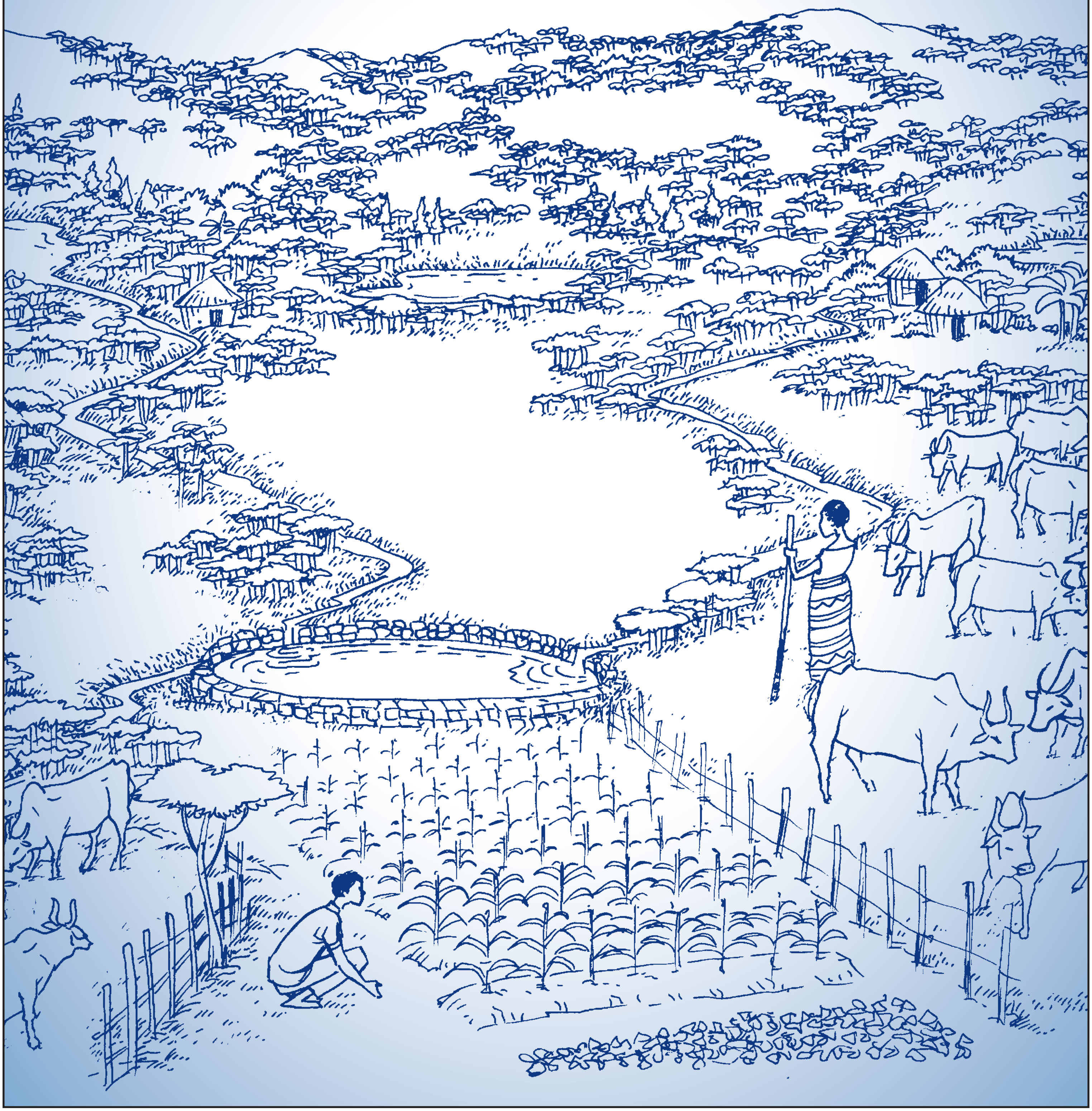
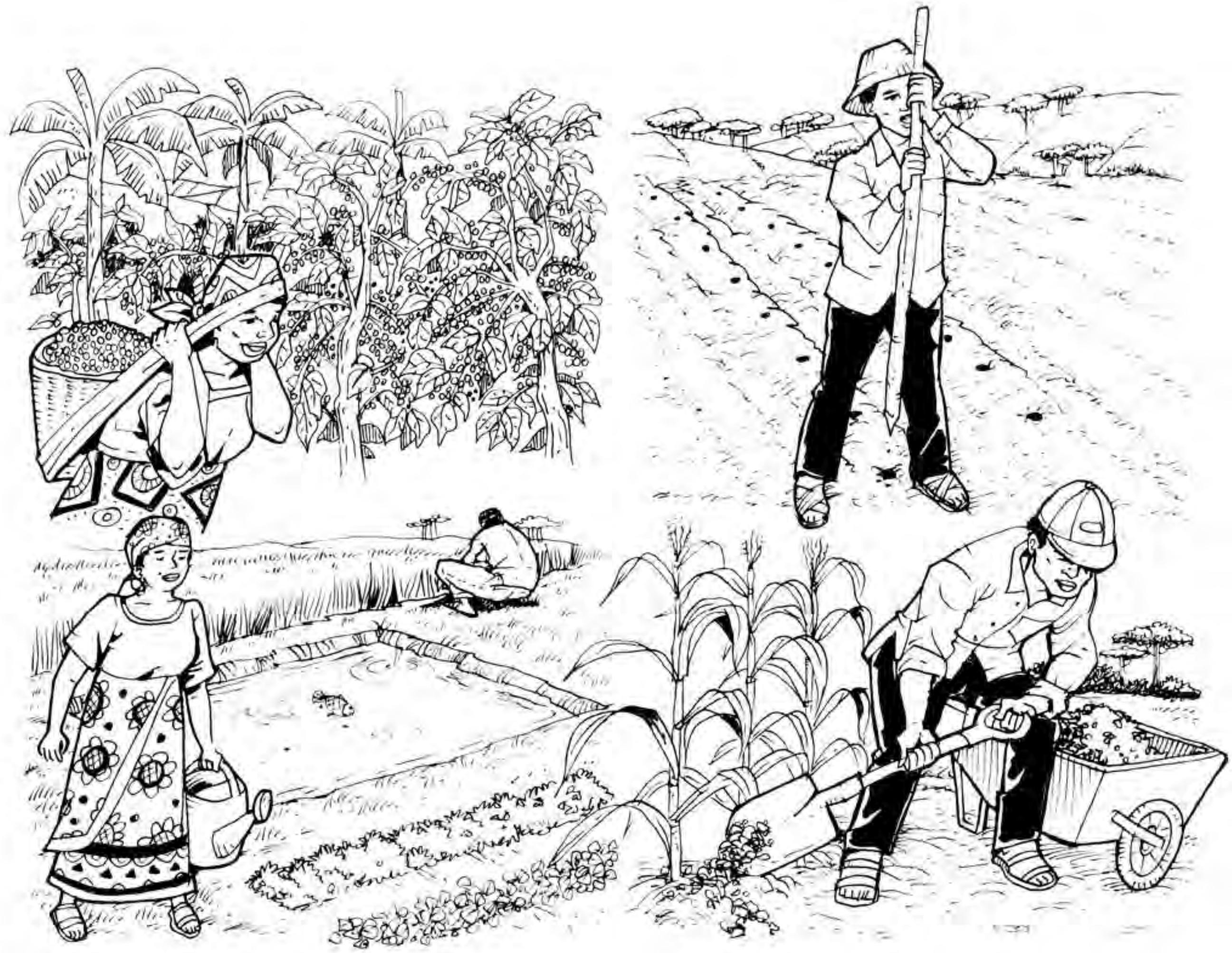
Sustaining Landscapes 2



Improving Land and Water Management



The world's food production systems face enormous challenges. Millions of farmers in developing countries are struggling to feed their families as they contend with land degradation, land use pressures, and climate change. Many smallholder farmers must deal with low and unpredictable crop yields and incomes, as well as chronic food insecurity. These challenges are particularly acute in sub-Saharan Africa's drylands, where land degradation, depleted soil fertility, water stress, and high costs of fertilizers contribute to low crop yields and associated poverty and hunger.

Farmers and scientists have identified a wide range of land and water management practices that can address land degradation and increase long-term agricultural productivity. The benefits of these improved land and water management practices to farmers and rural economies include higher crop yields, increased supplies of other valuable goods such as firewood and fodder, increased income and employment opportunities, and increased resilience to climate change. These benefits can be brought about through the following improved land and water management practices:

- increased soil organic matter,
- improved soil structure,
- reduced soil erosion,
- increased water filtration,
- increased water-use efficiency,

- replenished soil nutrients, and
- increased nutrient uptake efficiency.

Four of the most promising improved land and water management practices that are particularly relevant to the drylands of sub-Saharan Africa are:

1. Agroforestry—the deliberate integration of woody perennial plants—trees and shrubs—with crops or livestock on the same tract of land.
2. Conservation agriculture—a combination of reduced tillage, retention of crop residues or maintenance of cover crops, and crop rotation or diversification.
3. Rainwater harvesting—low-cost practices—such as planting pits, stone bunds, and earthen trenches along slopes—that capture and collect rainfall before it runs off farm fields.
4. Integrated soil fertility management—the combined use of judicious amounts of mineral fertilizers and soil amendments such as manure, crop residues, compost, leaf litter, lime, or phosphate rock.

The benefits of these four practices and their observed impacts on crop yields and other measurable benefits to farmers and rural communities are considerable. For example,

1. Agroforestry. In Malawi, maize yields increased by about 50% when nitrogen-fixing *Faidherbia albida* trees were planted in farms. In Senegal, the presence of *Piliostigma reticulatum* and *Guiera senegalensis* shrubs in fields has increased nutrient use efficiency over sole crop systems and has helped to create "islands of fertility" that have greater soil organic matter, nitrogen, and phosphorus concentrations under their canopies than in open areas.
2. Conservation agriculture. In Zambia, maize yields in conservation agriculture systems with crop rotation can be more than 50% higher than yields under conventionally tilled maize.
3. Rainwater harvesting. Farmers in Burkina Faso have doubled grain yields using multiple water-harvesting techniques, including stone bunds and planting pits.
4. Integrated soil fertility management. In West Africa, adoption of integrated soil fertility management across more than 200,000 ha resulted in yield increases of 33–58% over a 4-year period and revenue increases of 179% from maize and 50% from cassava and cowpea.

Farmers have realized even greater benefits when combining these practices and have further enhanced yields when combining them with conventional agricultural technology solutions such as fertilizers and improved seed varieties. An example of a cost-effective, complementary practice is "micro-dosing," the targeted application of small quantities of fertilizer—often just a cupful—directly to crop seeds or young shoots at planting time or when the rains fall. Nearly 500,000 smallholder farmers in Mali, Burkina Faso, and Niger have learned the micro-dosing technique and have experienced increases in sorghum and millet yields of 44–120%, along with an increase in family incomes of 50–130%.

These four improved land and water management practices can help smallholders boost crop yields and provide other benefits on individual farms. However, in many situations, sustaining or improving agricultural productivity will require coordination between resource users situated in different parts of the larger landscape, including in nonfarmed lands, wetlands, forests, and rangelands. Integrated landscape approaches bring sectors and stakeholders together to jointly plan, design, and manage their landscapes for improved agricultural production, ecosystem conservation, and sustainable livelihoods.

In spite of the multiple benefits of improved land and water management, adoption by smallholders remains limited in most regions. Some of the commonly cited barriers include a lack of awareness of the appropriate practices and their benefits, as well as low levels of investment in knowledge dissemination. In many cases, national policies and legislation do not provide sufficient incentives—such as secure land tenure and property rights—to stimulate farmers to invest in improved land and water management. Many smallholder farmers are not reached by extension agents at all. And where extension does exist, too often agroforestry, conservation agriculture, and other improved land and water management practices are insufficiently integrated.

Still, there is vast potential to scale up the improved management of land and water resources as an integral component of agricultural development strategies. In sub-Saharan Africa, conditions are ripe for investing in agroforestry and other improved practices on croplands covering more than 300 million ha. If improved land and water management practices were implemented on just 25% of this cropland to increase crop yields by an average of 50%, farmers would produce 22 million more tons of food per year. Such a scale-up could potentially provide 285 million people living in Africa's drylands with an additional 615 kcal per person per day.

The productivity of degraded agricultural land can be restored and crop yields boosted if tens of millions of smallholder farmers were motivated to invest their labor and their limited financial resources in these proven land and water management practices. This working paper proposes seven pathways to accelerate scale-up of these improved practices.

1. Strengthen knowledge management systems and access to information.
2. Increase communication and outreach in ways that amplify the voices of champions and leverage direct engagement with farmers.
3. Support institutional and policy reforms, particularly for strengthening property rights.
4. Support capacity building, particularly in community-based management of natural resources.
5. Increase support for integrated landscape management.
6. Reinforce economic incentives and private sector engagement.
7. Mainstream investments in improved land and water management to catalyze adoption of these practices as a strategic component of food security and climate change adaptation programs.

While smallholder farmers are the key actors, many other entities and organizations have a role to play in implementing these strategies. National governments should create enabling agricultural development policies—as well as land tenure and forestry legislation—that secure farmers' rights to their land and recognize their ownership of on-farm trees. Governments also should create enabling conditions for the private sector to invest in market-based approaches to strengthening agroforestry value chains. The public and private sector—working with local communities, international partners and development assistance organizations—can take these improved practices to scale by investing in knowledge management, communication, and outreach, which will help restore agricultural productivity, enhance rural livelihoods, and contribute to a sustainable food future.

Integrated landscape approaches

The four improved land and water management practices described above can help smallholders boost crop yields, sustain resources, and provide other benefits on individual farms. However, in many situations, sustaining or improving agricultural productivity will require coordination between resource users and managers situated in different parts of the larger landscape, including nonfarmed lands, wetlands, forests, and rangelands. As pressures increase on land, water, and biological resources—and as initiatives with multiple development objectives work in the same or adjacent and connected landscapes—a new set of approaches has also emerged to address and manage these pressures and sometimes conflicting objectives. Integrated landscape approaches bring sectors and stakeholders together to jointly plan, design, and manage their landscapes and institutional resources for improved agricultural production, biodiversity and ecosystem conservation, and sustainable livelihoods (Box 1).

Box 1. *Integrated landscape approach.*

Society has begun to recognize that farmland is important for more than just the production of food calories. Society values and benefits from a range of goods and services provided by healthy ecosystems that support agricultural production systems across rural landscapes (Ranganathan *et al.*, 2008). These include not only the production of grain, fodder, wood and other agricultural products, and ecosystem services that directly benefit farming (e.g., pollination, pest management, irrigation), but also other services such as source-water protection and the recharge of aquifers for diverse uses, nutrient cycling, regeneration of pastures and tree cover, conservation of wildlife habitat and biodiversity, and climate change mitigation and adaptation (Table 1).

Table 1. *Integrated landscape approaches take account of the importance of ecosystem services in managing agricultural landscapes.*

Provisioning	**Regulating**	**Supporting**	**Cultural**
• Crops and livestock • Biomass fuel • Wild food • Genetic resources • Natural medicine • Fresh water • Timber and other biological raw materials	• Erosion control • Climate regulation • Natural hazard mitigation (droughts, wildfire) • Water flows and quality	• Soil formation • Nutrient cycling • Water cycling • Habitat for biodiversity	• Local land races of agricultural crops • Cultural landscapes • Traditional agricultural practices • Sacred groves

Sources: Adapted from Millennium Ecosystem Assessment (2005); Wood, Sebastian and Scherr (2000).

Landscape-level coordination, therefore, is especially important in maintaining ecosystem services that operate at geographic scales larger than individual farms. Landscape management helps to manage the dynamics of land use change—mitigating impacts of agricultural development on forests and other native vegetation—while also ensuring that other uses of land—such as pasture lands or forests—complement agriculture (Bailey and Buck, 2013; Sayer, 2013; Scherr and McNeely 2008).

Integrated landscape management involves long-term collaboration and negotiation among different groups of land managers—farmers, pastoralists, forest and other resource user groups—and other stakeholders—local communities, government representatives, businesses—to achieve their multiple objectives within the landscape. Stakeholders seek complementary solutions to common problems and pursue new opportunities through technical, ecological, market, social, or policy means that reduce trade-offs and strengthen synergies among their varied objectives.

Agreed collaborative actions typically involve the farm-level improved land and water management practices described in the sections above, along with strategies that are spatially targeted, to ensure impacts in parts of the landscape that have the greatest aggregate effect. Landscape-level strategies can also mobilize investment from stakeholders who benefit from farmers' improved resource management or are engaged in complementary activities in nonfarmed areas. Strategies may be implemented through market mechanisms (such as payments for ecosystem services); strengthened social organization (such as community-based institutions); policy and institutional reforms (to empower landscape planning units); and other forms of capacity building, knowledge management, and technical support for integrated land use planning and collaborative management.

There are many different approaches to integrated landscape management, with different entry points, processes, and institutional arrangements. However, most share features of broad stakeholder participation, negotiation around common objectives and strategies, and adaptive management based on shared learning. Key features of integrated landscape approaches include

1. Agreement among key stakeholders on landscape objectives

2. Management of ecological, social, and economic synergies and trade-offs among different land and resource uses in the landscape;

3. Land-use practices that contribute to multiple landscape objectives

4. Development of supportive markets, policies, and investments

5. Establishment of collaborative processes for multi-stakeholder governance

While documentation of impacts from landscape initiatives remains generally poor, data are beginning to emerge.

Box 2. *Success in scaling up improved land and water management practices requires attention to gender.*

In assessing, designing, implementing, and monitoring activities to address the opportunities to scale up improved land and water management practices, it is essential to take account of gender. Addressing gender is important because women have been marginalized in the past and inequities need to be corrected. And experience shows that making progress on gender equity and the empowerment of women leads to better development outcomes.

In rural areas of sub-Saharan Africa, 95% of external resources and technical assistance (access to information and to inputs such as improved seeds and tools) are channeled through men, although women are responsible for 80% of agricultural work and their labor inputs into food production exceed those of men by 10–12 h a week (Reyes, 2011). Studies in sub-Saharan Africa indicate that agricultural productivity would increase by more than 20% if the gap in capital and inputs between men and women were reduced (Quisumbing, 2003). Women are also among those most affected by unchecked land degradation and associated shortages of fuelwood, fodder, food, and clean water (de Sarkar, 2011).

Women and men are both primary stakeholders in the adoption and scaling up of improved land and water management practices, yet they have different perspectives on the use of natural resources and the importance, feasibility, and cost-effectiveness of various practices. Women often do not have the same rights and management authority as men. Both customary and statutory provisions governing land tenure and resource rights need to be reviewed through a gender lens. Potential barriers to the adoption of improved land and water management practices that may be related to these differences in rights and security of tenure should be assessed and strategies developed to overcome these barriers.

Women and other marginalized stakeholders should be included in meetings and decisionmaking and should be represented in community-based institutions governing resource use. Women need to have direct access to information, training, and other assistance mobilized to scale up improved land and water management practices. Greater progress and success in mainstreaming these improved practices in agricultural development can be achieved by incorporating goals of gender equality and women's empowerment into agricultural program strategies and investments (Kanesathasan, 2012).

It will be important to address the gender dimensions to fully capitalize on the opportunities to ensure that investments in agricultural development and improved land and water management contribute to gender equality and women's empowerment (Box 2).

Source

This article is a considerably shortened version of the original article entitled Installment 4 of "*Creating a Sustainable Food Future*" *Improving Land and Water Management* by Robert Winterbottom, Chris Reij, Dennis Garrity, Jerry Glover, Debbie Hellums, Mike Mcgahuey, and Sara Scherr. October 2013, www.wri.org

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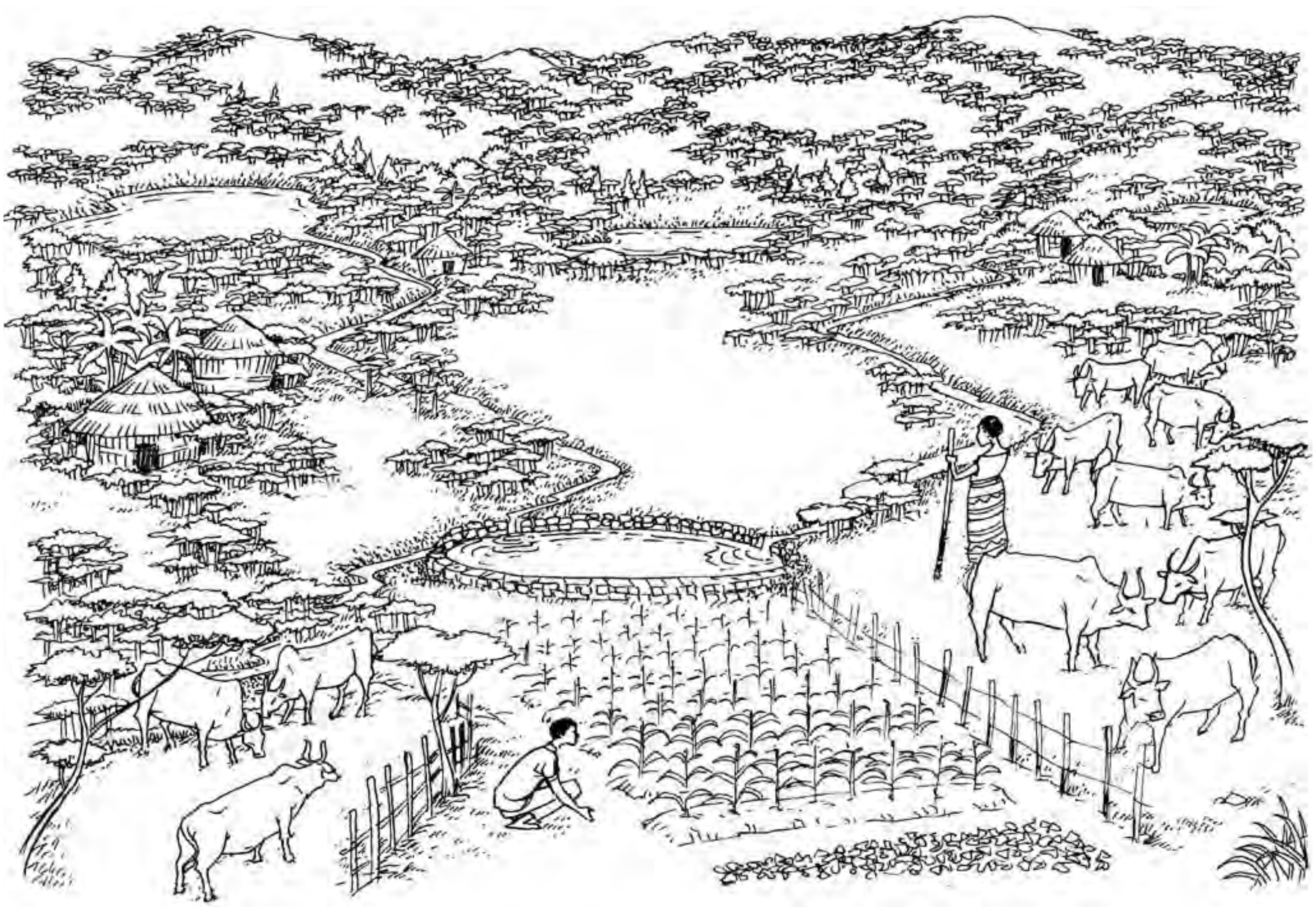
Thirty Years' Learning to Improve Rainwater and Land Management in the Blue Nile Basin of Ethiopia



The Nile Basin Development Challenge (NBDC) is funded by the CGIAR Challenge Program on Water and Food (CPWF) to improve the resilience of rural livelihoods in the Ethiopian highlands through a landscape approach to rainwater management.

The first project of the Program reviewed past research and development experiences with sustainable land and water management in Ethiopia. This brief summarizes key points from the study—online at http://mahider.cgiar.org/handle/10568/3317.

The study approached the subject from a broadly historical perspective, tracing changes in policies and strategies from the 1970s to the present.

Broad areas of investment in the Blue Nile Basin in the last 30 years mainly focused on land and water management, without explicit investment in rainwater management systems (RMS)—defined as interventions (technical, institutional, policy) that enable water to be captured, stored, and efficiently utilized. This broadly includes soil and water conservation, sustainable land management, rainwater harvesting, conservation farming, and micro-irrigation management of water for crops, livestock, agroforestry, and fish productivity.

Two broad concepts

The study is based on two broad concepts: The first is a landscape approach to rainwater management. Like 'integrated watershed management' (IWM), it shares a systematic integrated systems paradigm. IWM, however, emphasizes hydrological boundaries while the landscape perspective considers broad social, economic, and institutional networks that cut across hydrological boundaries. In the landscape approach, the aim of research is not necessarily to maximize the output of one element of the system but to optimize the range of services of the entire watershed resource system.

The second is an innovation system paradigm. Based around the notion of a learning platform, the underlying idea is that to optimize relevance and uptake of research results, research must be carried out from the beginning as a partnership of multiple stakeholders learning together.

Key messages

First of all, Ethiopia and its development partners have invested more in improving rainwater and land management than any other country in Africa.

In the past three decades, Ethiopia has adapted and improved its policies and implementation strategies. It has adopted participatory approaches, a livelihood focus, and an integrated watershed management paradigm.

The launch of the Sustainable Land Management (SLM) Program increased awareness by government of the need to use water more productively (captured in the term, 'water-centered growth'), allied donor and development communities for collective investment and action, and initiated a holistic approach to natural resource management (NRM) in Ethiopia.

The NBDC capitalizes on the good experiences of the ongoing SLM Program and offers significant opportunities to create a new paradigm for sustainable land and water management.

Sustainable land and water management for improved livelihoods and systems is achieved when researchers closely work with communities to test and promote institutional and technological innovations on watersheds. The government needs to further strengthen policy support for sustainable demand-driven, research-based rainwater management programs.

Ethiopia has a long history of large-scale research on SLM. Three decades of research have produced a large body of knowledge on land degradation, performance of various land management and soil water conservation technologies, soil and water conservation (SWC) interventions, the effectiveness of various implementation strategies, and the impacts of policies on incentives and productivity.

However, the results are often contradictory. There has been very little systematic comparative research on diverse SWC technologies, their performance, the conditions for which specific technologies are most appropriate, and accompanying crop, land, and water management practices that enhance their productivity.

In general, water management practices and technologies, ways to improve the productivity of water used by crops, livestock, and agroforestry, and the outcomes and social and economic impacts of these technologies are not well-researched in Ethiopia.

More broadly, implementation programs have rarely included an applied research component. Today, the Ethiopian government has comprehensive and well-thought out policies to promote agricultural and rural development, water resources development, environmental conservation, and poverty reduction, among others.

Historically, however, SLM programs were driven from the top and there is evidence that SWC structures promoted by government were often not perceived positively by farmers. There are many cases of inappropriate technologies being promoted and construction of structures that were not used. There are also excellent examples of community-owned and managed SLM that enabled communities to maintain and sustain the productivity of their agricultural systems.

In recent years, government programs, integrated rural development programs, and NGOs all began to adopt a new approach to implementation. The lead program in this was MERET ('Managing Environmental Resources to Enable Transitions'), a three-decade collaboration of the World Food Program and the Ministry of Agriculture.

While current approaches to promoting SLM are far more participatory and community-driven than in the past, there are still challenges and limitations.

- Programs tend to promote several 'best-practice' packages with little recognition of the value of farmer knowledge and indigenous practices.
- Some SLM programs have not completed the transition from reducing land degradation as a goal to improving water and land management to increase and sustain productivity.
- There is no specific policy with regard to the management of rainwater—specifically so-called 'green water.' Managing water for productivity and ecosystem functions should start from rainfall and examine the entire continuum, from field level to large-scale infrastructure options.
- Many RWM programs had mixed outcomes, not because the technologies were not useful but that implementation was weak. Much implementation was not sufficiently linked to research.
- The national research system has been dominated by crop breeding, identification of improved or new varieties, and soil research. Support to land and water management and RMS was very limited.

Source

Thirty years' learning to improve rainwater and land management in the Blue Nile basin of Ethiopia. CGIAR Challenge Program on Water and Food Nile Brief No. 6. http://mahider.cgiar.org/handle/10568/3317.
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Participatory Community-based Gully Rehabilitation on the Ethiopian Highlands: The Case of Birr Watershed

Soil erosion by water is a major problem in Ethiopia. The Ethiopian highlands have undergone substantial land use/cover changes that have resulted in changes in the hydrological processes of the landscape of the highlands (Tesemma *et al.,* 2010). More surface and subsurface water flow is produced, which, in turn, leads to the creation of gullies that carry off this excess water.

Gullies are a major threat to food security by swallowing fertile land, endangering environmental sustainability, and diminishing prospects for water resource development on the Ethiopian highlands (Teshome *et al.,* 2013; Tebebu *et al.,* 2010). In addition to its direct biophysical effects, gully erosion negatively affects the community's social and economic activities (Poessen *et al.,* 2003; Frankl *et al.,* 2011). The soil and water conservation practices so far on the Ethiopian highlands have usually targeted the steep slope areas through a top-down approach (Bewket and Sterk, 2002), not giving enough attention to gullies. For example, the new soil and water conservation campaign initiated by the government in 2012 focused only on putting bunds on the hill slopes and cultivated lands. However, gully erosion removed soil with an equivalent depth of 4 cm per year over these highlands (Tilahun *et al.*, 2013; Tebebu *et al.,* 2010).

The Birr watershed on the Ethiopian highland is one of the hot spot areas affected by gullies, swallowing agricultural and cultivated land (Ayele *et al.,* 2014). The bottom part of a particular sub-watershed (called Ene-Chilala) in the upper Birr watershed is dominated by active gullies on grazing and cultivated land. However, the communities have been mobilized through a top-down approach to dig deep infiltration furrows in the uplands since 2012. The overall objective of this case story is, therefore, to develop a participatory gully rehabilitation approach incorporating religious leaders and local elders in the Ethiopian highlands.

This paper describes the effect of a participatory gully rehabilitation work in Ene Chilala sub-watershed of the Birr area. The study was carried out under the umbrella of the Partnership for Enhanced Engagement in Research science program funded by the United States Agency for International Development.

Intervention approach

To start the community mobilization process, the researcher first conferred with religious leaders and local elders, and then with local village farmers about the possibility of rehabilitating the gully.

Biological and physical conservation measures the farmers undertook were check dams from wood and stones placed within the gully. They, then, planted local grass species and 214 *Sesbania sesban* in a mixed pattern. They also set 50 Ethiopian birr per animal as a fine for anyone who allowed his cattle into the enclosed gully.

The amount of sediment deposited in and around the gully was measured using 15 erosion pins installed in the gully and along the right and left sides of the shallow subgullies. Cross-sectional measurements were taken before and after the rainy season on the studied gully and on two other control gullies located near the rehabilitation gully. The measurements were taken on 23 April 2013 and on 3 September 2013.

Results

The conservation practice was able to reduce soil loss with the harvest of soil water in the gully. The measurements of cross-sectional change revealed that the cross-section of the studied gully was reduced in depth by 0.68 m and 0.55 m in the lower and middle areas of the gully, respectively. The width of the gully in the lower and middle areas of the gully remained unchanged. On average, the total depth of sediment trapped throughout the gully by both physical and biological conservation was 0. 26 m, and the total amount of soil trapped in one rainy season was approximately 2,300 tons. During the same period, the two non-treated gullies expanded greatly. One gully expanded in length by 23 m, the depth increased by 1.9 m and the width expanded

by 13 m. Soil loss was estimated at 1,900 tons. The gully that began in 2013 became 19 m long, 0.9 m deep, and 40 m wide with a soil loss of 1,500 tons.

The estimated forage yield from 0.7 ha of gully during the rainy season was 8.36 tons. This generated an estimated income of 10,200 Ethiopian birr from grass harvested in one rainy season. Most of the farmers used the grass harvested as feed for their cattle during the dry period. Those who did not have cattle, one male and two female household heads, sold the grass to other farmers for 460 Ethiopian birr each. Farmers as a group were able to negotiate with the Wereda Office of Agriculture to use their mandatory labor contribution for constructing soil and water conservation structures to rehabilitate the gullies.

However, this economic benefit resulted in conflict among the communities. The 22 farmers whose land surround the rehabilitated gully were reluctant to share the grass with the other 20 farmers who assisted with rehabilitation activities. In addition, they argued that they had not been allowed to graze their cows on this land as would have been the case if the rehabilitation had not been there and, therefore, demanded a greater share of the benefits. On the day that the 22 farmers began to harvest the grass, the farmers from the other villages stopped them from harvesting additional grass. This conflict was resolved by the elders in the village who eventually made the 22 farmers apologize and sign a promissory note to contribute labor and wood in the next program (2014 rainy period) to rehabilitate a gully in a second village.

This conservation practice was advocated to the adjacent villages, the development agents, and the community, and there was an uptake by the general community in the Ene-Chilala area of the Birr watershed. In the 2014 rainy season, communities from different villages of the watershed are taking their own initiatives to rehabilitate five more gullies.

The most significant accomplishment of the project was that the rehabilitation process, endorsed by the religious leaders and elders, modified the belief of farmers that God created gullies as a means of punishing them for their wrongful acts. The study showed that it is possible to alter the erosion dynamics of gullies. However, the study also notes that it is essential to address the root causes of the problem to prevent gullies from being formed in the first place.

A limitation of the study is that it is based on applied research in only one watershed where the community shares the same religion. It should be applied and tested in other communities with more diverse social backgrounds.

Conclusion

The importance of rehabilitating gullies should be advocated to soil conservation experts, development organizations, and policymakers. This form of environmental protection is often neglected. However, it can provide economic benefit to communities, decrease sediment concentration in rivers, and slow down siltation of downstream reservoirs.

This case study also showed the value of an approach that addressed a single hot spot erosion area and that communities would replicate the approach once they are convinced of its value. It also showed that farmers can be empowered to negotiate with authorities about the kind of land rehabilitation work they should be doing. Finally, the study found that it was important to involve religious leaders and elders in the process, since the possibility of conflict is significant, especially given that the environmental management initiative results in an economic benefit.

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The Impact of Large-scale Government-led Soil and Water Conservation on Runoff and Soil Loss in the Debre Mawi Watershed

Debre Mawi is an agricultural watershed in the upper Blue Nile Basin. The slope ranges from 1% to 30% and the altitude varies from 2,195 m near the outlet to 2,308 m in the southeast. The area receives a mean annual rainfall of 1,240 mm with most of it concentrated between June and September (Dagnew *et al.,* 2014). Smallholder farmers produce cereals such as teff, maize, finger millet, barley, and wheat, which dominate land use in the watershed, followed by grassland and sparse vegetation.

The watershed is characterized by very low vegetation cover, severe sheet, rill and inter-rill erosion, and an active gully formation. The rate of erosion in the region is far beyond the tolerable rate, reaching 36 tons/ha/year from upland erosion (Zegeye *et al.,* 2010) and 234 tons/ha/year from gully erosion (Zegeye *et al.,* 2014). Erosion in the watershed has resulted in a loss of crop productivity due to loss of soil nutrients and land that is severely damaged by gully erosion.

Of the 528 ha covering the watershed, instruments were installed in an area of 95 ha by the Amhara Agricultural Research Institute and Bahir Dar University for erosion and hydrology studies. Traditionally, contour furrows were mainly used by farmers as soil and water conservation (SWC) measures. In 2012, the government initiated a large-scale SWC campaign, where 67 ha of the 95-ha study area was covered with SWC measures. The case study presented here discusses the effects of the government-led, large-scale SWC work on runoff and soil loss in the Debre Mawi watershed, which was studied under the umbrella of the Partnership for Enhanced Engagement in Research (PEER) science program funded by the United States Agency for International Development.

The intervention

Under the large-scale government-led intervention in the watershed, both physical and biological SWC measures were implemented. The physical measures included erecting soil bunds, stone-faced soil bunds, and stone bunds with infiltration ditches as deep as 50 cm. The SWC measures were placed in the up-slope, mid-slope, and bottom-slope positions and mainly on cultivated fields. To support the physical SWC structures, tree and grass species such as Sesbania (*sesbania grandiflora*), vetiver grass (*Chrysopogon zizanioides*), elephant grass (*Pennisetum purpureum*), and pigeon pea (*Cajanus cajan*) were planted (Dagnew *et al.,* 2014).

Farmers in the area received 2-week training on the causes of natural resource degradation, its effects on crop and livestock productivity, and the need to undertake watershed management to reverse the situation. With the support of development agents (DAs) and the local government, farmers formed village watershed committees and developed bylaws. The SWC campaign was conducted during the dry period when there were fewer farming activities. What differentiates this program from previous donor-driven interventions in Ethiopia is the no-cash-payment-to-farmers policy adopted by the campaign. In the SWC campaign, it was mandatory for women, men, youth (including the landless), and the elderly to participate. Absentees were penalized with a fine of up to 80 Ethiopian birr ($4). Given that this intervention was a huge investment in the environment and farmers' time, it is particularly important to investigate its effects in terms of hydrology and soil loss.

Methodology

Rainfall was measured by installing automatic tipping-bucket rain gauges. Stream flow was computed at the gauging stations using manual depth measurement and velocity of flow. Suspended sediment concentration (SSC) was evaluated by taking water samples every 10 min, filtering and weighing, and then determining the weight of the sediment per liter. Perched groundwater table was assessed by installing piezometers, whereas infiltration rates were measured by using a single ring infiltro-meter. Four years of data (2010–2013) of the main rainy months (June to September) were collected for this study. Outside of these months, rainfall, runoff, and soil loss were minimal and too inconsequential to evaluate the effects of SWC practices. In addition, a continuous observation of conservation structures and the watershed using transect walks, photo monitoring, and informal discussions with farmers helped acquire information pertinent to the study.

Results

Precipitation and infiltration

The total rainy-season rainfall from 2010 to 2013 was 890 mm, 917 mm, 832 mm, and 858 mm, respectively. The maximum intensity of rainfall in the 4 years was 38 mm/h/yr. The median infiltration rate was 33 mm/h/yr, 24 mm/h/yr, and 31 mm/h/yr, in 2010, 2012, and 2013, respectively. A comparison of rainfall intensity and infiltration capacity shows that rainfall intensity exceeded the infiltration capacity of the soil less than 5% of the time. This indicates that the dominant runoff-generating mechanism is saturation excess (Tilahun *et al.,* 2014) where runoff is initiated when the soil becomes saturated.

Water table dynamics

The groundwater table was deep up-slope, got shallower in the mid-slope, and was close to the surface down-slope in August. The water table is deep in the up-slope because the contributing area is small and the slope is steep. Thus, a relatively small flux with a large driving force provides for fast drainage. The lower slope position has a large drainage area, a low slope, and is the convergent area of the lateral subsurface flow and overland flow. To carry off the imposed flux, the water table rises until it intersects the surface. Water-table dynamics are extremely important for the design of infiltration furrows because when the water table intersects the infiltration furrows, water will flow out of the soil instead of into the soil. In the lower parts of the watershed, the water table comes near the surface, the soil saturates, and this further leads to the saturation of soil bunds. In fields where the groundwater is slightly deeper, the bunds are stable and they carry the drainage water off the field. But in fields where the groundwater is near the surface, any excess saturated flow through the furrows will flow at the end of the furrow down the hill and initiate gullies.

Discharge before and after SWC

The total runoff volume was, respectively, 33%, 21%, 13%, and 12% of the rainy-season rainfall from 2010 to 2013. Though there is monthly and interannual rainfall variability in the watershed, runoff reduction was 46% after SWC implementation, indicating that the interventions have resulted in reduced surface runoff as rainwater was collected and as it infiltrated in the furrows of bunds. The comparison of discharge for the month of September showed that it increased after SWC implementation. This is related to the effect of rainwater that infiltrated the furrows during July and August. The water was stored in the watershed, flowed with deeper flow paths to the outlet, and appeared as interflow and base flow, indicating that the measures have positive impacts on increased base flow response.

Changes in suspended sediment concentration and load

Sediment loads in July were the largest. The monthly sediment loads after the SWC intervention were reduced by half in July and August. The annual trend was very distinct where the loads were reduced fourfold. The decrease in sediment loads is mainly caused by the decrease in runoff and, to a smaller degree, a decrease in sediment concentration as sediment is trapped in the ditches of bunds. The mean sediment concentrations decreased from 22 g/liter before SWC implementation to 14 g/liter, in the first year after the intervention (in 2012). The lower rainfall in 2012 partly contributed to the reduction in sediment concentration. But the concentration increased to almost the previous level (20 g/liter) in 2013.

The disturbed soil from tillage and bund construction, together with the low vegetation cover and rills, may have played a role in the elevated sediment concentrations at the beginning of the rainy season. Later, sediment concentrations decreased because of the increase in vegetation cover and fewer rills. A large amount of sediment was trapped in the infiltration furrows of bunds. In the first year after implementation, an average depth of 21 cm of silt was deposited in the ditches (Fig. 2). Despite the sediment collected in the infiltration furrows of soil bunds, the 2013 reduction in SSC was not as large as that of 2012. In the watershed, the sediment concentrations do not show large reductions because the loose soils of the collapsed banks in the gullies contribute a significant amount to the sediment concentration at the outlet (Zegeye *et al.,* 2014).

Conclusion

The terraces installed as part of the government-led large-scale SWC program produced some very clear changes in the watershed, such as lower runoff and lower sediment load. However, sediment concentrations were not reduced. Unless gullies are treated, sediment from the gullies would lead to an increase in the sediment at the outlet. When soil bunds are placed in saturated bottomlands, the bund loses its strength and may initiate new gullies.

The recommendations in light of the findings from this case study are as follows:

- Treat gullies to reduce sediment in streams: Currently, gully treatment is not part of the large-scale SWC work in the watershed. To reduce sediment concentration, control and treatment of gullies need to be prioritized as part of large-scale SWC programs.
- Consider local hydrology: In the existing large-scale SWC works, SWC structures are sometimes installed without taking into account local hydrologic conditions. Increased performance of government-led SWC works can be achieved by taking local hydrologic conditions, such as high groundwater tables that prevent infiltration of rainwater, into account. This not only reduces the effectiveness of the SWC practices this not only reduces but also causes sediment loss as well.
- Maintain bunds to sustain their impact: Bunds that were installed in the Debre Mawi watershed in the last 2 or 3 years were not maintained. Although great reduction in sediment load was observed for the 2 years after SWC implementation, sustaining the reduction might not be easy. Furrows were half-filled with sediment within the first year and, therefore, their trap efficiency would only last for another 2-year period. This would be similar to the graded Fanya Juu bunds (infiltration furrows just off the contour, with soils thrown uphill) installed in the Anjeni watershed in the 1980s, which were only effective over a 4-to-6-year period (Elkamil, 2014).

- Consider further research into innovative practices: Continuous work is needed to maintain the infiltration furrows and this could be expensive as the SWC practices are currently under way on a large scale. Thus, research into other inexpensive ways to increase infiltration such as planting deep-rooted plants on bunds or deep plow by breaking the hard pan could be an area of further research.

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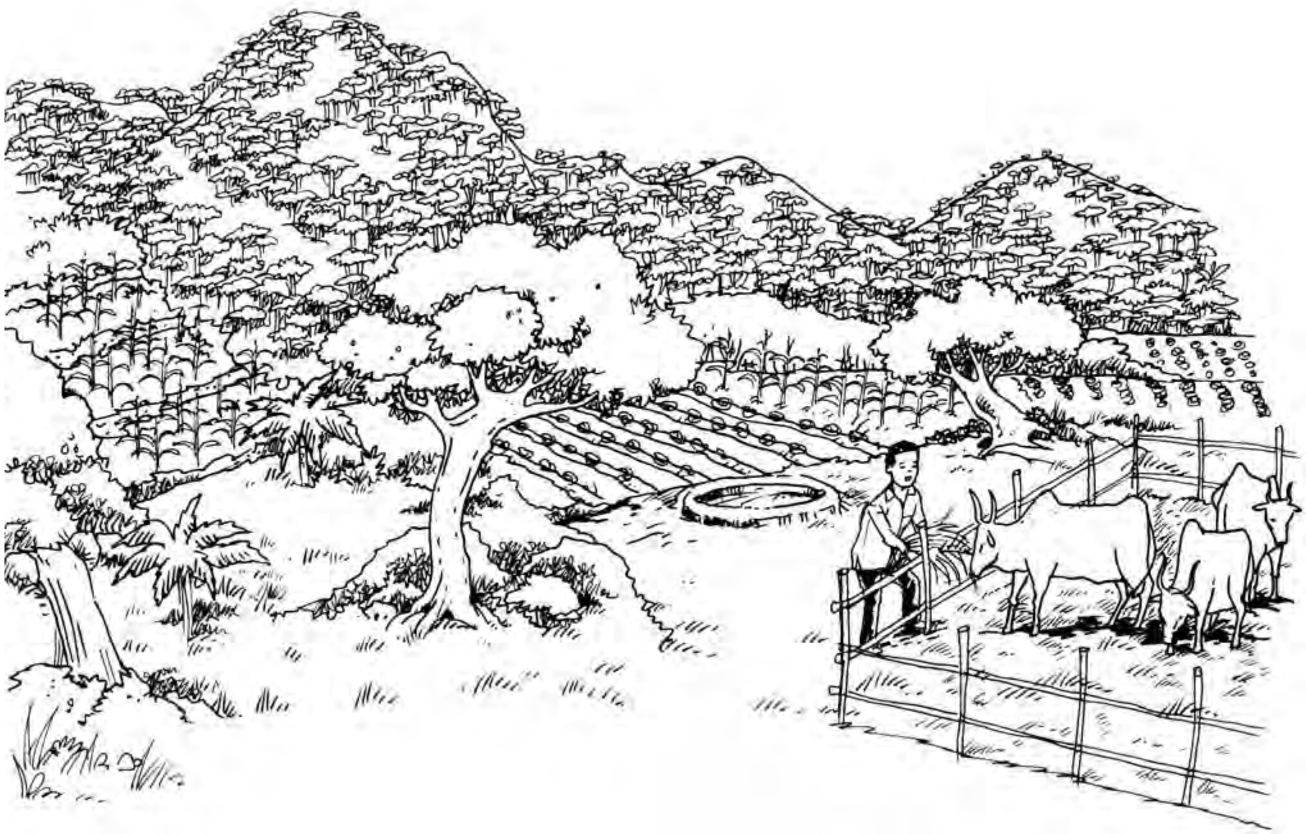
Participatory Watershed Management as the Driving Force for Sustainable Livelihood Change in the Community:

The Case of Abreha we Atsebeha



Agriculture, the main sector of the Ethiopian economy, accounts for 85% of total employment and is the backbone and mainstay of the economy (Pausewang *et al.*, 1990). However, agricultural productivity is decreasing because of land degradation, particularly due to soil erosion. Hurni (1988) estimated that the extent of erosion from arable land in the highlands of Ethiopia averaged 42 tons/ha/yr. This erosion results in a decline of soil productivity.

As in all parts of Ethiopia, the economy of Tigray is based on agriculture, with more than 90% of the population depending on rainfed subsistence crop production (REST, 1997). Soil erosion, nutrient depletion, and soil moisture stress are the major land degradation problems facing the region (Hagos *et al.*, 2003).

Abreha we Atsebeha watersheds in the eastern part of Tigray located northwest of Mekelle, the capital of Tigray region, were highly degraded and the people have been food-insecure for many years. Drought occurs almost every year. During the previous Ethiopian government's regime, for example, the people of Abreha we Atsebeha were selected for resettlement, and many were moved far away from their homes to the southwestern part of Ethiopia. The community of Abreha we Atsebeha is one of the most food-insecure communities of the Wereda.

The intervention

Participatory watershed management

Two decades ago, the Tigray regional government designed a strategy to reverse the immediate causes of land degradation in the whole region (REST, 1997). The World Food Program (WFP) took the initiative of assisting watershed development in collaboration with the Ethiopian government. They embarked on a program called MERET, Managing Environmental Resources to Enable Transition to a More Sustainable Livelihood.

The Abreha We Atsbeha watersheds were included in the MERET project and other development initiatives,[1] including participatory community soil and water conservation (SWC) campaigns initiated by the regional government to mitigate land degradation problems. Many physical and biological conservation measures were implemented as part of the environmental management of watersheds. As a result of improved watershed management and the land and water resource rehabilitation efforts carried out in the area since 1991, the people of Abreha we Atsebeha have successfully attained food self-sufficiency.

This article describes the impact of the intervention—i.e., the MERET project—as a participatory watershed management approach, on reversing land degradation and improving the watershed, encouraging water-smart agriculture, and improving the livelihood of the community. It is based on a study that assessed the impact of specific conservation measures: stone bunds, stone-faced trenches, deep trenches, check dam, constructions, percolation pits, gabion check dam, and sediment storage dam constructions and area closures (Table 1).

Assessing the impact of the intervention

The impact assessment study is entirely focused on four sub-watersheds. In three sub-watersheds (Mendae, Anchel, and A/Atsebeha[2]) different environmental management practices were implemented, including area closure and reforestation activities. The fourth one, Machew, received very little or no environmental management support and was therefore used as a control to compare the impacts of the conservation practices. Major watershed characteristics (geologic data, rainfall data, SWC measures put in place and effects on runoff and infiltration) were analyzed.

Transect walks were undertaken, dividing the landscape into three areas with each landscape then divided into upper, middle, and lower ranges. Two plots, 10 m wide by 10 m long, were established to estimate the percentage of vegetation canopy cover in each landscape position for all study sites. The area of each sub-watershed was 561.34 ha in the case of Mendae, 601.21 ha in Machew, 921.62 ha in Anchel, and 556.31 ha in A/Atsebeha.

The study compared soil loss rate from treated and untreated watersheds. Eight soil samples were collected during the transect walk using systematic random sampling, combined to form a composite sample. This was done across three slope ranges (upper, middle, and lower) and across three locations in each of the four sub-watersheds. The soil samples collected and analyzed totaled 36.

***Fig. 1**. Community members participate in soil and water conservation activities.*

[1] For example, work by GTZ and the PSNP USAID–funded program.
[2] A/Atsebeha is a sub-watershed name within the wider Abreha we Atsebeha watershed.

Results

Improved vegetation cover and impact on soil erosion

The study found that most of the area closures under the steep slopes of the study sites are covered by a large variety of grasses and herbs, which humans and animals are restricted from accessing. The exception is in the control site, which permits free grazing but prohibits cutting of trees/shrubs. Ground vegetation cover was very significant in Mendae (40%) and least significant at Machew (4%), the control site. The variation in ground cover among the study sites can be explained by the difference in access to livestock for free grazing. The control site has lower amounts of trees/shrubs and saplings primarily because free grazing was allowed in the sub-watershed.

Reduced erosion occurs in well–protected sites because the canopy formed by the mature shrubs and under-story vegetation shields the soil from the erosive energy of the falling raindrops, thereby protecting the soil from splash erosion and surface or sheet erosion. Soil loss was less pronounced in the treated sub-watersheds, e.g., 14.69 and 19.1 tons/ha/yr for Anchel and A/Atsebeha, respectively. The result is mainly attributed to the relatively high vegetation canopy cover in the two sub-watersheds, 32.8 and 36.6% at 2–m effective height and to ground vegetation cover of 23-40%.

In contrast, the control sub-watershed had higher rates of soil erosion (37.33 tons/ha/yr), which might be the result of very low vegetation cover (4%) and canopy cover (36.7%). When the soil's protective vegetation cover is removed, the structurally unstable soils are exposed to the striking action of rains. Losses due to erosion immediately after land clearing are normally alarmingly high.

However, the study also found that steep slopes and cultivated areas are more affected by soil erosion in all the sub-watersheds. The mean calculated soil loss in the control site varied between 29.09 and 39.23 tons/ha/yr with a mean of 37.33 tons/ha/yr. The soil loss was higher than the mean of the treated sites but was closer to the mean calculated from cultivated areas of 42 tons/ha/yr (Hurni, 1988). The mean annual soil loss in Mendae where mitigation measures were done intensively and which has loamy sand varied from 1.69 to 29.42 tons/ha/yr and at the other two sites, from 8.35 to 29.23 tons/ha/yr.

Increase in honey bee production and restoration of biodiversity

Before the intervention there were 470 traditional beehive colonies and no modern ones. After the intervention there was an increase in honey-bee flora, farmers therefore switched from traditional beehives to modern beehive colonies. The previous 268 traditional beehives were replaced with 1,077 ones. The annual production of honey before the intervention was 3kg/yr with the traditional colonies. The honey production after intervention with the modern ones was 45kg/year, an increase of 1,500%. As a result of area closures, endangered tree species also regenerated.

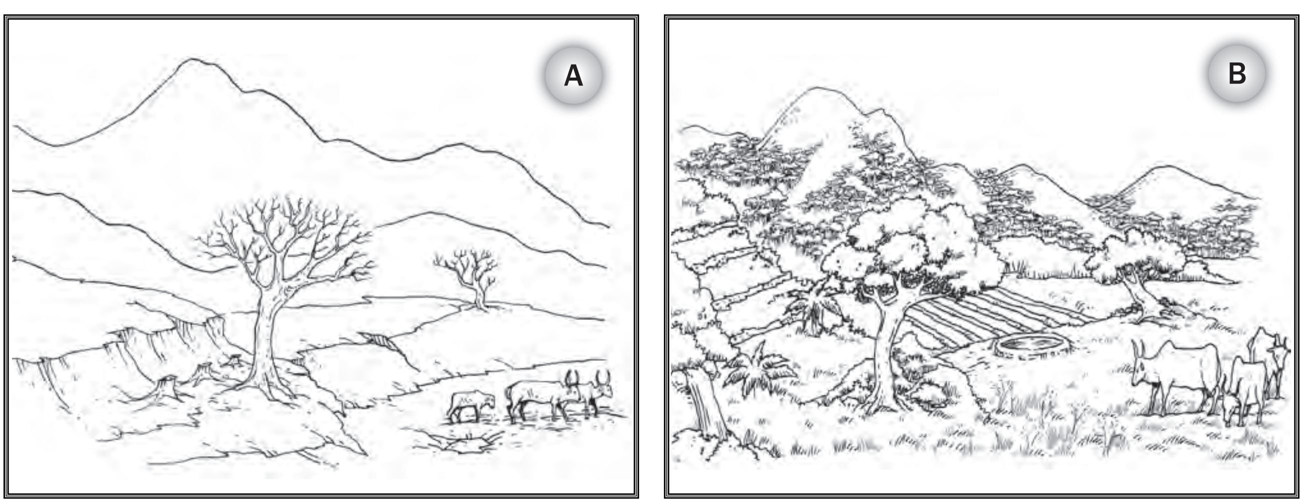


Fig. 2. *The area before (A) and after the intervention (B).*

The water management structures in the sub-watersheds before and after the intervention are shown in Table 1. The data very clearly demonstrate the difference between the control site and the others in terms of both environment and water resource development.

The annual income of all study sites before the intervention was below US$1/day (US$0.72). After the intervention, all study sites (including the control) recorded incomes above US$1, however, the increase was lowest in the control site. These findings are similar to those of other studies that demonstrate that watershed development programs influence biophysical and environmental aspects and thereby bring changes in the socioeconomic condition of the people (Kuppannan *et al.*, 2009). Socioeconomic indicators that could be measured include changes in household per capita income and changes in consumption and expenditure, employment, migration patterns, household assets, and wage rates at the village level.

Table 1. *SWC structures in the sub-watersheds before and after the intervention.*

Activity	Number	Mendae	A/Atsebeha	Anchel	Machow
Trench construction before intervention	15,906 (m^3)	9.09%	9.02%	72.3%	8.9%.
Area enclosure before intervention	800 (ha)	50%	25%	25%	0%
Shallow hand-dug wells, SS dams or deep trenches before intervention	0%	0%	0%	0%	0%
Trench construction additions after intervention	13,778 (m^3)	50.3%	49.7%	0%	0%
Check dams after intervention	16,934 (lm)	100%	0%	0%	0%
Percolation pits after intervention	16,750 (m^3)	10%	90%	0%	0%
Enclosure after intervention	4,100 (ha)	44%	20%	24%	12%
SS dams after intervention	4	75%	25%	0%	0%
Deep trenches after intervention	1,987 (m^3)	0%	50%	50%	0%
Shallow hand-dug wells after intervention	700	33%	31%	53%	0%

Source: Kelte Awelaelo Wereda office of Agriculture and Rural Development (WOARD)

Increased household income

The biophysical improvement of the study sites has brought significant changes in the income of households in the community. Data obtained on differences in household income before and after the intervention are shown in Table 2.

The data showed an increase in income in all study sites, including the control site (Maichew).

Table 2. *Mean annual income of households in the study sites (US$)[3].*

Study site	Time of intervention	Income (birr/yr)	Income (US$/yr)	Income (US$/day)
A/Atsebeha	Before intervention	1,897.83	171.75	0.47
	After intervention	9,538.00	870.44	2.38
Anchel	Before intervention	3,850.00	348.42	0.95
	After intervention	8,382.00	758.52	2.08
Mendae	Before intervention	3,617.00	327.30	0.90
	After intervention	10,193.00	922.47	2.53
Machew	Before intervention	3,357.00	303.77	0.83
	After intervention	4,557.00	412.37	1.13
Total	Before intervention	2,922.92	264.52	0.72
	After intervention	6,806.25	615.95	**1.69**

[3] Exchange rate (2008): US$1 = 11.05 birr.

Conclusion

This study looked at four sub-watersheds, three of which had significant environmental management support (one was the control). This allowed an assessment of the effects of environmental management on vegetation cover, soil erosion, honey bee production, and restoration of biodiversity. The links between these different effects of environmental management and the links with water resource management were also presented. It was shown that these effects in turn influence the socioeconomic conditions and livelihood opportunities in the community.

For each measure, the control sub-watershed fared worse. Environmental management initiatives very clearly resulted in benefits across the board in terms of land and water management, and they also translated into improved livelihoods. It was shown that the unbelievable journey from famine and risk of resettlement in 1991 to becoming a winner of the 2012 UNDP Equator Prize at Rio de Janiero is the result of water availment for agriculture, the consequence of good watershed management practices.[4]

Due to the complex nature of soil nutrient patterns (which, to a large extent, depends on land use and landscape position), additional research is needed to more fully understand the interactive relationships between landscape position, soil erosion, soil nutrients, land use, and its history and management.

An overall recommendation is that a complete sedimentation and erosion control plan be made for all sub-catchments and should include protection of degraded land from the interference of livestock. It should also include the installation of grassed waterways to carry runoff from the catchments at velocities that will not destroy the vegetation.

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[4] 2012 World Food Program Award.

Improving Food Security by Using Tied Ridges in the Semiarid Areas of Northern Tanzania

In semiarid areas, one of the primary factors that limit crop production is soil moisture deficiency. Due to climate change, there have been attempts to optimize crop yield by planting drought-tolerant crops, particularly maize, sorghum and millet in semiarid areas of Northern Tanzania. This is not enough because crop failure due to water stress is still observed (Mahoo *et al.,* 1999). Maize is the most important staple in the drought-prone areas of Longido and the western lowlands of Mwanga and Same districts in the northern part of Tanzania. Most producers of maize are smallholder farmers who intercrop it with cereals and legumes. In these districts, however, there is food insecurity caused by frequent crop failure brought about by drought. Despite the droughts, farmers continue to grow maize. Majority of farmers in these areas do not use available rain water efficiently.

The introduction of tied ridges has beneficial effects of reducing runoff loss; and soil loss and increasing grain yield. Tied ridges are a variation of the micro catchment approach for trapping and holding water. Its construction follows the contours but, in addition, the furrows between ridges are linked by cross-ties to create closed micro basins 1 to 5 m long (Fig. 1). The cross-ties are kept lower than the ridges so they act as spillways in the event of heavy rainfall.

The mechanism behind tied ridges allows small basins to retain runoff so that the retained water basins have more time to infiltrate and increase soil water storage. This practice is particularly effective in areas where rainfall intensity is low to medium and soils are freely drained and on gentle slopes. The construction of tied ridges requires minimum knowledge—local people can do it easily without close supervision from experts.

Fig. 1. The farmer prepares the land by constructing tied ridges.

Objectives

The main objective of the study was to assess tied ridges as a water-smart agricultural practice. The specific objectives are the following:

- To test the effect of tied ridges on the yield of maize intercropped with legumes.
- To demonstrate the efficiency of tied ridges on crop yield.

Materials and methods

Location of sites

Same District is located at 4°15' S and 37°55' E. In this district, the study was conducted in villages Lembeni, Mabilioni, Saweni, and Ishinde. Mwanga District is located at 3°45' S and 37°40' E. The work in Mwanga was carried out in the villages of Kwakoa and Kisangara. Longido District (2°43' 57" S and 36°41' 54" E) has the work sites in Mairowa, Ngoswaki, Mndarara, Olmolock, and Kamwanga villages.

Climate

Same

The western lowlands of the district are semi-arid and receive less than 500 mm of rainfall per annum. The highlands receive between 600 and 800 mm. There are two distinct rainy seasons (*vuli*) from October to December and (*masika*) from March to May.

Mwanga

Mwanga, one of the semiarid areas in the Kilimanjaro Region, experiences 500–600 mm of rainfall per annum in the lowlands and 800–1,250 mm in the highlands. The distinct rainy seasons are *vuli* and *masika*. The district experiences some strong and dry winds blowing normally from east to west.

Longido

All the target sites are located in semiarid areas with unreliable and unpredictable probability of receiving 400–600 mm of rainfall per year. There are two distinct rainy seasons, short (*vuli*) and long (*masika*). The area is characterized by repeated water shortages. Even during an average year, rains may start well and then disappear in a month at the critical plant growth stage.

Experimental method

A randomized complete block design with two replications and 12 treatments was adopted at each site. Dimensions of the plots were 10 m x 10 m per treatment. The technology tested in Same District involved a cover crop (either pigeon pea or *Dolichos lablab)* intercropped with drought-tolerant maize

***Table 1**. Crops tested in Same and Mwanga districts using tied ridges.*

Maize variety	Type of legume used
Situka M-1	Farmer's practice
TZM-309	Farmer's practice
Situka M-1	Pigeon pea
TZM-309	Pigeon pea
Situka M-1	*Dolichos lablab*
TZM-523	*Dolichos lablab*

***Table 2**. Crops tested in Longido District using tied ridges.*

Maize variety	Type of legume used
Situka M-1	Farmer's practice
TZM-523	Farmer's practice
Situka M-1	Green gram
TZM-523	Green gram
Situka M-1	Green gram
TZM-523	Green gram

Fig. 2. Maize planted on tied ridges.

(Situka M-1 and TZM-309) and the use of tied ridges (Table 1, Fig. 2).

For Longido District, maize varieties Situka-M1 and TZM 523 intercropped with green gram (Table 2).

Data collection

Initially, a reconnaissance survey was conducted in the case study areas and the status of maize production was evaluated. Yield-related data were collected from each treatment: plant population, plant height, number of cobs, weight of cobs, grain weight, and biomass.

Data analysis

The data taken for analysis were the grain yield of maize, grain yield of pigeon pea, grain yield of *D. lablab,* and grain yield of green gram. These were subjected to statistical analysis using the GenStat computer package.

Results and discussion

Maize yield

In the Same sites, the lowest maize grain yield was found in Lembeni (0.3 to 0.5 t/ha), followed by Mabilioni (0.7 to 1.3 t/ha). The highest maize grain yields were observed in Saweni and Ishinde, 1.6 to 2.6 and 2.3 to 2.9 t/ha, respectively. The average yield was 0.4 in 2012 and 1.5 for 2013 (Fig. 3).

In the Mwanga sites, the highest yields were recorded in Kwakoa and Kisangara, 0.7 to 2.0 and 1.4 to 2.3 t/ha, respectively. Maize grain yield at Kisangara was inferior to those of the two sites above. Mean yield varied significantly for each site and treatment. Hence, in 2012, average maize grain yield was 0.65 t/ha; and 1.26 t/ha in 2013 (Fig. 3). In the western part of Longido District, the highest maize grain yield of 3.9 t/ha was recorded at the Mairowa site, while Ngoswaki and Mndarara sites had the same grain yield. There were significant differences among the treatments tested. In eastern Longido, the highest maize grain yield was recorded in Olmolock; the value ranged from 1.3 to 2.2 t/ha. The Kamwanga site had the lowest maize grain yield ranging from 0.7 to 1.0 t/ha. There were significant differences among treatments within the Olmolock site, whereas in Kamwanga, no significant differences were seen among the treatments. Generally, Longido's average maize grain yield was 0.53 t/ha in 2012 and 1.72 t/ha in 2013 (Fig.3).

Legume yield

At the same sites, both pigeon pea and *D. lablab* were intercropped with maize. Average *D. lablab* grain yield was 0.7 t/ha in 2012 and 1.4 t/ha in 2013. Grain yield of pigeon pea averaged 1.64 t/ha in 2012 and 2.1 t/ha in 2013 (Fig. 4).

In the Mwanga sites, pigeon pea and *D. lablab* were intercropped with maize. Average *D. lablab* grain yield was 1.3 t/ha in 2012 and 1.9 t/ha in 2013. Grain yield of pigeon pea averaged 1.9 t/ha in 2012 and 2.4 t/ha in 2013 (Fig. 5).

In the Longido sites, green gram was the only legume intercropped with maize. Average green gram grain yield was 1.1 t/ha in 2012 and 1.15 t/ha in 2013.

This study demonstrates the beneficial effects of intercropping drought-tolerant cereal and legume varieties, coupled with efficient soil and water conservation with a focus on water harvesting using tied ridges (Figs. 5, 6, and 7).

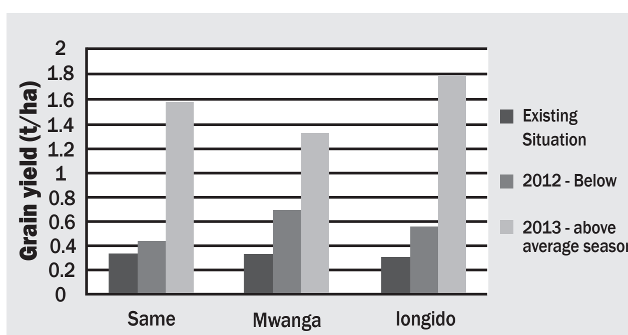

Fig. 3. Results after practicing the smart-water technology of using tied ridges in comparisonwith existing situation.

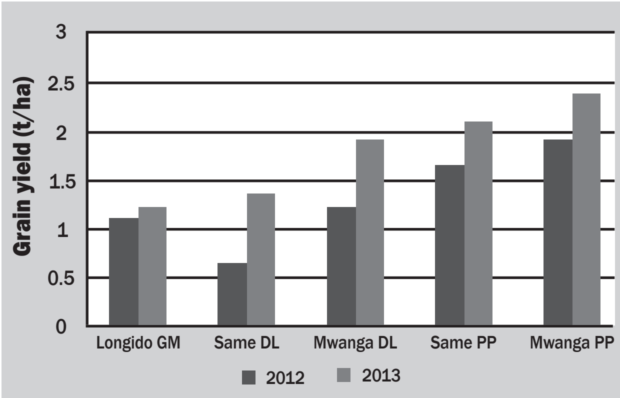

Fig. 4. Average legume grain yield in two seasons.

Fig. 5. Maize and pigeon pea intercrop with tied ridges.

Conclusions and recommendations

Field experiments have demonstrated that water-smart agriculture practice using tied ridges increases crop yields and improves food security of smallholder farmers. Tied ridges have been found to be very efficient and have resulted in substantial yield increase in semiarid areas of northern Tanzania.

- Farmers should prepare land and plant early so that their crops get enough water for good growth.
- Efforts should be put into training farmers about other technologies for water-smart agriculture to mitigate climate change and improve food security in their area.

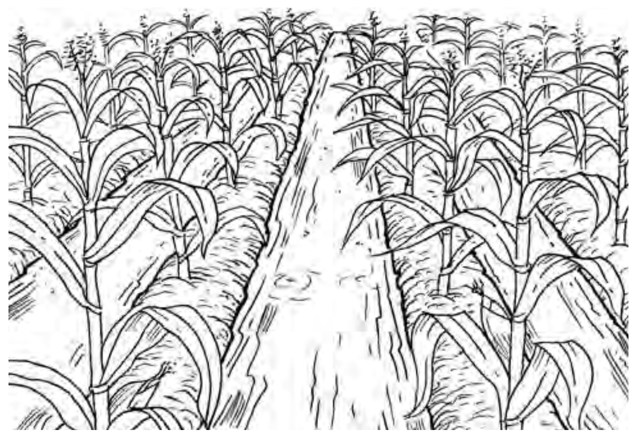

Figure 6. Water harvested through the use of tied ridges.

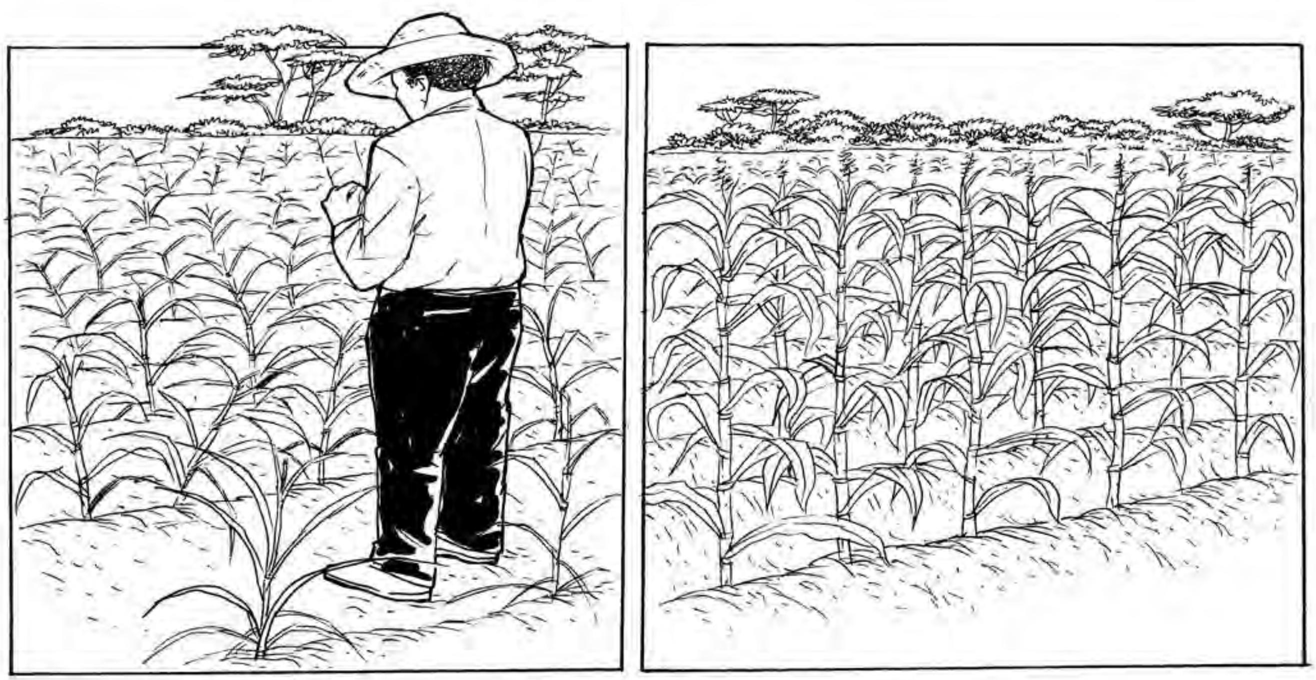

Fig. 7. Field in dire need of using tied ridges (left) and field showing good crop growth (right).

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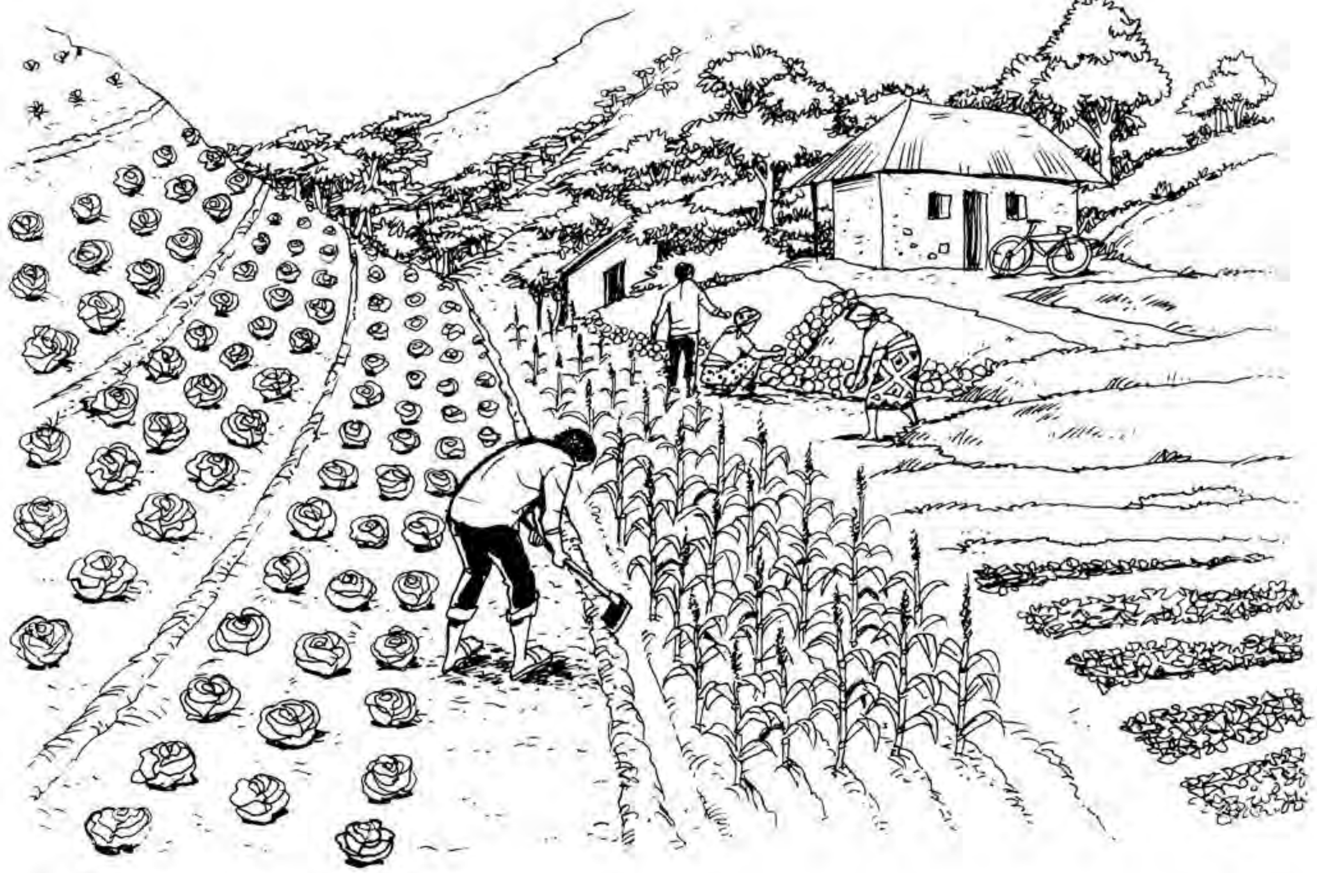
The Role of Sustainable Land Use Management to Achieve Effective Water Use



The agriculture sector of the Tanzanian economy contributes about 24.1% of gross domestic product, 30% of export earnings, and employs about 75% of the total labor force. Given the low level of agricultural development, the current average agricultural growth rate of 4.4% is insufficient to lead to significant wealth creation and poverty alleviation. To reduce poverty, annual agricultural growth rate must range from 6 to 8% (URT, 2013).

Population growth is one of the factors that add pressure on available natural resources such as land. This has given rise to increased demand for land on which to live and develop livelihoods. This results in land degradation, which, in turn, threatens agriculture and food security. It is therefore important for farmers to adopt sustainable land management approaches, which include sustainable farming technologies and natural resource management practices, including physical, cultural, and biological measures for increasing agricultural productivity, ensuring food security, and improving incomes.

Sustainable land management (SLM) can be defined as the use of land resources such as soil, water, animals and plants for the production of goods to meet changing human needs while assuring the long- term productive potential of these resources and maintaining their environmental functions. Herweg *et al.* (1998). On the basis of this understanding, this paper focuses on SLM as a way of engaging in water-smart agriculture in order to improve soil health, resulting in production increases alongside increases in water use efficiency, and ultimately leading to greater farm income.

Objectives

The general objective of the study is to examine the role of sustainable land use management practices in enhancing water-smart agriculture.

Specific objectives

- To describe existing sustainable land use management practices for water-smart agriculture
- To document costs and benefits of various SLM practices, determine social benefits accruing from adoption of SLM practices, and describe the challenges facing smallholder farmers in implementing SLM.
- To propose approaches to address challenges in the implementation of SLM practices.

Methodology

Description of study area

Uluguru and Pare mountains are part of a chain of mountains in eastern Africa collectively called the Eastern Mountains. The area is characterized by a mountainous and hilly landscape consisting of extensive cliffs, rocky outcrops, and steep and deep valleys. While the Uluguru mountains are located in Morogoro and Mvomero districts, the Pare mountains are located in Same District. The mountains are sources of many streams. For example, the Uluguru mountains has tributaries contributing to Ruvu River, which is the major source of water for people living along the river within Morogoro, Dar es Salaam and the coastal regions.

The districts are divided into three ecological zones—the upland middle, and lowland plateau. The upland plateau has an altitude of 1,100 and 2,462 m asl, and annual rainfall of 1,250 to 2,000 mm. In the middle zone, altitude is 900 – 1,100 m asl, and annual rainfall is 800 – 1,250 mm. The lowland plateau zone has an altitude of 500 – 900 m asl, and annual rainfall of 500 – 800 mm. The Uluguru mountains rise to 2,630 m altitude. Climatically, the Uluguru inland from the Indian Ocean and the east-facing slopes are especially wet, with rainfall estimated at more than 3,000 mm per annum, with some rain falling every month.

Review of documents

Various documents with information related to sustainability of water-smart agriculture were reviewed. These included project documents from CARE offices, reports from UMADEP/SUA, and other relevant literature, including those downloaded from the Internet.

The document review showed that the Uluguru and Pare mountains have experienced rapid population growth, resulting in higher food demand and greater need for more agricultural land. For example, a study by Chamshama *et al.* (2009) observed that the root causes of anthropogenic threats that the Uluguru Forest Reserve faces include widespread poverty growth. As a result, agricultural sustainability in these areas continues to be threatened.

In an effort to sustain agricultural activities, a number of sustainable land management (SLM) practices are being promoted in the Uluguru and Pare mountains. These are physical measures, such as bench terraces, stone terraces and *fanya juu* terraces; cultural measures such as ridges, borders, and pits; and biological measures such as grass strips, cover crops, mixed cropping, crop rotation, mulching, and trash lines. Other practices are agro-forestry, application of organic manure (farmyard manure and compost), double digging, and contour strip cropping (Malisa, 2009; CARE, 2014). These practices enhance water-smart agriculture—they improve soil health, resulting in production increase and they increase water use efficiency, leading to higher farm income.

Despite efforts to promote SLM practices, recent studies (Chamshama *et al.,* 2009; Mussa *et al.* 2012) reveal that land degradation is still one of the main threats to food security in the Uluguru mountains and that adoption of SLM practices is not widespread (Malisa, 2009). The recommended ways to curb this adoption gap include promotion of SLM practices that are profitable (Wamba, 2008; CARE 2014), that can be integrated into existing farming system, and that support soil nutrient and moisture retention (Malisa, 2009). Adoption that enhances the ownership of interventions is necessary.

Results and discussion

Relevance of SLM as a strategy in promoting water-smart agriculture

Experiences from the Uluguru and Pare mountains show that SLM practices are relevant because they result in economic, environmental, and social benefits.

Economic benefits

Investment analysis of three key SLM practices—bench terraces, *fanya juu* terraces, and borders (*majaluba*), done in the Pare mountains using net present value (NPV), benefit cost ratio (BCR), and internal rate of return (IRR), showed that investment in any of the three practices was profitable (GWI-CARE, 2014). Comparing the with and without SLM practice scenarios, the findings showed that farmers not applying any SLM practice experienced loss and that SLM practices resulted in incremental net benefits.

Considering other factors such as technical aspects, it can be asserted that, on flat land or gentle slope, borders are potentially profitable, whereas *fanya juu* and bench terraces are profitable on moderate and steep slopes. The findings also demonstrated that SLM practices were more profitable when integrated with high-value crop production. For example, from the results, two high-value crops, namely onions and tomatoes, had the highest NPV, whereby onions ranked first (NPV of 2,887,660 Tsh) followed by tomato (NPV of 1,375,160 Tsh) (Table 1).

The following are the main considerations and assumptions made for the NPV, BCR and IRR computations:

- Discount rate of 15%, which is assumed to reflect the prevailing opportunity cost of capital
- Farm size considered for each practice is 1 acre (0.405 ha)
- Projection of costs and benefits over a 5-year period: This is based on the fact that agricultural harvesting practices in question have long-term effects (more than 5 years)

A study conducted in the Uluguru mountains by UMADEP and GRET (2014) showed that *fanya juu* terraces, contour strip cropping, bench terraces, and agro-forestry were profitable. They resulted in a positive NPV and a value of BCR greater than 1. In this regard, *fanya juu* terraces had the highest NPV (TZS 2,415,318), followed by contour strip cropping (TZS 1,677,633), bench terraces (TZS 944,698), and lastly, agro-forestry (TZS 725,665). Likewise, with regard to BCR, *fanya juu* terraces had the highest BCR (7), followed by contour strip cropping and bench terraces, (both with BCR value) of (4), and lastly, agro-forestry (BCR value of 2).

***Table 1**. Investment analysis of various SLM practices.*

Practice	Criteria	Maize	Lablab	Onion	Tomato
Bench terraces	NPV (TZS) BCR IRR	453,331 1.4 70%	-375,444 0.6 na	748,347 1.3 93%	1,375,160 1.6 577%
Fanya juu terraces	NPV (TZS) BCR IRR	453 331 1.3 59%	na na na	na na na	na na na
Border	NPV (TZS) BCR IRR	862 742 24 na	897 045 2.3 na	2 887 660 3.2 na	na na na
Conventional	NPV (TZS) BCR IRR	168 336 0.7 na	4 820 1.0 na	na na na	na na na

NPV = net present value, BCR = benefit cost ratio, IRR = internal rate of return, NA = not available.

Environmental benefits

- Soil erosion control: In the Uluguru mountains, about 63 ha were converted into terraces by 327 farmers in Kibungo juu ward during the 2009–2012 period.

- Land cover restoration: In Kibungo juu ward, over 300,000 timber tree species (*Grevillea robusta, Khaya anthotheca, Afzelia quanzensis, Markhamia lutea)* and fruit trees were planted from 2009 to 2012. Total land planted with trees under agroforestry and reforestation programs is about 370 ha belonging to 873 farmers (477 male, 396 female).

- Improved water quality: According to CARE Tanzania (2012), there has been a significant decrease in sediment load in Mfizigo River as a result of SLM interventions (Fig. 1).

Social benefits

Improved food security: A survey conducted in 2012 in eastern Uluguru mountains showed that farmers got higher crop production and productivity per unit of conserved land (*fanya juu* and bench terraces) due to improved biological and chemical properties of the soil (Table 2).

By linking farmers with markets, Kibungo juu farmers managed to generate a high income of Tshs 19,500,000 ($13,000) through the sale of cabbage, tomato, and onion (CARE, 2012). This has improved the community's access to social services such education, health, and housing.

Challenges

The challenges facing smallholder farmers in SLM implementation include lack of tools and inputs, destruction of water-harvesting structures by livestock, incidence of crop pests and diseases, and high establishment cost and labor requirement. Other issues include worn-out irrigation infrastructure, poor market access, and lack of collective action against environmental degradation.

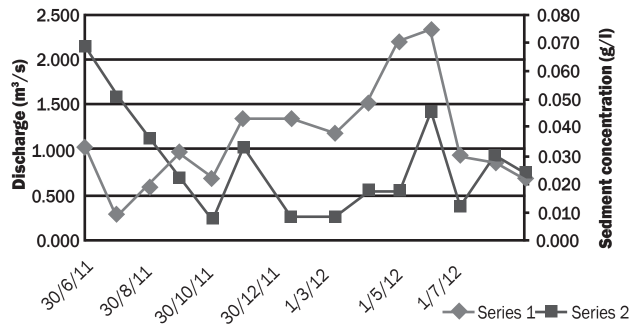


Fig. 1. *Relationship between discharge and suspended sediment in Mfizigo River.*

Table 2. *Changes in crop production.*

Crop	Baseline (2008)	(May 2012)
Maize	< 400 kg/acre	>1,600 kg/acre
Beans	< 120 kg/acre	≥ 950 kg/acre
Cabbage	Nil	≥ 9,600 pcs/acre
Tomato	Nil	≥ 9,000 kg/acre
Union	Nil	≥ 4,000 kg/acre

Source: (CARE, 2012)

Conclusion and recommendations

Adoption of SLM practices is necessary if we are to achieve water-smart agriculture. SLM practices relevant to water-smart agriculture include bench terraces, stone terraces, *fanya juu* terraces, borders, cover crops, mixed cropping, crop rotation, mulching, and trash lines. Other practices are agro-forestry, use of organic manure, double digging, and contour strip cropping. These are relevant in the sense that they control soil erosion, increase crop production, improve farm income, and are sustainable.

For wider adoption of SLM practices that promote water-smart agriculture, the following recommendations are made:

1. As SLM benefits not only land users but also society in general (e.g., through downstream effect), this justifies the use of incentives.

For continued adoption, incentives should be accompanied by creating awareness among beneficiaries as to why they receive the incentive and when it ends.

2. Establish rules and set mechanisms to enforce compliance with SLM agreement.
3. Champion farmers or paraprofessionals need to be identified and trained, especially on the use of technical aspects of SLM and general agriculture. This is to be accompanied by provision of line level for plot measurements.
4. Interventions that involve primary and secondary schools must be done to inculcate environmental stewardship among the young generation.
5. Micro-finance institutions must be promoted in the project area to improve access to capital.
6. SLM practices should be promoted together with irrigation improvement, use of high-value crops and linkage of farmers to markets. For SLM practices to be widely adopted, they should be profitable.
7. Ensure regular field follow-up and evaluation of ongoing activities.

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Managing Water

3

Flexible Water Storage Options and Adaptation to Climate Change

Agriculture is by far the largest human use of water. It uses 70% of global freshwater withdrawals, mainly for irrigation to supplement water for rainfed crops and livestock. Natural variability in rainfall and temperature means that, in many places, access to freshwater is already unpredictable. How climate change will alter this 'natural' variability is the subject of considerable study.

For many millions of smallholder farmers, reliable access to water is the difference between plenty and famine. The classic response is to store water behind dams or in tanks or ponds when it is abundant and where it can be conserved for times of shortage. Water storage spurs economic growth and helps alleviate poverty by making water available when and where it is needed. Today, many developing countries, even those with abundant water, have insufficient water storage capacity.

Inadequate storage leaves farmers vulnerable to the vagaries of climate. Ethiopia is one such example. Ethiopian farmers are heavily reliant on rainfed subsistence agriculture. The lack of storage infrastructure means farmers have limited ability to cope with droughts and floods. These limitations are estimated to cost the economy one-third of its growth potential. The Ethiopian case is a good illustration of the urgent need for appropriate investments in water storage to increase agricultural productivity and to ensure that farmers have options for adjusting to the coming climate changes.

Dams are one of the many surface and below-surface water storage options for agriculture. Others include natural wetlands, water stored in the soil, and rainwater-harvesting ponds. Historically, irrigation depended heavily on water in rivers or naturally stored in lakes, floodplains, and wetlands.

Groundwater provides much of the water used for irrigation. In India, more than 19 million pumps withdraw 230 km^3 of groundwater annually. In Spain, northern China, and California, crop production is almost entirely dependent on groundwater. All groundwater originates as rainfall that percolates down through the soil into aquifers. In some places, the groundwater in these aquifers came from rains that fell many thousands of years ago when rainfall patterns were very different. Libya, for example, is currently exploiting vast reserves of water stored beneath the Sahara Desert, where almost no rain falls today. Water from these ancient aquifers is sometimes called 'fossil water.' Pumping fossil water is like pumping oil; once used, there is no more. Even where groundwater is recharged, if pumping exceeds the rate of recharge, water levels will fall until the aquifer is exhausted or until it becomes uneconomical to pump. This can be devastating for poor farmers as can already be seen in a number of places, including Gaza, northern China, and California. Artificial recharge of groundwater aquifers is possible (for example, using recharge ponds) and is an element of water storage that should not be neglected.

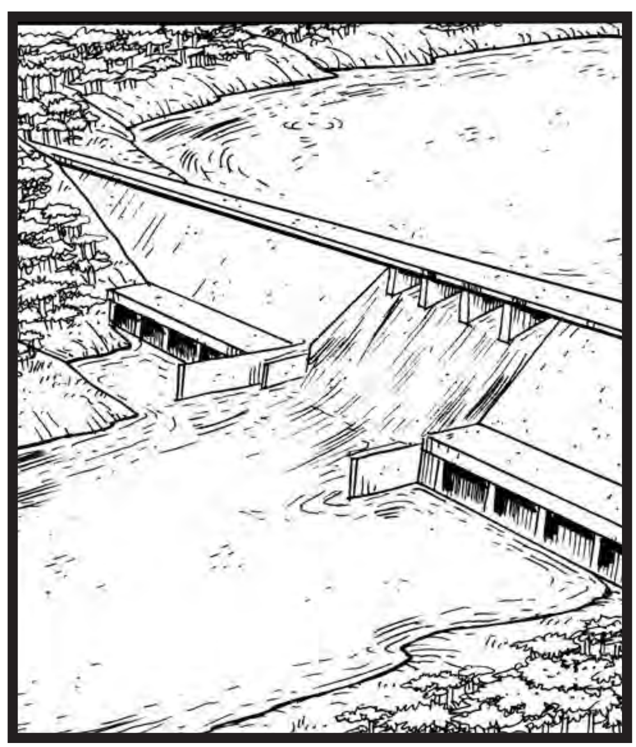
Some effective methods for storing water are also relatively simple and cheap, bearing in mind that in some regions such as Ethiopia, even simple ponds and tanks are beyond the financial means of the poorest. Ponds and tanks built by individual households or communities can store water collected from microcatchments and rooftops. Individual ponds and tanks may be small in volume, but, in some places, this water is vital to supplement domestic water supplies, household gardens, rainfed crops, and livestock.

Water storage and the environment

Of all the choices available for water storage, large dams are the most controversial. Many large dams contribute significantly to economic development. However, it is also true that inappropriate construction and operation have been the cause of significant social and environmental costs and have adversely affected poor people. For most of the world's large dams, downstream economic and environmental consequences have been given little attention in design and operation. Most dams were constructed with the emphasis on maximizing the economic returns from the dam itself, with little understanding of the long-term consequences of changing river flow patterns downstream.

Over the last 40 years, there has been an increasing understanding of how dams modify riparian ecosystems. Using dams to regulate flow has been found to cause serious degradation of ecosystems and the natural resources and services upon which many people living downstream of the dam depend. Concerns about the negative social and environmental impacts led to reduced investment in large dams in the 1990s. More recently, there has been a reevaluation of the role of dams and though the controversy continues, investment in large dams in Africa and Asia is increasing again.

Other forms of water storage and water use can also have negative environmental impacts, affecting river ecosystems and wetlands. Pumping from aquifers lowers the water table and can reduce dry-season flows and spring discharges and can cause wetlands to dry up. Even storage in small tanks and in the soil can modify flow regimes if scaled up over large areas.



The importance of ecosystem services is now widely recognized. Providing water to support those services is increasingly viewed as an essential use of water, along with water for agriculture, industry, and domestic use. In many countries, national legislation now makes explicit provisions to safeguard flows in rivers to protect the environment and support basic human needs.

Different types of water storage also have a unique carbon footprint. Tropical hydropower reservoirs produce greenhouse gas (GHG) emissions from the decomposition of flooded vegetation and primary production. Under certain circumstances, these GHGs may exceed that of comparable fossil fuel power stations. Pumping from deep groundwater aquifers takes a lot of energy, usually in the form of electricity or diesel fuel.

IWMI's partners and research collaborators estimate that the groundwater irrigation in India accounts for about 4% of the country's total GHG emissions.

Population growth, rising incomes, and urbanization are just some of the drivers increasing the demand for water in cities and industry. Part of the problem in supplying these needs is that the pattern of demand is seldom the same for all users. For example, hydropower demand is more or less constant through the year with diurnal variations, whereas irrigation water is needed only at specific times of the year. For flood control, water levels in a reservoir need to be lowered, while irrigation requires that a reservoir be kept as full as possible. These differences are often a source of competition for, and conflict over, stored water. To reduce conflicts, it is important that everyone with a stake in the storage (including local people) participate in decisionmaking processes pertaining to the water and its use.

Impact of climate change on water storage options

Climate change will increase rainfall variability and average temperatures, affecting both the supply and demand side of the irrigation equation. In some areas of the world, annual precipitation will decline, decreasing river flows and groundwater recharge. In other places, total precipitation may increase but it will fall over shorter periods with greater intensity so that dry spells are longer. Higher temperatures will increase evaporation so that crops will use more water. Although the effects will vary from place to place, farmers will generally need to adapt to less soil moisture and higher evaporation. This means larger volumes and more frequent use of supplemental water.

All storage options are potentially vulnerable to the impacts of climate change. For example, less rainfall and longer dry periods mean that soil water conservation measures may fail to increase soil moisture sufficiently for crops. Groundwater recharge may be reduced if infiltration decreases. Many near-coast aquifers will be at risk from saltwater intrusion as a result of sea level rise. Ponds, tanks, and reservoirs may not fill enough to support agriculture or may be at risk of damage from more extreme floods. Larger, more intense floods could also cause catastrophic large dam failures.

The externalities created by different storage types are also likely to be affected by climate change. For example, water storage tanks, ponds, and reservoirs create breeding grounds for mosquitoes and can lead to increases in malaria and other water-borne diseases. The higher temperatures expected with climate change may worsen the situation. Similarly, adverse environmental impacts, arising from changes in the flow regimes of rivers, may be exacerbated by climate change. Factors such as these must be considered in the future planning, design, and operation of water storage schemes.

Role of water storage in climate change adaptation

With increased uncertainty, higher demand, and greater competition, water storage is only one component of a multipronged approach for adapting agriculture to climate change. Future water resource management must also include reallocation of water between users and increasing water productivity wherever possible. There is no doubt that providing more and diverse physical storage infrastructure is an imperative for securing reliable supplies of water for agriculture and other uses.

Each type of storage has its own niche in terms of technical feasibility, socioeconomic sustainability, impact on health and environment, and institutional requirements. Each needs to be considered carefully within the context of its geographic, cultural, and political location. With so much uncertainty in climate change scenarios, the best option is to focus on flexibility in storage systems, wherever possible combining a variety of types to take advantage of their unique characteristics.

Poor farmers already struggle to cope with changing and unpredictable weather patterns and this will be worsened by climate change. As climate change becomes a greater threat to water systems and agriculture, variety in the types of water storage systems used will provide an important mechanism for adaptation. However, the types of storage must be tailored to the specific needs and socioeconomic conditions of an area. Planners need to start taking climate change into account when they design and manage integrated storage systems.

Type of farming system	Possible biophysical risks associated with climate change
Reservoirs	• Reduced inflow, resulting in longer periods between filling • Higher evaporation, increasing the rate of reservoir depletion • Infrastructure damage as a result of higher flood peaks • Improved habitat for disease vectors (e.g., mosquitoes) • Increased risk of eutrophication and salinization • Increased siltation
Ponds and tanks	• Reduced inflow, resulting in longer periods between filling • Higher evaporation, increasing rates of pond/tank depletion • Infrastructure damage as a result of higher flood peaks • Improved habitat for disease vectors (e.g., mosquitoes) • Increased risk of eutrophication and salinization • Increased siltation
Soil moisture	• Reduced infiltration resulting from modified rainfall intensities • Waterlogging resulting from modified rainfall intensities and duration • Longer dry periods resulting from altered temporal distribution of rainfall • Depleted soil moisture arising from higher evaporative demand • Soil erosion resulting from modified rainfall intensities and duration • Reduced soil quality (including water-holding capacity and nutrient status) resulting from modified rainfall and temperature
Aquifers	• Reduced recharge resulting from modified rainfall intensities • Reduced recharge resulting from land-cover modification and increased soil moisture deficits • Saline intrusion in near-coast aquifers • Increased percolation through frequent flooding
Natural wetlands	• Reduced rainfall and runoff inputs resulting in wetland desiccation • Higher flood peaks resulting in wetland expansion and flooding of fields and homes • Improved habitat for disease vectors (e.g., mosquitoes) • Retreat of glaciers due to higher temperatures and altered precipitation patterns

Source

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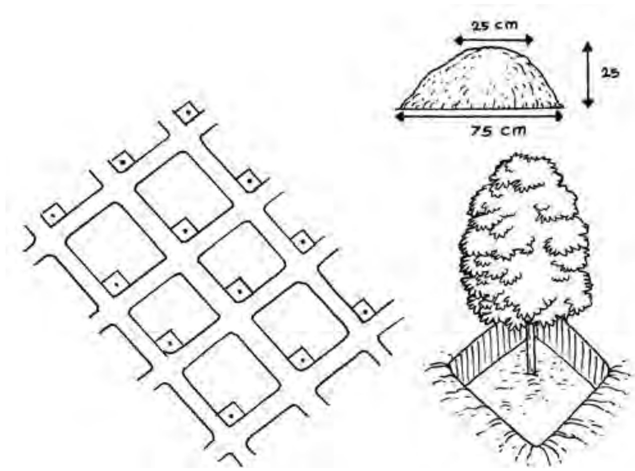
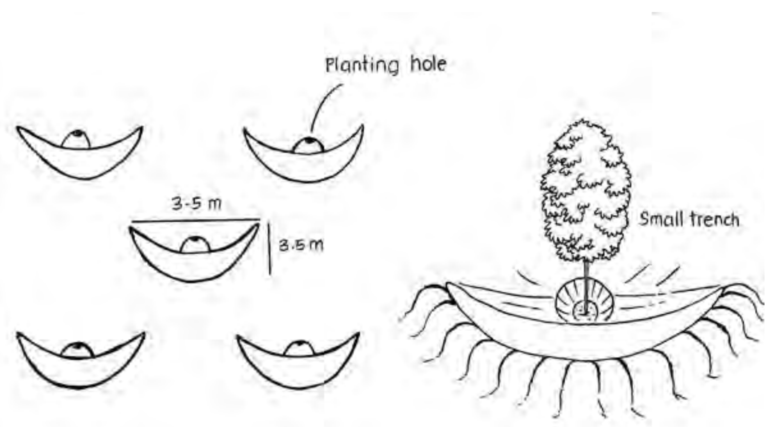
Some Interventions for Managing Water for Agriculture in Eastern and Southern Africa

The water resources of Eastern and Southern Africa (ESA) are considerable and, if managed more effectively, could make a substantial contribution to rural poverty reduction. Within the region, major opportunities to increase food security and household incomes are being missed because of inadequate management of agricultural water, especially in rainfed systems. Yet, evidence from the region shows that the technologies and approaches for agricultural water management (AWM) are known and have been practiced in the region. However, this knowledge is scattered in various places, publications, and locations around the region, even though much has been published. To bring it together, a study covering the ESA region was done to compile a compendium of technologies, practices, and approaches in AWM in the ESA region, in a one-stop-drop publication.

Interventions, description, where found, and references.

1.	**Basins** are normally small, circular, square, or diamond-shaped microcatchment systems, intended to capture and hold rainwater and/or runoff for plants (especially for growing fruit crops) and seedling establishment. Basins are constructed by making low earth ridges on all sides to keep rainfall and runoff in the mini-basin. Runoff water is then channeled to the lowest point and stored in an infiltration pit. The size of the basins may vary between 1 m and 2 m in width and up to 30 m in length for large external catchments.
2.	**Bench terraces** are made by reshaping a steep slope to create flat or nearly flat ledges or beds, separated by vertical or nearly vertical risers. They are made on very steep slopes. Due to the high labor demand, they are usually made for high-value crops such as irrigated vegetables and coffee. The benches are normally designed with vertical intervals that may range from 1.2 m to 1.8 m.
3.	**Broad-bed and furrow** systems are a modification of contour ridges, with a deliberate effort to ensure that there is a “catchment” ahead of the furrow. It is a within-field microcatchment water-harvesting system. The catchment area is left uncultivated and clear of vegetation to maximize runoff. Crops can be planted on the sides of the furrow and on the ridges. The distance between the ridges varies between 1 m and 2 m, depending on the slope gradient, size of catchment area desired, and amount of rainfall available. The system is suitable where annual rainfall is from 350 mm to 700 mm, land is of gentle slope (about 0.5-3% steepness), and soil is fairly light.
4.	**Charco dams** are small, rectangular, excavated pans or ponds, which are constructed at well-selected sites on relatively flat topography for livestock watering. They are constructed by hand or by machinery and can reach depths of 3 m. The design is simple and can be implemented at the village level with minimum engineering requirements.
5.	**Chololo pits** are so named after the village where they were invented, in Dodoma Region of Tanzania. These comprise a series of pits, which are about 22 cm in diameter and 30 cm in depth. The pits are spaced 60 cm apart within rows and 90 cm between rows, with the rows running along the contour. The soil removed during excavation is used to make a small bund around the hole. Inside the pit, ashes (to expel termites), farmyard manure, and crop residues are added, then covered with the requisite amount of soil while retaining sufficient space in the hole for runoff to pond. These preparations ensure that the water infiltrated is held by organic materials.
6.	**Contour bunds** (ridge terraces) are constructed of earth, by excavating a channel and creating a small ridge on the downhill side across the slope for soil conservation. The contour bunds resemble narrow channel terraces. Contour bunds are used for prevention of flooding and erosion control. They are popular in the highland areas of Ethiopia, where they are usually designed with a standard 1-m vertical interval.
7.	**Contour furrows** are small, earthen ridge and furrows, which are essentially microcatchment or within-field systems for small-scale production of food crops. In design, the ridges are about 0.15 m – 0.2 m in height and spaced at approximately 1.5 m apart on the contour. The furrow, which is upslope, accommodates runoff from the uncultivated microcatchment strip between the ridges. Small earthen ties were made within the furrow at a spacing of 4–5 m to prevent lateral flow. The objective of the system is to concentrate local runoff and store it in the soil profile, close to the plant roots. A cereal intercropped with pulse is usually recommended (Critchley *et al.*, 1992; Mati, 2005).
8.	**Contour stone bunds** are buffer strips created by arranging stones across the slope on the contour to form a barrier. However, the crop is grown just ahead of the stone bund, leaving the upper end of the terrace free to make a catchment. Since the bunds are permeable, they slow down the runoff rate, filter it, and spread the water over the field, thus enhancing water infiltration and reducing soil erosion. Stone bunds are commonly placed in areas receiving 200–750 mm of annual rainfall and are usually spaced about 15–30 m apart, with narrower spacing on steep slopes. They can be reinforced with earth or crop residues to make them more stable.
9.	**Cutoff drains** (also known as diversion ditch or storm-water drain) is a channel, made across the slope, with the ridge of the downhill side. It is meant to intercept surface runoff and convey it safely to an outlet such as a waterway, usually above cropped land.

10.	**Excavated bunded basins** (*majaluba*) are small basins that usually utilize an external catchment. They are constructed by digging to a depth of 0.2–0.5 m and by using the scooped soil to build a bund around the field perimeter. Normally, the bunds have a height of between 0.3 and 0.7 m above the ground. Farmers usually start with small-sized basins, for example, 10 m by 10 m, and then go into large areas of about 1 ha. This system is one of the methods of runoff utilization, management, and storage for the production of paddy rice and is widely used in the semiarid areas of Mwanza, Shinyanga, Tabora, Singida, and Dodoma regions of Tanzania (Hatibu *et al.*, 2000).
11.	***Fanya juu* terraces** are earthen embankments, created by digging a trench about 60 cm wide along the contour and throwing the soil upslope to form a ridge. This effectively reduces slope length, and hence soil erosion from steep cropland. *Fanya juu* terraces are suitable on slopes with annual rainfall of 500 – 1,000 mm.
12.	**Grass strips** is a vegetative buffer, in which grass is planted in dense strips, about 0.5–1 m wide, along the contour, at intervals equivalent to calculated terrace spacing. These lines create barriers that minimize soil erosion and runoff, through a filtering process. Silt builds up in front of the strip, and with time, benches are formed.
13.	**Gully control and utilization.** This involves rehabilitating gullies and converting them into productive land. Most of the gully control work involves creating check dams with locally available materials (stones, brushwood, or living vegetative hedges). The check dams are built in stages by raising the height of the check dam by about 0.3 m each year. As runoff flow velocities within the gully are reduced, deposition causes soil buildup to adequate depth. The excess flow over the gully is trapped, allowing for water harvesting, conservation, and the growing of crops even in marginal rainfall areas.
14.	**Hafir dams** are found in eastern Ethiopia and are used for human and livestock watering. Generally, they are excavated reservoirs with a water volume ranging from 500 to 10,000 m^3. Hafirs are located in natural depressions and the excavated soil is used to form an embankment around the reservoir to increase its capacity. Bunds and improvements to the catchment apron may help increase runoff into the reservoir, but seepage and evaporation are often high in the dry season. Hafirs differ from other earthen dams in they are generally bigger and also have good sedimentation basins.
15.	**Infiltration ditches** are used for harvesting water from roads or other sources of runoff. They consist of a ditch, 0.7–1.5 m deep, dug along the contour, upslope from a crop field. Water is diverted from the roadside into the ditch, which is blocked at the other end. Water trapped in the ditch seeps into the soil, raising the soil moisture storage in adjacent land.
16.	**Microcatchment systems** are runoff farming techniques in which a relatively small portion of upslope land is allocated for runoff collection, which is "harvested" and directed to a cultivated area (cropped area) downslope. The cropped area may be basins, pits, bunds, or ordinary tilled land. Microcatchments are normally within-field systems since runoff comes from within the vicinity of the cropped area.
17.	**Negarims** are a newer microcatchment method of designing basins used for the establishment of fruit trees in arid and semiarid regions where seasonal rainfall can be as low as 150 mm. In design, they are regular square earth bunds, which have been turned 45 degrees from the contour to concentrate surface runoff at the lowest comer of the square. They are, therefore, efficient in land utilization. Negarims are practiced in Kitui, Thika, and Meru districts of Kenya for fruit tree production (Hai 1998; Critchley and Siegert 1991; Thomas 1997). 

18.	***Ngolo* pits** or *Matengo* pits, are a special type of soil and water conservation practiced in the Mbinga highlands of Tanzania. This is characterized by a pattern of square pits and ridges, created using crop residues and weeds on slopes with about 35-60% steepness. The ngolo system involves a crop rotation of mainly maize and beans, with specific activities to maintain the pits throughout the season. It is labor-intensive but quite effective in controlling soil erosion on very steep slopes.
19.	**Permeable rock dams** are long, low structures consisting of well-packed stones, creating contour bunds across valley floors. In design, they are 0.5–1 m in height and can be up to 50 m wide and 300 m in length. They are used for controlling gully erosion while causing deposition of silt and spreading and retaining runoff for improved plant growth. They are popular in semiarid areas, especially for rehabilitation of denuded rangeland.
20.	**Runoff harvesting from hillsides and open surfaces**. Runoff may be harvested from rocks, hillsides, and open surfaces and channeled into large basins or directly onto cropped land. Research in Baringo District of Kenya showed that due to the high runoff-producing characteristics of the hillsides, rainfall storms of as little as 8 mm were able to initiate surface runoff.
21.	**Semicircular bunds** (also known as demi-lunes or crescent-shaped bunds) involve making earth bunds in the shape of a semi-circle with the tip of the bunds on the contour. The dimensions of the holes and the spacing of the contours are dictated by the type of crop or the farming system. In design, the holes are made with a radius of at least 0.6 m and a depth of 0.6 m. The subsoil excavated from the pit is used to construct a semicircular bund with a radius ranging from 3 m to 6 m on the lower side of the pit. Bund height is normally 0.25 m. The excavated planting pits are filled with a mixture of organic manure and topsoil to provide the required fertility and also to help retain moisture. 
22.	**Spate irrigation** or diversion of flood flow from highlands into lowlands and "wadis" has a long history in the Horn of Africa. It still forms the livelihood base for rural communities in arid parts of Eritrea and the upper rift valley in Ethiopia. Storm-floods are harvested from rainfall-rich highlands and diverted into leveled basins in the arid lowlands. In Eritrea, the embankments conveying the storm-water can be extremely large (5–10 m high) and are built by shoveling the sandy soil using animal traction.
23.	**Tied ridging** are a modification of the normal contour ridges used for water conservation in dry areas. The technique involves digging major ridges that run across the predominant slope and then creating smaller sub-ridges (or cross-ties) within the main furrows. The final effect is a series of small microbasins that store rainwater in situ, enhancing infiltration. Depending on the system, the crop is planted at the side of the main ridge, to be as close as possible to the harvested water, while also avoiding waterlogging in case of prolonged rains. Tied ridges have been found to be very efficient in storing rainwater, which has resulted in substantial grain yield increase in some of the major dryland crops such as sorghum, maize, wheat, and mungbean in Ethiopia.
24.	**Zai pits** (or zay pits) utilize shallow, wide pits that are about 0.6 m in diameter and 0.3 m in depth, in which four to eight seeds of a cereal crop, (e.g., maize) is planted. Manure is usually added into the pit to improve fertility. It works by a combination of water harvesting and conservation of both moisture and soil fertility in the pit. There have been some modifications of the zai system in the ESA, for instance, the "katumani pit", which is wider than the zai. In southern Tanzania, the pits are made bigger and deeper (at least 0.6 m deep), with some 20-liter volume of manure added. The zai system has been adopted from the Sahel Region of West Africa and is commonly practiced in the ESA (Critchley and Siegert, 1991; Reij *et al.*, 1996; Malley *et al.*, 1998; Hai, 1998).

25.	**Zero tillage** or no-till system is minimum tillage at its most absolute. It involves growing a crop in a field that has had no tillage operations preceding the planting. The land is planted by direct seed drilling without opening any furrows or pits. Old crop residues act as a mulch and weeds are controlled using herbicides. In the dry areas of East Africa, zero tillage has not worked well due to poor infiltration, since most ASAL soils have surface-sealing problems, and the costs of herbicides are prohibitive to smallholder farmers.

Note that this article only includes a small section of the original 100 interventions covered in the IMAWESA study. Refer to the full study for complete information including references.

Source

The original article consisted of 100 interventions. These can be found in the original article. *100 ways to manage water for smallholder agriculture in Eastern and Southern Africa: a compendium of technologies and practices.* SWMnet Working Paper 13 by Bancy M. Mati. March 2007. (This article only highlights a few of the interventions.)

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Microcatchment Rainwater Harvesting

Arid and semiarid zones are characterized by low erratic rainfall of up to 700 mm per annum, periodic droughts, and different associations of vegetative cover and soils. Interannual rainfall varies from 50 to 100% in the arid zones of the world, with averages of up to 350 mm. In the semiarid zones, interannual rainfall varies from 20 to 50% with averages of up to 700 mm (CASL, 2006).

The majority of the population in the arid and semiarid areas depend on agriculture and pastoralism for subsistence. These activities face many constraints due to predominance of erratic rainfall patterns, torrential rainfall that is mainly lost to runoff, high rate of evapotranspiration that further reduces yields, weeds growing more vigorously than cultivated crops, competition for scarce reserves of moisture, low organic matter levels, and highly variable responses to fertilizers (CASL, 2006).

There is a need of more efficient capture and use of scarce water resources in the arid and semiarid areas. An optimization of rainfall management, through water harvesting in sustainable and integrated production systems, can contribute to improvement of small-scale farmers' livelihood by upgrading rainfed agricultural production.

Microcatchment rainwater-harvesting systems have the following characteristics: overland flow harvested from short catchment length, catchment length usually between 1 and 30 cm, runoff stored in soil profile, ratio of catchment: cultivated area usually from 1:1 to 3:1, normally no provision for overflow and even plant growth. These are typical examples of this type of system: Negarim microcatchments, contour bunds, and semicircular bunds (Critchley and Siegert, 1991).

The general design principle of microcatchment rainwater harvesting systems involves a catchment area that collects runoff coming from roofs or ground surfaces and a cultivated area that receives and concentrates runoff from the catchment area for crop water supply. The relationship between catchment area and cultivated area, in terms of size, determines by what factor the rainfall will be multiplied. For a more efficient and effective system, it is necessary to calculate the ratio between the two if data related to the area of concern in terms of rainfall, runoff, and crop water requirements are available (Moges, 2004).

Major techniques

The microcatchment rainwater-harvesting system is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration area (Cofie *et al.,* 2004). The system is mainly used for growing medium water-demanding crops such as maize, sorghum, groundnut, and millet (Hatibu and Mahoo, 1999). It has also been used to supplement rainfall for native vegetation (Matthew and Bainbridge, 2000).

Microcatchment systems provide many advantages over other irrigation schemes. They are simple and inexpensive to construct and can be built rapidly using local materials and manpower. The runoff water has low salt content and, because it does not have to be transported or pumped, is relatively inexpensive. The system enhances leaching and often reduce soil salinity (Matthew and Bainbridge, 2000). The major techniques include pitting, earth basins, strip catchment tillage, semicircular bunds, earthen bunds, meskat-type system, negarim microcatchments (water harvesting sudan), contour ridges and stone lines (Critchley and Siegert, 1991).

Pitting system

A pitting system consists of small circular pits, about 30 cm in diameter and 20 cm deep, dug to break the crusted soil surface in order to store water and build up soil fertility. Variations of the system include Zai, Tassa, half moon, Katumani pitting, planting pits, chololo pits, and "five by nine" pits. They are used in areas with rainfall between 350 and 600 mm (Hatibu and Mahoo, 1999).

The Zai technique uses shallow, wide pits that are about 30 cm in diameter and 15–20 cm in depth into which four to eight seeds of a cereal crop are planted (Itabari and Wamuongo, 2003). Organic manure and compost are usually added into the pit to improve fertility. It works by a combination of water harvesting and conservation of both moisture and fertility in the pit. In the Njombe district of southern Tanzania, the pits are made bigger and deeper (at least 0.6 m deep), and 20-liter volume of manure is added. Since the area receives an annual rainfall close to 1000 mm, the farmers plant about 15 to 20 seeds of maize per pit and yield is more than double those in conventionally tilled land (Mati, 2005).

The chololo pit technique is a pitting method comprising a series of pits that are about 22 cm in diameter and 30 cm in depth. The pits are spaced 60 cm apart within rows and 90 cm between rows, with rows running along the contour. The soil removed during excavation is used to make a small bund around the hole. Inside the pit, ashes (to expel termites), farmyard manure, and crop residues are added, then covered with the requisite amount of soil while retaining sufficient space in the hole for runoff to the pond. One or two seeds of either maize/millet or sorghum are planted per hole. Crops usually survive even during periods of severe rainfall deficits and yields have been noted to triple. The required labor for digging the holes is low (Mati, 2005).

The "five by nine" is a pitting method for maize crops, which are 60 cm square and 60 cm deep. They are larger than Zai pits but have a square shape. The name is based on the five or nine maize seeds planted at the pit diagonals (five for dry areas and nine for wet areas). This type of pit can hold more manure than a Zai pit. Hence, it is capable of achieving higher yields that have a long-lasting effect. The pit can be reused up to 2 years (Mati, 2005).

Strip catchment tillage

Strip catchment tillage involves tilling strips of land along crop rows and leaving appropriate sections of the interrow space uncultivated so as to release runoff. It is normally used where slopes are gentle and runoff from the uncultivated parts adds water to the cropped strips. The catchment-basin area ratios used are normally less than or equal to 2:1. The system can be used for almost all types of crops and is easy to mechanize. Herbicides are used to control weeds in the catchment area (Hatibu and Mahoo, 1999).

Earth basins

Earth basins are normally small, circular, square or diamond-shaped microcatchments intended to capture and hold all rainwater that falls on the field for plant use. They are constructed by making low earth ridges on all sides to keep rainfall and runoff in the mini-basin. Runoff water is then channeled to the lowest point and stored in an infiltration pit. The technique is suitable in dry areas , where annual rainfall amounts are at least 150 mm, where slope steepness ranges from flat to about 5%, and where soil is at least 1.5 m deep to ensure enough water-holding capacity. Earth basins are especially used for growing fruit crops. The seedling is usually planted in or on the side of the infiltration pit immediately after the rains begin. The size of the basin may vary between 1 m and 2 m in width and up to 30 m in length for large external catchments with a depth at about 0.5 m (Mati, 2005).

Earthen bunds

Earthen bunds are various forms of earth shapings, which create run-on structures for ponding runoff water. The most common are within-field runoff harvesting systems, which require less mechanization, relying more on manual labor and animal draft. The variations of the system include contour bunds, semicircular bunds, and negarim microcatchments. Contour bunds are not suitable for small-scale agriculture; they are most appropriate for large-scale endeavors, especially when mechanized.

The normal design for semicircular bunds involves making earth bunds in the shape of a semi-circle with the tip of the bunds in the contour. In Busia District, Kenya, semi-circular bunds are made by digging out holes along the contours. The dimension of the holes and the spacing of the contours are dictated by the type of crop. For common fruits, the holes are made with a radius of at least 0.6 m and a depth of 0.6 m. The subsoil excavated from the pit is used to construct a semicircular bund with radius ranging from 3 m to 6 m on the lower side of the pit. Bund height is normally 0.25 m. The pits hold a mixture of organic manure and topsoil to provide the required fertility and to help retain moisture. It is a common practice to plant seasonal crops such as vegetables, including beans and other herbaceous crops in the pits before the tree crops develop a shady canopy (Mati, 2005). The technique is found in areas with annual rainfall ranging from 200 mm to 275 mm, and land slope with less than 2% steepness. The main problems associated with this type of bunds are difficulty in construction with animal draft, high labor requirement, regular maintenance needed, and inability to use machinery (Critchley and Siegert, 1991).

Negarim microcatchments are regular square earth bunds, which have been turned 45 degrees from the contour to concentrate surface runoff at the lowest corner of the square where there is an infiltration pit dug. The shape of the infiltration pit can be circular or square, with dimensions varying according to the catchment size. Three seedlings of at least 30 cm should be planted in each infiltration pit after the first rain of the season (Critchley and Siegert, 1991). Manure or compost should be applied to the pit to improve fertility and soil water-holding capacity. The bund height changes with catchment size and slope of the area. The system is used to establish fruit trees and grass in arid and semiarid regions where seasonal rainfall can be as low as 150 mm (Mati, 2005). The catchment areas range from $10m^2$ to $100m^2$, depending on the tree species planted (SCTD, 2001).

Negarim microcatchments are appropriate for small-scale tree planting in any area that has a moisture deficit. Besides harvesting water for trees, they simultaneously conserve soil. The system is efficient, precise, and relatively easy to construct. However, there are limitations on its implementation: not easily mechanized (limited to small scale) and very difficult to cultivate between tree lines (Critchley and Siegert, 1991).

Contour ridges

A contour ridge is a microcatchment technique that involves making ridges following the contour at a spacing of usually 1.5 to 2 m, which means that the ratio between catchment and cultivated area is 2:1 to 3:1, respectively (Haile and Merga, 2002). Runoff is collected from the uncultivated strip between ridges and stored in a furrow just above the ridges. Crops are planted on both sides of the furrow. The system is simple to construct, by hand or by machine, and can be even less labor-intensive than conventional tillage. The following conditions are most suitable for its implementation: annual rainfall between 350 and 750 mm, soils suitable for agriculture, slope steepness from to 5%, and smooth areas (Critchley and Siegert, 1991).

The overall layout of the contour ridge system consists of parallel earth ridges approximately on the contour at a space of between 1 and 2 m. Soil is excavated and placed downslope to form a ridge, and the excavated furrow above the ridge collects runoff from the catchment strip between ridges. Small earth ties 15–20 cm high and 50–75 cm long are provided above the furrow every 4 to 5 m to ensure even storage of runoff. A diversion ditch 50 cm deep and 1–1.5 m wide is usually done before the contour ridges are built to protect the system against runoff from outside (Critchley and Siegert, 1991).

In the contour ridge system, the main crop (usually a cereal) is seeded into the upslope side of the ridge between the top of the ridge and the furrow. An intercrop, usually a legume, can be planted in front of the furrow. It is recommended to use approximately 65% of the plant population for rainfed cultivation, so that the plants can have more moisture available in years of low rainfall. Weeding must be carried out regularly around the plants and within the catchment strip (Critchley and Siegert, 1991).

Broadbed and furrow systems are a modification of contour ridges, with a catchment ahead of the furrow and a within-field microcatchment water-harvesting system. In Ethiopia, Kenya, and Tanzania, the systems are made as small earthen banks with furrows on the higher sides, which collect runoff from the catchment area between the ridges. The catchment area is left uncultivated and clear of vegetation to maximize runoff. Crops can be planted on the sides of the furrows and on the ridges. Plants that need much water, such as beans and peas, are usually planted on the higher side of the furrow, and cereal crops such as maize and millet are usually planted on the ridges. The distance among the ridges varies between 1 m and 2 m, depending on the slope gradient, size of catchment area desired, and amount of rainfall available. The system is most suitable in areas where the annual rainfall is from 350 mm to 700 mm, even topography, gentle slope of about 0.5–3% steepness, and soils fairly light due to high infiltration rates (Mati, 2005).

In-field rainwater-harvesting technique

The in-field rainwater-harvesting technique is a microcatchment technique that combines the advantages of water harvesting, no-till, and basin tillage to stop runoff completely on clay soils (Hensley *et al.*, 2000). The technique consists of a catchment area, which promotes in-field run-off, and a cropped basin, which allows the stoppage of ex-field runoff completely and maximizes infiltration and stores the collected water in the soil layers beneath the evaporation-sensitive zone. Ridges are immediately done after each cropped basin to allow better conservation of water in the soil profile. Mulch is placed in the cropped basin to minimize evaporation losses. The ratio between catchment area and cropped area, based on field experience with crops in the semiarid areas is 2:1 (Rensburg van *et al.*, 2003). Herbicides are used to control weeds in the catchment area.

Meskat-type system

The meskat-type system is a type of microcatchment system in which the catchment area diverts runoff water directly onto a cultivated area at the bottom of the slope (Rosegrant *et al.*, 2002). In this system, instead of having catchment area and cultivated area alternating as in the previous methods, here, the field is divided into two different parts: the catchment area and cultivated area, which is placed immediately bellow the catchment area. The catchment area must be compacted and free of weeds. The recommended ratio between catchment area and cultivated area in semiarid areas is 2:1 (Hatibu and Mahoo, 1999).

Source

Rainwater Harvesting Technologies for Small-Scale Rainfed Agriculture in Arid and Semi-arid Areas by N. Ibraimo and P. Munguambe. February 2007. Department of Rural Engineering, Faculty of Agronomy and Forestry Engineering, University Eduardo Mondlane, Mozambique.

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Economic Benefits of Rainwater Harvesting Technologies to Farmers:

Evidence from Minjar Shenkora District of Amhara Region

Over the last three to four decades, farmers in sub-Saharan Africa (SSA) have experienced weather-induced problems such as drought, prolonged dry spells, erratic rainfall, and floods. The average incidence of severe drought has been on the increase, with seven serious droughts occurring in Africa from 1980 to 1990 and 10 others between 1991 and 2003. The result is that drought-induced crop failures are prevalent in the region (FAO, 2005). There is broad agreement that one of the biggest climate change impacts will be on rainfall, making it more variable and less reliable (Lenton and Muller, 2009).

To counteract such problems, various agricultural water management (AWM) technologies can be used by smallholder farmers to improve production and productivity (Mati, 2007). Rainwater harvesting (RWH), which is about collecting, conserving, storing, and utilizing rainwater for various purposes, is one such technology. Rockström *et al.* (2007) indicated that rainwater harvesting has great potential to contribute to poverty reduction efforts by improving land productivity and profitability in rainfed areas in Africa. Rainwater harvesting interventions could also be useful as an adaptation method responding to climate change.

In Ethiopia, massive RWH structures were constructed in 2003–04. For example, 14,976 structures were constructed in the Amhara Region alone (BoWRD, 2005). Nearly 88% of the structures were built in moisture-deficient districts. However, the returns on investment and socioeconomic impacts of this investment remain largely unquantified and, thus, unknown.

The objective of the study was, therefore, to determine the impacts of RWH on agricultural productivity, household income, return on family labor and, overall, to assess the viability of the investment. The study explores the potential value of RWH in the transformation of smallholder agriculture and rural livelihoods but also warns against the dangers of inappropriate use of RWH not only in Ethiopia but also in SSA.

Study context

This study was undertaken in Minjar Shenkora District of the Amhara Region, Ethiopia, where uneven and erratic rainfall is a common occurrence. The lack of potable water near homesteads increases the workload of women and children who have to travel long distances to fetch water as there are no permanent rivers in the area (MSWoARD, 2008).

Rainwater harvesting in the area started in 2004 initially involving 308 households. By 2008, the number of those adopting the technology had expanded to 7,618 households. Some farmers even own more than one pond. About 45% of the harvested rainwater was used for onion seedlings and fruit production, 50% and 5% went to farm households' consumption and livestock, respectively. Pond size and water-holding capacity differed from one agroecology to another due to water evaporation and seepage losses. The net water volume harvested was estimated to be 95 m^3, 90 m^3, and 80 m^3 in the highland, mid and lowland areas, respectively. On average, 100 m^2 of land was cultivated with one RWH pond.

Study approach

The impact of the technology was evaluated by comparing the situation with and without (control) RWH schemes. Farmers, stratified into three categories based on altitude, (highland, midland, and lowland), were identified with the assistance of technical staff from the district office of agriculture. One peasant association (PA) from each stratum and 30 farmers per PA were then randomly selected. Field data were collected through farm visits and interviews. Data such as yield (kg/ha/year), farm-gate prices (US$/kg), amount and cost of all agronomic inputs, costs of husbandry practices, harvesting, handling, and marketing, and establishment and maintenance costs were collected. In total, 90 farmers were interviewed and their ponds assessed. In addition, group discussions were held with experts and leaders of the respective PAs.

The average prices of inputs and outputs for the year 2007 were used as the basis for calculation. A profitability analysis was done using the average cost of inputs and farm-gate prices of produce. Return to family labor was determined by dividing the net income or profit, excluding the costs of family labor with the number of family labor inputs in adult-days.

Evaluation criteria for financial feasibility such as the net present value (NPV), internal rate of return (IRR), and return on investment (ROI) determined whether the technology was profitable or not. NPV compares the value of a dollar today to the value of that same dollar in the future, taking inflation and returns into account. The difference between the sum of all discounted benefits and costs represents the NPV. IRR is the discount rate under which the discounted benefits are equal to the discounted costs—i.e., where the NPV is exactly zero. ROI is also a performance measure used to evaluate the efficiency of an investment. It is the ratio of money gained or lost on an investment relative to the amount of money invested.

Results

Viability for improving productivity and profitability

Results of crop productivity and profitability are presented comparing 'with' and 'without' scenarios. Under the 'without' scenario, farmers were mostly reliant on field crops—i.e., teff and wheat. After the introduction of RWH, farmers grew vegetables in small gardens as well as in the fields. Of special interest were onions, which have been dealt with in the analysis. Onions were important because the availability of harvested rainwater enabled farmers to grow onion seedlings during the dry season, making them available for planting at the onset of the rains. This, in turn, made it possible for onions to be grown as a rainfed field crop by more farmers, including those without storage ponds. The area became a source of onions as a marketable crop. In the 'before' scenario, the average yields of teff and wheat were 1.85 and 2.84 tons/ha, respectively. Teff is considered a cash crop, earning an average farm gate-price of US$ 0.4708/kg compared with wheat at US$ 0.282/kg. Consequently, although wheat has higher yield, the gross incomes from teff and wheat were US$ 871/ha and US$ 801/ha, respectively (Table 1).

On the other hand, onions are a bulky cash crop, yielding, on average, 13.36 tons/ha and an average farm-gate price of US$ 0.169/kg, which translates into a gross income of US$ 2,258/ha. In addition, onion seedlings were also sold as cash crops, produced on plots measuring 100 m^2 (0.01 ha) and using about 40 m^3 of water from the pond. Onion seedlings earned a gross income of US$229 (Table 1) when farmers sold extra seedlings. As a result, the gross incremental income due to RWH for onions alone adds up to US$ 2,487/year per household. The average net income of rainfed teff, wheat, and onion was US$ 523, US$ 525 and US$ 1,848/ha/year, respectively. On the other hand, the average net income of onion seedlings was US$ 155/100 m^2 per year. Similar results were found by Mulinge *et al.* (2010) in Lare Division, Nakuru District, Kenya, where the increment in net income with supplementary irrigation was US$ 110, US$ 625, US$ 1,428, and US$ 4,603/ha for cabbage, kale, tomato, and onion, respectively, against rainfed agriculture.

Profitability analysis was done using the average prices of inputs and outputs, excluding family labor (Table 1). The average net income excluding family labor was US$ 2,100/ha for rainfed bulb onions, while teff and wheat, also rainfed, earned US$728 and US$685/ha, respectively. The average net income of seedling production with RWH ponds was US$ 118.13/year from a 100 m^2 area of land. The costs of production are generally low since farmers use family labor and low levels of inputs. About 72% of the total cost of seedling production with RWH was family labor. It also comprised the largest share of input cost for rainfed field crops.

Total family labor and gross economic returns to family labor are presented in Table 2. The return to family labor of RWH is determined by subtracting all costs from total revenue, excluding family labor inputs. Dividing this net profit with the number of family labor in man-days gives the gross return to family labor. Thus, the family labor used in the production of bulb onions, teff, and wheat per hectare was 150, 120, and 90 man-days, respectively. Meanwhile, onion seedling production used 13 man-days per 100 m^2 while production of bulb onion crop used 163 man-days per ha.

The study indicates that the gross return to family labor from onion seedlings under RWH was US$ 13.6 per man-day, while incremental return to labor due to the rainwater harvesting intervention was US$ 15 per man-day. By contrast, the returns to family labor for rainfed wheat and teff were only US$ 7.6 and 6 per man-day, respectively. This indicates that the returns to labor with RWH are significantly higher than those in rainfed systems.

Return on investment

A financial analysis (cost-benefit analysis) based on agricultural enterprises alongside RWH with storage ponds was done. Initial investment costs of RWH were US$ 154, 175, and 187 per pond in highland, midland, and lowland areas, respectively. The maintenance and production costs were US$ 48.8,

Table 1*. Gross and net incomes (US$) from major crops at Minjar Shenkora.*

Crop type	Mean gross income	Cost of inputs	Net income
Teff rainfed	871	348	523
Wheat rainfed	801	276	525
Onion seedlings	229	74	155
Field onions rainfed	2258	410	1848

35.8 and 27.1 per pond in the highland, midland, and lowland areas, respectively. The gross incomes from seedling production were US$ 301, 212 and 174 in high, middle, and lowland areas, respectively.

The average discounted benefits and costs of RWH for onion seedling production were US$ 1,527 and 304, respectively. In general, assuming a discount rate of 10%, the average NPV of investment in storage ponds over 7 years was about US$ 1,223. (The economic life of a RWH pond is estimated to be around 7 years in the study areas). Moreover, the average financial IRR for the three agro-ecologies was 202%. The average ROI was also 483%. All these showed the financial variability of RWH ponds (Table 3).

The real benefits of RWH would have been much higher than the calculated values if the water amount used for domestic purposes and livestock (about 50% of harvested water) had been considered in the analysis. Rainwater harvesting reduced long distance travelling of animals to watering points and, thus, the energy wasted can improve the performance of animals in terms of more meat and milk. The work burden of women and children and the time required to fetch water from distant rivers and streams helped them engage in other productive farm activities such as watering onion seedlings.

The economic potential of RWH is very clear as seen in this study. However, the history of RWH in Ethiopia is dogged by many failed programs. To ensure the uptake and sustainable use of the technology, attention needs to be given to policy support for the technology to encourage farmers to adopt it. The technology is also only appropriate where there is water stress. The exact technological options chosen are also critical and need to be both cost-effective and durable. For example, the concrete domes have not been as successful as geo-membrane structures, which themselves have failed where inappropriately laid or not maintained. In addition, the right crops for cultivation need to be selected, i.e., ones that generate a quick and high return, such as onions.

Key limitations

Some health hazards associated with RWH and storage include pests, especially mosquitoes in lowland parts of the district. There were also safety concerns since the ponds are open, while contamination of the water reduces its value for domestic use. Many farm households fenced their water-harvesting ponds to prevent entry of animals and protect children from danger. Water treatment is also required if households use the water for domestic purposes.

Conclusion

Rainwater harvesting has positive multiplier effects—improving the productivity and income of smallholder farmers while addressing the prevailing problems of moisture stress in the area. In the study area, before RWH was introduced, high-value crops such as onions, which can bring about a quick and high return on investment, were not widely cultivated due to lack of water. With the advent of the RWH technology, it was possible for farmers to grow onion seedlings on about 100 m^2 in the dry season and sell or plant them during the rainy season. The results

Table 2. *The average total family labor inputs and gross return to family labor.*

Crops/system	Total family labor	Net income excluding family labor (US$)	Return to family labor (US$/man-day)
Teff rainfed	120 (man-days/ha)	728	6.0
Wheat rainfed	90 (man-days/ha)	685	7.6
Seedling production with RWH	13 (man-days/100 m^2)	118.13	13.6
Onion rainfed	150 (man-days/ha)	2100	14.0
Incremental labor due to RWH intervention (onion crop only)	163 (man-days/yr)		15.0

Table 3. Net present value, internal rate of return, and return on investment from onion seedling production.

Performance parameter	Highland	Middle	Lowland	Average
Discount factor	10%	10%	10%	10%
NPV (7 years)	US$ 1,477	US$ 1,158	US$ 1,033	US$ 1,223
IRR	256%	189%	163%	202%
ROI	514%	467%	468%	483%

showed that the average net income from onion seedlings was US$ 155 per 100 m^2 plot, while that from rainfed bulb onions, once transplanted, was US$ 1848 per ha, making the contribution to farmer incomes from onions alone to be about US$ 2,003 per year, which is higher than what they earned from rainfed teff and wheat combined. Due to such visible benefits, the RWH technology has the potential, when properly constructed and supported, to have a transformational effect on livelihood.

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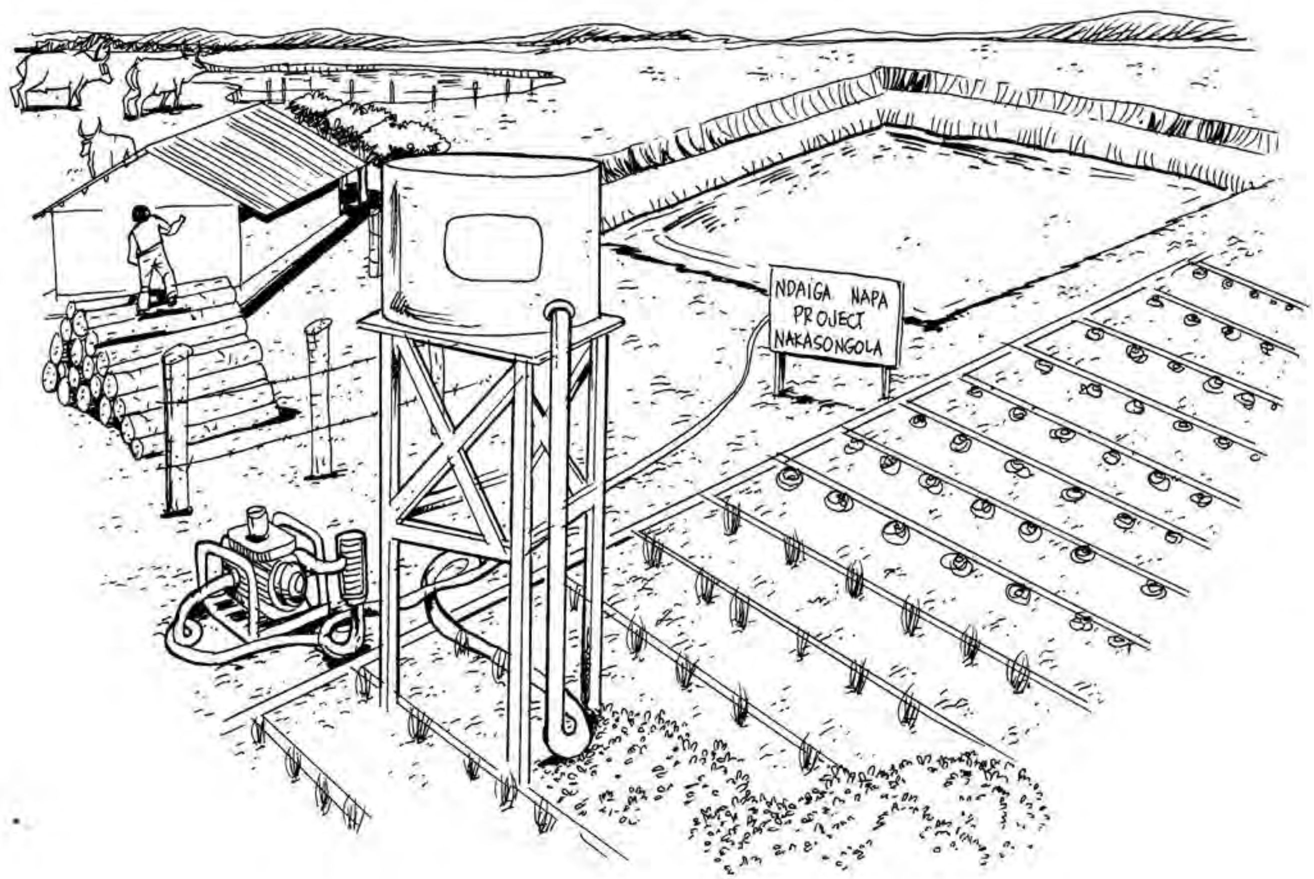
Exploring the Potential of Micro-irrigation in Promoting Food and Income: The Case of Nakasongola



Water security (be it the challenge of too little water over long periods of time or too much water all at once) is one of the most tangible and fastest growing social, political, and economic challenges the world faces today (World Economic Forum, 2012). Nakasongola, a cattle corridor district, usually faces water stress challenges, and therefore, interventions involving water harvesting will always produce results. The national adaptation programs of action (NAPA) pilot project sought to address this gap through harvesting water not only for production but also for household use. The project aimed at enhancing crop production and productivity using drip irrigation as a water-efficient technology in this semiarid farming ecosystem. Good lessons under the project would be replicated and scaled up in areas with similar agroecological zones under a public-private partnership (PPP) arrangement. The NAPA pilot intervention was community-driven and based on what people have. It also promoted the use of indigenous knowledge.

Prolonged dry spells and droughts, occasionally, severely affect farmers, leading to unsustainable coping strategies such as sale of household assets and unsustainable charcoal production (which degrades the environment), reducing the number of meals per day and, in extreme cases, migration. Sometimes, crop failure is so severe that up to 92% of yield losses occur; in such scenarios, farm families totally become food-insecure (Nakasongola Production Department Statistics, 2013).

Nakasongola has bimodal rainfall, with the main season occurring between March/April and June/July and the second one between August-October/ and November. Rainfall amount ranges from 500 mm to 1,000 mm per annum, which is inadequate and generally unreliable.

Topography is flat, between 3,400 and 3,800 ft above sea level. Much of the low-lying areas are drained by seasonal streams into Lake Kyoga with tributaries to rivers Sezibwa, Lugogo and Kafu.

The soils are very old and generally of low fertility (Buruuli and Lwampanga soil catena). Vegetation is dominantly open deciduous savannah woodland with short grasses.

Maximum temperature ranges between 25°C and 35°C and the minimum diurnal range is 18°–25°C The total area of 3,424 km2 represents about 1.4% of the country's total surface area and 32.6 km2 is occupied by swamps, wetlands, and Lake Kyoga.

Nakasongola has a total population of 181,863 (92,957 males and 88,906 females). Of these, 24,816 are urban and 157,047 are rural dwellers (NPHC, 2014). Average household size is five per household, which is higher than the national figure (4.7 persons per household). Sixty-eight percent of the households are crop farmers, 21% livestock keepers and 12% in fisher folks (Nakasongola DDP, 2013). However, it is important to note that many households practice mixed farming.

Problem statement

Farming is the major source of livelihood in Nakasongola. However inadequate precipitation has always caused frustration to many a farmer. Interventions in the agriculture sector should address supplementary moisture requirements through irrigation to enable crop farming in Nakasongola become a worthwhile business.

Objectives

The Nakasongola NAPA pilot project was run under the overall objective of enhancing resilience of the most vulnerable communities to adverse impacts of climate change.

1. To promote water harvesting (surface run-off and roof-top) for irrigation, livestock, and household use.
2. To encourage alternative sources of livelihood by promoting diverse sources of income-generating activities.
3. To encourage re-vegetation and build capacity of communities to sustainably manage the environment.

Methodology

The NAPA pilot project was based on the assumption that community empowerment promotes sustainability. The district technical team used secondary data and experience to purposively sample the most vulnerable communities to impacts of climate change. These acted as demonstration centers for best practices, and the good lessons would later be scaled up to other communities. The project was hosted by the Ndaiga community in Lwabiyata subcounty and the Kyangogolo community in Nabiswera subcounty from February 2012 to June 2014.

Communal nursery beds for assorted vegetables were hosted by selected farmers for better raising of seedlings. These later supplied part of the seedlings for planting at the main community field, and the rest were distributed among interested community members. However, priority was given to women because they determine the rural household food basket. In both communities, the project worked with 462 farmers (281 females and 181 males).

As to irrigation issues, the following questions are raised:

- What method of irrigation is appropriate for which crop?
- Which is the most efficient and reliable type of irrigation?
- Which crops give higher returns with irrigation?
- How and at what stage can a water-deficient plant be detected?
- How can soil properties be manipulated best to balance between water absorption/percolation and retention?

Whereas harvested water in valley tanks had multiple uses, the major focus was to promote small-scale irrigation using the drip method, which was judged the most efficient.

Results

Preliminary results after two seasons gave an interesting story of increased production and income through vegetable farming. The entire cost for an acre irrigation kit was UGX 12,500,000 (about $5,000), inclusive of installation costs. The initial inputs of vegetable seeds and agro-chemicals cost UGX 120,000. Labor was provided by group members, as community contribution. In one of the irrigation sites, a farmer's group managed to get a gross margin of UGX 1,300,000 (about $520) from an acre of tomatoes and onions in season one, when all inputs were procured by the NAPA project. In the subsequent season, the same plot yielded a gross margin of 800,000 UGX (about $320) when inputs were procured by the community. All the produce was sold locally within the community and in the neighborhood.

However, it is important to note that profitable and sustainable irrigation has many facets, which have to be harnessed by the farmers. These include but are not limited to soil fertility management, soil and water conservation practices, use of quality seed, pest and disease management, and other related agronomic practices. These were achieved through community training by district technical staff. It is worth noting that water is required more at critical stages of plant growth like at flowering and at the right time of the day, preferably in the early morning and late evening when evaporation rates are low. This minimizes wastage, in addition to reducing incidences of salinity, capping, and leaching.

It should also be observed that, to break even, irrigation should target high-value crops and, preferably those with of shorter gestation periods such as vegetables in order to recoup both sunk and variable costs.

Farmers within the NAPA pilot communities were encouraged to use the cheapest method of rooftop harvesting. This is where water from the tanks constructed under the pilot project or otherwise was used for backyard farming using equipment such as watering cans, empty mineral water bottles, and other rudimentary methods to maximize production.

Lessons learned

- Adoption is a process. However, the major driver of technology uptake among farmers is profit.
- Many farm families are reluctant to keep production records; this makes it hard to calculate gross margins. Farm labor and domestically consumed food (intrinsic cost) are rarely factored in as farmers calculate their gross margin levels.
- The agriculture sector in Uganda has enormous potential if it could only be fully exploited with irrigation and soil and water conservation.
- Co-investment (co-funding) should be promoted in all projects because it creates a sense of ownership and responsibility.
- Communities can manage and own projects if they could only be properly guided.
- Community procurement is cheap, efficient, and time-saving. This should be promoted as much as possible.

Challenges

There were capacity gaps within the communities as far as operationalization and maintenance of irrigation equipment are concerned. Expertise in the calculation of the amounts of irrigation water required is also lacking, hence leading to wastage, which is contrary to water-smart agriculture principles. The above have been partly solved through hands-on capacity building, including training, and mentoring.

Conclusion

Amidst seasonal changes, rainfall unpredictability, and water stress as a result of climate variability/change, water harvesting for irrigation is inevitable if sustainable and profitable crop production were to be realized. Therefore, all stakeholders in farming should ensure that resources are directed towards water-smart agriculture as an ecofriendly approach to boost farm production.

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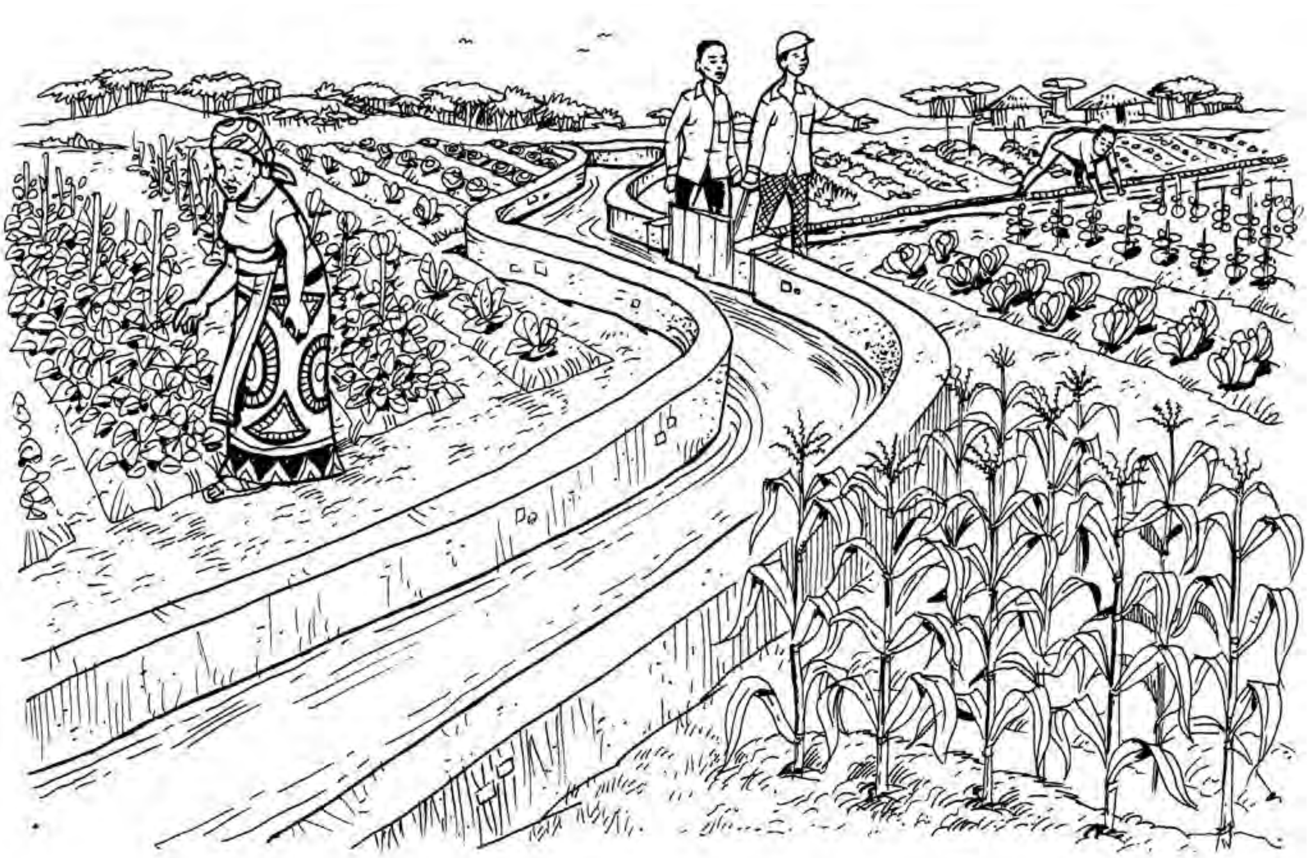
Water Resource Management Options for Smallholder Farming Systems in sub-Saharan Africa



Agriculture and climate change are inextricably linked. Nelson (2009) stated that "Agriculture is part of the climate change problem, contributing about 13.5% of annual greenhouse gas emissions (with forestry contributing an additional 19%), compared with 13.1% from transportation. Agriculture is, however, also part of the solution, offering promising opportunities for mitigating emissions through carbon sequestration, soil and land use management, and biomass production. Climate change threatens agricultural production through higher and more variable temperatures, changes in precipitation patterns and increased occurrences of extreme events like droughts and floods."

The challenges of water resources development in sub-Saharan Africa (SSA) will be aggravated by the ensuing climate change, with serious implications on socioeconomic development. IPCC (2001) noted that "these challenges include population pressure, problems associated with land use such as erosion/siltation and possible ecological consequences of land use change on the hydrological cycle. Climate change—especially changes in climate variability through droughts and flooding—will make addressing these problems more complex. The greatest impact will continue to be felt by the poor, who have the most limited access to water resources." In the savanna regions, the incidence of seasonal flow cessation may be on the increase, as shown by some streams in Zimbabwe (Magadza, 2000). Southern Africa has experienced more recurrent drought and flood episodes in recent times. Drought periods now translate into periods of critical water shortages for industrial and urban domestic supplies (Magadza, 1996). The frequent droughts and floods in most parts of SSA—leading to severe food shortages, food insecurity, water scarcity, hunger/famine, and acute shortage of hydropower—signify the region's vulnerability to climate change. Reduced hydropower also affects energy supply for pumping water.

There is a general consensus that the African continent is particularly susceptible to the onset of climate change (Boko *et al.,* 2007). A variety of factors exacerbates susceptibility to the effects of climate variability but, in focusing on strictly physical elements, the range of ecosystems present on the continent poses particular challenges in developing mitigation and adaptation mechanisms. FAO (2008b) identified 16 distinct ecosystems (agroecological zones [AEZs]) in which various farming systems exist and which would be affected differently by climate change. However, according to Greenfacts2, over the past 40 years, some general climatic trends have emerged on a more regional scale.

The IPCC Fourth Assessment Report noted that, since the 1960s, the African continent has experienced a general warming trend with certain regions experiencing more warming than others (Boko *et al.,* 2007). Since 1900, warming has occurred in Africa at approximately 0.5 ^{0}C per century (Hulme *et al.,* 2001). Precipitation is also highly variable across the continent, although much of the continent has experienced decreases in annual precipitation. An increase in interannual variability has been noted with the indication that extreme precipitation events (floods, droughts) are on the rise (Boko *et al.,* 2007). Notwithstanding the inconsistency of predictions about climate change, the effects of the phenomenon are being experienced throughout SSA, especially in areas typified by variable rainfall shifting growing seasons (IPCC, 2001). Most African farmers, particularly those working in rainfed agriculture, have been affected in one way or another.

It is important to delineate expected regional differences in determining and assessing mitigation strategies for future water stresses resulting from the onset of climate change in Africa. Some African countries are much more economically dependent on agriculture, leaving them more vulnerable than others (Kurukulasuriya *et al.,* 2006). The precarious state of water resources in Africa is such that water stress (use exceeds renewable supply) is relatively high for the majority of the continent's population. Yet, nearly two-thirds of Africans rely on limited water sources prone to high yearly variability (Vorosmarty *et al.,* 2000). In total, about a quarter of the continent's entire population lives in water-stressed regions (UNEP, 1999).

Because the amount of available freshwater is relatively finite, increases in population result in corresponding decreases in per capita water supply, while rising temperatures exacerbate an already alarming situation in Africa (Human Impact Report, 2009). In terms of freshwater, annual runoff and water availability are projected to increase by 10–40% at high latitudes but to decrease by 10–30% over some dry regions at mid-latitudes and in the dry tropics (Falkenmark 2007). This means that drought-affected areas will likely increase in extent. Agricultural production is projected to be severely compromised in many regions by these trends (UNFCCC, 2008).

Agriculture accounts for more than 70% of global water use (FAO, 2008a; World Bank, 2006). According to projections, there will be increasing challenges in terms of increased water stress and areas suitable for agriculture along the margins of semiarid and arid areas are expected to decrease significantly (Falkenmark, 2007).

Seasonal variability in water availability is also critical for agricultural production. For instance, a comparatively small decrease in rainfall during one season may have more severe consequences than a much larger precipitation decrease in another season. Although many past studies have revealed different climate change scenarios in Africa (Christensen *et al.,* 2007), here are some of the expected climate changes that would affect water resources for agriculture:

- Warming is very likely to be larger than the global annual mean warming in all seasons, with drier subtropical regions warming more than the moister tropics.
- Annual rainfall is likely to decrease in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall toward the Mediterranean coast.
- Rainfall in southern Africa is likely to decrease in much of the winter rainfall region and western

margins, leading to longer dry seasons and more uncertain rainfall.

- An increase in annual mean rainfall in East Africa is likely.
- A warmer and drier environment is expected in the Sahelian region (Falkenmark, 2007).

IPCC 2007 stated that "Africa is one of the most vulnerable continents because of multiple stresses and low adaptive capacity. The multiple stresses may arise from current climatic hazards, poverty and unequal access to resources, food insecurity, globalization trends, social and political conflicts, and incidences of diseases such as malaria, tuberculosis, and HIV/AIDS." Nevertheless, the overall climate will largely be defined by the change in precipitation corresponding to what appears to be a marked increase in temperature. This will lead to extreme rainfall events with dire consequences to agricultural production, especially for the vulnerable smallholder farmers. The impact of climate change on agricultural water management (AWM) will be aggravated by demographic change. In eastern and southern Africa, climate change vulnerability is heightened by the large number of people who depend on the already marginalized natural resource base for their livelihoods (Ziervogel *et al.,* 2008). Moreover, within the next 15–20 years, the area considered to have relative water security in Africa will fall from 53 to 35% (Ashton, 2002). Therefore, due to the current population growth, many SSA countries are expected to experience a severe increase in water stress, with or without climate change. Population changes could, in fact, nullify any increases in precipitation/available water. The situation will be aggravated by overdependence on natural resources (Raleigh and Urdal, 2007). Overdependence on surface water, especially for irrigation, will aggravate the impacts of climate change and variability on agricultural development.

The predicted impacts of climate change must be introduced into development planning, including land use planning, natural resource management, infrastructure design, and measures to reduce vulnerability in disaster reduction strategies. According to Falkenmark (2007), the array of adaptation options is very large, ranging from purely technological measures to managerial adaptation and policy reform. For developing countries, availability of resources and adaptive capacity building are particularly important. Based on anticipated climate change and impacts on water resources in Africa, IPCC (2001) identified four necessary adaptive strategies.

a. Adaptive measures. Measures should be adopted that would enhance flexibility, resulting in net benefits in water resources (irrigation and water reuse, aquifer and groundwater management, desalinization), agriculture (crop changes, technology, irrigation, husbandry), and forestry (regeneration of local species, energy-efficient cook stoves, sustainable community management).

b. Risk sharing. A risk-sharing approach between countries will strengthen adaptation strategies, including disaster management, risk communication, emergency evacuation, and cooperative water resource management.

c. Enhancement of adaptive capacity. Local empowerment is essential in decisionmaking in order to incorporate climate adaptation within broader sustainable development strategies. Most countries in Africa are particularly vulnerable to climate change because of limited adaptive capacity as a result of widespread poverty, recurrent droughts, inequitable land distribution and dependence on rainfed agriculture.

d. Diversification. To minimize sensitivity to climate change, African economies should be more diversified, and agricultural technology should optimize water usage through efficient irrigation and crop development.

Why focus on smallholder farmers?

Smallholder farmers are particularly vulnerable to changes in the climate that reduce productivity and negatively affect their weather-dependent livelihood systems. For instance, in Malawi, frequent droughts and floods have eroded assets and knowledge, leaving people more vulnerable to disasters (Gandure and Alam, 2006) such as water and food insecurity, diseases, and land degradation. Evidence strongly suggests that increased droughts and floods may be exacerbating poverty levels, leaving many rural farmers trapped in a cycle of poverty and vulnerability to diminishing resources (Phiri *et al.,* 2005). Water scarcity is already a major problem in arid and semiarid areas of SSA (Rijsberman, 2006)

—areas mainly inhabited by smallholder farmers in both agropastoral and pastoral communities.

Climate change and increasing population contribute to water scarcity and limit its availability for irrigation (Turner, 2006) and other productive uses. Although the potential to invest in irrigation in much of Africa is high, poor performance of large-scale irrigation schemes in Africa and competition for diminishing water resources suggest that smallholder irrigation is preferable. Smallholder farmers must develop water conservation and water-harvesting systems in order to maximize rainfall use efficiency on their own farms. Beside lower investment costs and higher rates of returns, smallholder irrigation development is easier to manage and operate than large-scale, centrally managed irrigation schemes. However, in spite of the low development cost and high rate of returns, there have been inadequate investments, mainly due to misplaced government priorities, declining external support, poor marketing infrastructure, and nonconducive policy and institutional frameworks. However, as the potential of irrigated agriculture continues to gain recognition as an adaptation strategy to climate change, the pattern appears to be changing.

Virtually all large-scale irrigation schemes in SSA have been undertaken by government agencies. While some farmer groups have grown more active in operating these projects, government agencies have largely been responsible for maintenance and operation, often with little cost recovery (Peacock *et al.,* 2007) and poor performance. The experience of Mali irrigation parastatals like the Segou Office for Rice Development and similar government-controlled schemes in SSA attest to this. In such government-controlled schemes, farmers rarely pursue an active role in improving these irrigation systems. Some reasons include insignificant incentive for individual users, lack of cohesion among users, isolation and poor means of communication, and reforms that often reduce subsidies and increase individual expenses (Aw and Diemer, 2005). However, reforms in government-controlled schemes, which give farmers more responsibility in water management, operation, and maintenance, have shown positive results. A good model is the case of the Mwea Irrigation Scheme in Kenya (Blank *et al.,* 2002). In Mali, reform of the Office du Niger irrigation scheme over a period of 20 years led to a quadruple increase in rice yields, a sixfold increase in total rice production (Aw and Diemer, 2005).

In addition to low costs and high economic impact, many factors support additional investments in smallholder irrigation development over large-scale irrigation projects.

Smallholder irrigation systems have strong local community governance, are relatively free of political intervention, have relatively low operation and maintenance cost (FAO, 2008a), and sometimes constitute a means of poverty alleviation. Water management is also improved by the relatively low number of users and the diverse options for water sources (small streams, shallow wells, boreholes, rainwater storage, etc.), many irrigation technological options (surface irrigation methods like the furrow and small basin methods, and pressurized systems (sprinkler and drip, both high-head and low-head systems), and water-lifting technologies (gravity, manual and motorized pumps, wind and solar pumps).

The potential is high for rehabilitation and improvement of existing smallholder irrigation systems, some of which have been initiated by farmers on their own but have fallen into disarray. According to FAO (2005), about 2 million ha of land equipped for irrigation are unused. This potential farmland could be developed, along with approximately 13 million ha of additional land with irrigation potential, of which about 9 million ha are in West Africa (FAO, 2008a). Given smallholder farmers' vulnerability to climate change, the low development costs and high economic performance of smallholder irrigation schemes underscore the need for investments in these AWM farming systems.

Recommendations

The study identified and recommended feasible AWM interventions that can be promoted by development agencies to enhance smallholder farmers' strategies for coping with climate change and variability in SSA. The following are some of the promising AWM interventions that should be considered:

1. Smallholder irrigation development includes rehabilitation of existing schemes to improve water use efficiency and productivity. This covers both gravity-fed (most preferable, where applicable, due to low organization and maintenance cost) and pumped schemes (from either groundwater or surface water sources (rivers, dams, etc.).

2. Upgrading rainfed agriculture through in situ rainwater harvesting systems—farming practices that retain water in crop land (terraces, contour bunds, ridges, tied ridges, planting pits, conservation agriculture, etc.).

3. Supplementary irrigation systems—farming practices that supply water to crops during critical growth stages. They are appropriate where irrigation water is inadequate for full irrigation or where crops are grown under rainfed conditions and only irrigated during intraseasonal dry spells or in case of early rainfall cessation.

4. On- or off-farm water storage systems—rainwater harvesting and management systems that allow the farmers to store runoff in ponds (unlined or lined). For communal land or farmers with appropriate sites, large storage structures such as earth dams or water pans can be considered. Water can be supplied to crop land either by gravity or pumping and applied to crops either by surface irrigation (furrow or basin) or pressurized (especially low-head irrigation systems). Other rainwater-harvesting structures such as sand dams, sub-surface dams and rock catchment systems fall under this category.

5. Spate irrigation—flood diversion and spreading into crop land is appropriate in areas where flash floods occur, especially in lowlands adjacent to degraded or rocky catchments.

6. Micro-irrigation systems—these include various technologies, among which low-head drip irrigation kits are most appropriate. Low-head drip kits can use many different water sources. They are mainly used for irrigating high-value crops such as garden vegetables and orchard fruits, and for green maize production at times.

7. Land drainage, wetland management, and flood recession are appropriate for areas with excess soil moisture and should therefore be considered where necessary.

Adaptive strategies are needed to promote these AWM interventions and must include overcoming barriers that hinder adoption by smallholder farmers. They must also provide the focus for replication and upscaling of best practices in SSA. The identified strategies can be implemented in most SSA countries, since most of them target smallholder farmers who are already experiencing similar problems and constraints to socioeconomic development. To ensure adoption, replication, upscaling, and sustainability, the study identified the following prerequisite measures that should be considered to enhance adoption and sustainability of proposed AWM interventions.

1. Capacity building and awareness creation at different levels (from farmers to policymakers)
    - Training of middle-level professionals working with different organizations and government—launching a regional training program with local universities.
    - Building capacity of smallholder farmers and extension staff, including NGOs and civil society organizations (CSOs), to adopt and promote integrated AWM interventions.
    - Policymakers—campaign to raise political and public awareness on climate change to influence development and implementation of appropriate and adaptive policies and strategies focusing on both legislative bodies and district development institutions.
    - The need to enhance capabilities and scientific strengths of African countries to address integrated AWM and climate change adaptation, while addressing immediate societal needs. This includes MSc and PhD training on AWM and adaptation to climate change to enhance capacity at local training and research institutions and government departments.
    - Enhancing the sharing of expertise and networking among African professionals—establishing exchange programs within SSA (South-South technology exchange).
    - Institutional support to regional centers of research and policy advocacy in AWM and adaptation to climate change: one each in eastern, southern, and west and central Africa to be based at the relevant CGIAR centers or other strong regional organizations (e.g., the regional MDG centers based at Nairobi and Bamako).
    - Support for the development and implementation of comprehensive national plans and strategies for adaptation of smallholder agriculture to climate change —these plans should be government-led, multistakeholder efforts, the results of which serve to inform national development policies and plans.

2. Research, technology development, and information dissemination

- Assessing the potential for sustainable water resource development (both surface and groundwater extraction) at local and national levels.
- Farmer-based demonstrations/piloting on plot and adaptive research on promising best practices for climate change adaptation in a range of agroecological zones and farming systems. The focus should be a district or hydrological unit where a wide range of feasible adaptation interventions, policies, and institutional arrangements are piloted. These districts or units serve as models for best practices. Special emphasis is placed on assisting women farmers in adapting to climate change.
- Analyzing the yield gap, including cost-benefit of alternative irrigation interventions, to ascertain the appropriate systems for bridging yield gaps.
- Establishing climate change adaptation tools for monitoring early warning systems and adaptive coping strategies. To effectively monitor adaptation strategies and impacts, a stakeholders' coordination forum will be necessary to build synergies and partnerships.
- Support for applied research and policy dialogue to determine the agronomic and socioeconomic potential for adopting AWM interventions, especially in countries that depend on rainfed agriculture for food security and rural livelihoods.
- Support for applied research and policy dialogue to better understand how best to address the effects of climate change on major transboundary river basins (e.g., the Nile, Zambezi, Limpopo and Niger rivers, which are already experiencing water stress due to climate change.

3. Appropriate policy and institutional reforms

- Support for a professional, public and political awareness campaign that raises the profile of AWM and adaptation to climate change.
- Support development of comprehensive national investment plans for promoting the adoption of rainwater harvesting and low-cost smallholder irrigation schemes.
- Reforms that support investments in AWM and partnership among actors/stakeholders.
- Reforms that improve water governance and water users' involvement in the decisionmaking process (i.e., empowerment of farmers).
- Mainstreaming gender issues targeting women and vulnerable groups.
- Strengthening climate communication and information networks to enhance delivery of timely weather information to intended users.

4. Farmers' support services to promote adoption and adaptation of integrated AWM systems

- Establishment of rural service centers to provide technical advice and information on viable AWM options and other services to farmers.
- Microcredit/revolving grants to farmers, especially to women who form the backbone of smallholder farming systems in SSA.
- Crop insurance, where applicable, to reduce farmers' risks of crop failure.
- Contract farming (farmer-private sector partnership).
- Value addition (processing and storage) and marketing infrastructure.
- Crop diversification—introduction of high-value crops for irrigated lands.

Increased investments in all of these areas are urgently needed. The aggregate requirements across the continent are much greater than the financial and managerial capacity of a single development partner. The question is how to create maximum impact and leverage through collaboration and building synergies among different development partners and investors in SSA. To enhance sustainability, a participatory, integrated, and multisectoral approach is recommended, in which different stakeholders will collaborate and work together to implement different aspects of the proposed interventions—improved AWM. Development partners and investors should target strong collaborative linkages among communities/farmers (CBOs), self-help groups, NGOs/CSOs, the private sector, agricultural research institutions, and relevant government departments (e.g., ministries of water, agriculture, irrigation).

Programs and projects should target an integrated and multisectoral approach—the entire production and market chain (i.e., market-oriented production process). Programs/projects that integrate the needs of smallholder farmers (bottom-up approach), participatory action research, demonstrations, development, training on feasible AWM interventions, information dissemination, and networking should be prioritized.

The MVP model is a good learning lesson that can be adopted by development partners and investors. The 14 MVP clusters in 10 countries in SSA have already developed AWM strategies, which should be the basis for funding consideration. The AWM strategies can be converted into smallholder farming business development plans to widen the scope of funding opportunities, and especially to attract social investments in SSA.

Finally, it is clear that opportunities for smallholder farmers to adapt to water shortage induced by climate change are attainable (especially integrated AWM interventions). Addressing climate change adaptation for smallholder farmers is a prerequisite to a sustained green revolution in Africa. However, for this to be achieved, increased investment, adaptive research, and capacity building are needed. This visionary investment requires a pooling of resources and building synergies among various stakeholders.

Source

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Application of Gravity-drip Irrigation Technology for Vegetable Production

The Learning and Practice Alliance (LPA) approach is used with farmers who are engaged in water harvesting efforts. Groups of stakeholders come together to innovate, share experiences, and scale-up good practices using a common platform. The groups are usually composed of different stakeholders: implementers, policy and decision makers, researchers and private sector actors, operating at various levels, who would normally be working in isolation from one another, but have joined hands through a joint platform to address common sector challenges. The premise of the LPA approach is that addressing complex sector problems in a sustainable manner requires the involvement of all the stakeholders in the problem-solving process and focus on developing local knowledge to support local solutions.

Implementation approach

Farmers who have water harvesting structures at Aliyu Amba area in Ankober District, North Shewa administrative zone were consulted to request their participation in demonstrating the gravity-drip irrigation side by side with the can application method during the dry season of 2004 and 2005. Five volunteer farmers were selected. Including those farmers, a Farmers Research Extension Group (FREG) composed of 20 farmers (6 were women), development agents in the kebele, and researchers as facilitators was established.

The FREG members were trained on the concept and procedures of FREG and the characteristics and application of the gravity-drip irrigation technology. To facilitate wider promotion and enhance group learning, the FREG members came together during seedbed preparation and the laying out of the drip system, seedling stages, development stages, and maturity stages to learn from each other on the application and utilization of the technology. Farmer-managed demonstrations and promotion of the drip technology was carried out on five farmers' plots. On the other hand, other farmers who cultivated tomatoes and onions were advised to use cans so that the outputs could be compared with those obtained from the drip application methods. Finally, field days were held to share the lessons and introduce the technology to other farmers and experts in the nearby kebeles.

Drip laterals (60 m length) having either 60 cm or 30 cm emitter spacing manufactured by Selam (a private enterprise in Addis) were provided to the five farmers. The spacing of the emitters can vary, depending on the type of vegetables raised. For example, tomatoes require an emitter spacing of 60 cm, while onions need only 30 cm or below. The number of laterals varied from farmer to farmer based on the area under irrigation. Locally made water storage tanks or, in this case study, oil barrels having a 200-liter capacity, were used to store water extracted from the water-harvesting ponds. The storage barrel was placed about 1 m above the ground surface in order to gain sufficient gravitational energy for drip emitters to discharge the required amount of water uniformly along the laterals. The laterals were directly connected to the barrels. One drip lateral can be used alternatively for different rows of tomatoes and onions. The farmers were required to fill the barrels before starting irrigation, to check the uniformity of water discharged by emitters, and to clean clogged emitters.

Since the variation in plant spacing requires different numbers of drip laterals, onions and tomatoes were purposely selected and used as test crops on each plot of the participant farmers. The plot sizes varied from farmer to farmer. Sandy clay soil was the dominant type of soil in the demonstration sites.

The amount of water applied per irrigation was determined by the soil water available prior to irrigation using the feel method. Initially,

Table 1. *Amount of water and labor required for drip and can methods of application.*

Vegetable	Replication	Volume of water applied (m^3/ha)			Labor (person-days/ha)		
		Drip	Can	Difference (Drip-Can)	Drip	Can	Difference (Drip-Can)
Tomato	1	53.33	70.41	17.07	82.38	98.85	16.48
	2	77.58	113.27	35.69	108.95	181.76	72.81
	3	83.64	103.57	19.93	100.45	247.66	147.22
Average		**71.52**	**95.75**	**24.23**	**97.26**	**176.09**	**78.83**
Onion	1	142.55	177.86	35.31	255.21	245.54	-9.67
	2	256.25	267.86	11.61	368.31	358.63	-9.68
	3	244.37	265.00	20.63	293.90	602.68	308.78
Average		**214.39**	**236.90**	**22.51**	**305.81**	**402.28**	**96.48**

the participant farmers demonstrated the shape of the squeezed moist soil under different soil moisture content. They were oriented to apply water when they obtain the similar shape of sample moist soil squeezed at critical water content. All farmers who used drip and can methods were told to record the amount of labor and water applied and the yield obtained from their plots, so that costs and benefits can be compared.

Water and labor requirements

Evidence on farmer-managed on-farm demonstrations (Gizaw and Tegenu, 2008) indicated that using low-cost gravity-drip irrigation reduced the total amount of irrigation water required, by 24.23 m^3 and 22.51 m^3 per hectare of land for tomatoes and onions, respectively, compared with the can irrigation method (Table 1). The amount of water saved could have been used to irrigate tomatoes on an additional area of approximately one-third of a hectare using drip systems. Moreover, using the drip irrigation system, 79 and 97 person-days per hectare labor on average was saved over the can method for tomato and onion production, respectively. Sometimes, depending on the condition of water availability and lift from water-harvesting structures, the labor requirement for the drip method was slightly more than that of the can method. The tomato and onion producers would thus reduce labor cost per hectare by 3,000–4,000 birr and 3,800–4,800 birr, respectively. As a result, the opportunity cost of labor for drip-using households increases.

Productivity of the drip system

Using the gravity-drip irrigation method, applying 214 m^3 and 72 m^3 irrigation water to 1 ha during the growing season provided 20 and 27 tons of onion and tomato marketable yields in that order. However, using the can method, the equivalent to total yields of 18.4 tons for onions and 20.5 tons for tomatoes per hectare were obtained by applying the respective amounts of 237 m^3 and 96 m^3 irrigation water. In addition to the amount of water saved by the drip system, a considerable yield advantage was obtained using the drip system compared with the can irrigation method. The mean yield advantages by using drip irrigation were 6.29 tons for tomatoes and 1.43 tons for onions in a hectare of land (Table 2). The drip method has also shown better water productivity than the can method. Under the on-farm situation, average water productivity of tomatoes was 0.38 kg/L and 0.21 kg/L while that of onions was 0.09 kg/L and 0.08 kg/L for drip and can applications, respectively.

Benefits

Partial cost and benefit analysis was done by considering only variable costs such as labor and value of water in the locality between drip and can methods. Costs related to fertilizer and seed varieties were uniform for both methods. The results indicated that the benefit obtained from the drip system was much better than the can method (Table 3). Despite the low price of onions (1.50 birr/kg) and tomatoes (1.00 birr/kg) during the harvesting season, the drip marginal rate of return, which was 451.18% for tomatoes and 138.27% for onions, was higher. Users of the drip technology would obtain a return of 4.5 birr and 1.4 birr from tomatoes and onions by investing 1 birr. From the partial budget analysis, one can easily realize that tomatoes can give smallholder farmers a much higher return than onions, in a short period of time, if they apply gravity-drip technology packed with local water storage.

Lessons learned

Drip irrigation is a very simple technology to use. Often, farmers do not allocate large sizes of plots (e.g., not more than 1,000 m^2) for vegetables as the labor costs are higher compared with costs of other field crops. As a result, the labor required for cultivating vegetables on small plots was less and its drip investment cost was affordable to the average farmers. Producing vegetables that demand less labor for cultivation using the drip system pays back quickly. Both its direct benefits and the amount of water and labor saved by using it make the drip technology far preferable to the can method. Therefore, drip irrigation system needs to be considered in household irrigation programs and should be scaled out among smallholder vegetable farmers, along with the development of a market in the supply of drip laterals and technical skill support from experts to facilitate application.

Table 2. Yield of tomatoes and onions and water-use efficiency for both irrigation systems.

Vegetable	Replication	Total yield (tons/ha)			Water productivity (kg/L)	
		Drip	Can	Difference	Drip	Can
Tomato	1	23.50	17.20	6.30	0.44	0.24
	2	16.05	10.31	5.74	0.21	0.09
	3	40.92	34.08	6.84	0.49	0.33
Average		**26.82**	**20.53**	**6.29**	**0.38**	**0.21**
Onion	1	8.04	10.00	-1.96	0.06	0.06
	2	35.71	29.64	6.07	0.14	0.11
	3	15.89	15.71	0.18	0.07	0.06
Average		**19.88**	**18.45**	**1.43**	**0.09**	**0.08**

Table 3. Partial budget analysis for drip irrigation technology compared with the can method.

Variable	Tomato		Onion	
	Drip	Can	Drip	Can
Labor cost (birr/ha)	778.05	1,408.72	2,446.44	3,218.27
Drip material cost	1,860.20	---	1,860.20	---
Total cost (birr/ha)	2,638.25	1,408.72	4,306.64	3,218.27
Benefit, yield (birr/ha)	26,819.67	20,527.33	29,821.50	27,678.50
Benefit, water (birr/ha)	484.62	---	450.29	---
Total benefit (birr/ha)	27,304.29	20,527.33	30,271.79	27,678.50
Net benefit (birr/ha)	24,666.04	19,118.61	25,965.15	24,460.23
Marginal rate of return (%)	451.18	---	138.27	---

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Water-harvesting Technology Using Micro Dams: A Case Study of Same District, Tanzania

In Tanzania, it is estimated that 60% of the country is semiarid or arid. These areas receive short-interval rainfalls and experience long dry spells with high evapotranspiration rates and erratic temporal and spatial distribution of rainfall (Liwenga *et al.,* 2012). Often, long dry spells occur during the growing season to the extent that crop and pasture production becomes poor even when total seasonal rainfall amount is high.

Same District in Kilimanjaro region of Tanzania experiences semiarid condition, which is characterized by low, erratic, and unreliable rainfall with upstream users enjoying more rain than downstream users. The average annual rainfall ranges from 500 mm/a in the lowlands to 800 mm/a in the upper areas. This rainfall is distributed over two crop-growing seasons, with the farmers predominantly growing maize (crop water requirement is 500 mm/season) (FAO, 1998).

The onset and duration of rainfall in semiarid areas are inherently stochastic, and the probability of occurrence of acute dry spells during a growing period is high (Mahoo *et al.,* 1999). Such a situation makes farming in semiarid areas a risky venture with a very high likelihood of production failure (Hatibu *et al.,* 1999). There is general water scarcity, which is partly a result of climatic change and variability and partly a result of increased competition for the limited resource. Climate change and abstractions over the past decades have reduced in-stream flows from several hundred cubic meters to less than 40 m^3/s in rivers such as Pangani River (IUCN, 2003).

Water harvesting is highly considered in areas where rainfall is heavy during storms of considerable intensity, with short intervals compared with no-rainfall periods. It requires adequate provision for the interception, collection, and storage of the water. The effectiveness of these tasks depends on the catchment characteristics and location, whether it is on the field or runoff from upstream catchments.

Agricultural practices, in turn, are highly dependent on rainfall, either directly or indirectly, through traditional irrigation systems (including *ndiva*). The farmers in the Pare mountains have resorted to supplementary irrigation in order to increase crop yield. Supplementary irrigation is necessary in order to realize crop yield and thus support smallholder rainfed rural livelihood. The highlands provide an almost perennial source of inflow into the micro dams (DAICO, 2014). More than 157 micro dams have been established to supply water for crop growth during dry-spell periods and in the mountainous area where they can even irrigate crops during the dry season.

Micro dams for water-smart agriculture

A micro dam (*ndiva*) can be defined as a small traditional water storage structure which involves the modified furrow irrigation method. The structure is incorporated at suitably selected points in the system. Storage is usually done during day and night. Most of the existing *ndiva* have sizes ranging from 200 m^3 to 2000 m^3 (DAICO, 2014).

Ndivas are traditional water harvesting and storage technologies used in most of the Pare areas. In Same District, the use of this technology dates back to early 18th century. Irrigation started as a way of getting water for crops during dry seasons. This was indeed the early method of adaptation to climatic change. Crops grown during dry season were mainly root crops, which were the staple during periods of famine.

Ndivas are built in the upper part of a catchment. These micro dams receive water from a diversion canal from the main river and supply areas ranging from a couple of hectares to about 400 ha. Most farmers are connected to furrow systems, often combined with a small reservoir. The micro dam is communally managed by a group of farmers within the irrigation zone served by the micro dam. Usually, within the catchment area are several systems. The micro dam intercepts runoff from perennial or seasonal streams, which otherwise would have been lost. There are no external incentives to maintain the micro dams. Farmers organize themselves in groups to manage and maintain the *ndivas*. Through participation in a group, a farmer gets access to his ration of water (WHaTeR report, 2011).

Due to erratic rainfall and the resulting high degree of variability and unpredictability, smallholder farmers have resorted to supplementary irrigation by using *ndiva* in order to reduce the impact of dry spells and to store water when they need to irrigate. The existence of *ndiva* is of great importance as it impounds water with low discharges to create high discharges that can be used during periods of high demand, reaching farmers far down the command area.

Supplementary irrigation in these areas can be traced back to the pre-colonial era in Tanzania. In Ndolwa and Vudee villages, irrigation furrows started before the Germans arrived. In Bangalala, it started during British colonialism. Taking into account that 90% of the population in the Pare Mountains live in the highlands, 80% depend directly or indirectly on agriculture (Mwamfupe, 1999).

However, unimproved micro dams have some disadvantages, which lead to poor performance. These include water losses due to seepage, evaporation, leakages, unstable walls of the structure, poor conveyance systems, and poor management.

On the other hand, improved micro dams are more efficient as there is very little or no water loss through seepage and leaching. Water stays longer in the reservoir. Canals that convey water from the source to the micro dam and those that convey and distribute water into the farmers' fields are lined, helping reduce water losses. Also, the collection chambers are redesigned (e.g., grit chamber and screens) to ease the collection and removal of sediments and other debris that come along with water from the source. Improved micro dams have been a very useful source of irrigation water for most farmers in the district.

Objectives

The main objective of this paper is to document and create awareness on the use and importance of micro dams (*ndiva*) as an effective and efficient water-harvesting technology to manage and use available water for supplementary irrigation in semiarid and arid areas.

Methodology

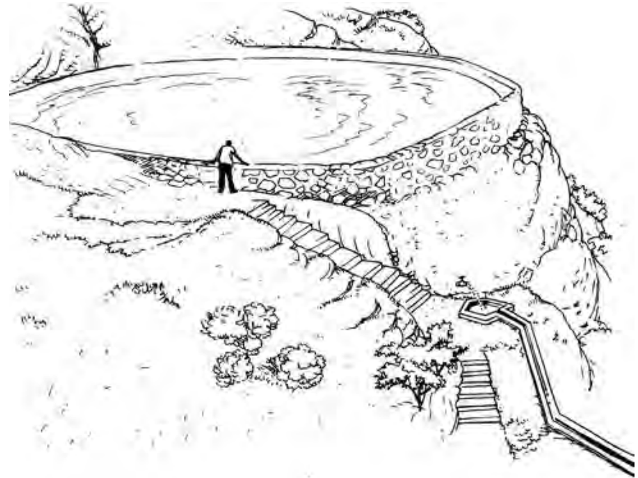
The methodology involved documenting field experience, conducting farmers' interviews, direct observation, and literature review. A literature review was done to gauge the existence and current use of water-harvesting techniques in Same District. The review covered the evolution of these technologies and their adoption in Same District. Both traditional and modern management systems of *ndivas* were described.

Through a participatory approach, village communities are enabled to prepare village agricultural development plans (VADPs). These plans later on became the basis of the district agricultural development plans. The most frequently identified problem is poor crop performance due to inadequate rainfall and hence less moisture in the soil for crop production. This has led to food shortages, progressively low income for farmers, poor contribution to development activities, and a low standard of living. Farmers identified the need to improve/rehabilitate existing irrigation infrastructure and build new ones. They also wanted interventions that will lead to efficient and effective utilization of available water in order to improve productivity.

Results and discussion

Key achievements

There are about 157 micro dams in the district (89 of them improved) and about 7,500 ha of land are under irrigation, getting the water from traditionally constructed and rehabilitated micro dams. In



The improved micro dam contributes to an efficient and effective use of available water for crop production.

addition, about 3,400 farmers in the middle and lowland areas are producing crops as source of food and income (DAICO, 2014). The area under irrigation has increased as a result of increased water availability due to reduced water losses.

There is an increase in production of maize from 0.6 ton/acre to 1.2 tons/acre due to irrigation. This has led to improved productivity and thus improved food security among farmers. The micro dams have created an opportunity for other stakeholders and development partners to come together and solve other social and economic problems in the community.

There was reduced conflict between farmers and pastoralists, which was caused by competing for scarce water from different sources. Also, the time spent by women to look for water for domestic use has been reduced.

Key challenges and limitations

- Inadequate financial resources to support the construction and rehabilitation of micro dams, which result in many unimproved micro dams.
- Poor management of catchment areas and water sources that result in siltation in the water collection chamber and reservoirs.
- Conflict between water users/beneficiaries due to lack of an equitable distribution scheme for users downstream.

Overcoming the limitations

- The government, in collaboration with different development partners, is making efforts to improve and rehabilitate existing micro dams. So far, 89 micro dams have been rehabilitated. A good example is the Manoo micro dam, the oldest in the area (established in 1936). It serves farmers up to 3.5 km downstream of the dam. The micro dam was rehabilitated in 2003, resulting in an increase in capacity to 1,620 m^3 thus benefitting 150 families over an area of 1,000 acres (400 ha) (SAIPRO, 2004).

- Farmers are advised to line canals that convey and distribute water into the farmers' fields. This is a better option to adopt to have rational use of water for agricultural activities.

- The district council and other development sectors are facilitating the formation of irrigator organizations to reduce conflicts among farmers. The irrigator organization has to design an efficient and equitable water distribution system.

Conclusions

The use of micro dams as a water-harvesting technology in semiarid areas is in line with the national irrigation policy that emphasizes the need to harness irrigation potential, along with improvement of irrigation schemes in both the highlands and lowlands. It is a water-smart technology as it serves as a storage facility for water that can be used when farmers need to irrigate. It intercepts runoff from perennial or seasonal streams, which otherwise would have been lost. Improvement in irrigation practices in potentially irrigable areas, together with a good package of extension services, may be one of the strategies to increase agricultural productivity.

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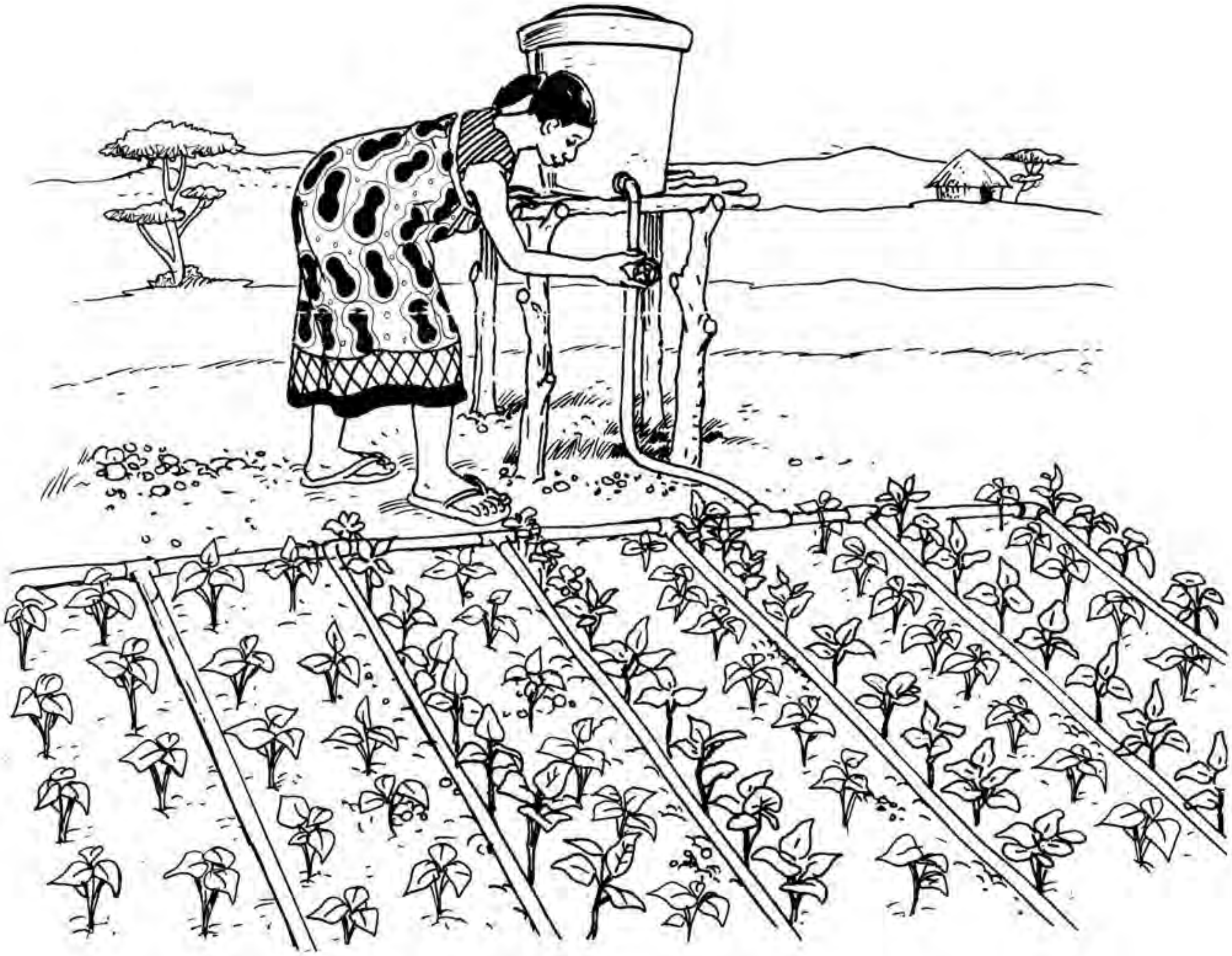
Low-cost Drip Irrigation Systems for Smallholder Farmers in Tanzania



Agriculture in Tanzania continues to be the largest sector in the economy with its output largely dependent on smallholder rainfed production. Its performance therefore has a significant effect on people's income and poverty levels. Tanzania covers an area of about 94.5 million ha, of which 44 million ha are classified as suitable for agriculture, of this, 23% (10.1 million ha) are cultivated. The country has substantial water resources and an irrigation potential of 1 million ha, of which 20% (200,000 ha) is under irrigation (URT, 2004).

Irrigation in Tanzania is very important as it helps in satisfying subsistence requirements in many parts of the country. It increases food security at the household level, generates local surpluses of main staples, particularly rice, in order to achieve food security in the country. It also helps ensure the production of much needed dietary supplements such as vegetables, fruits, and pulses. Conventional irrigation such as surface irrigation has been challenged because of its very low water use efficiency. Given the fact that water resources are diminishing, there is a need for innovations that are diminishing, "water-smart" innovations that can ensure better yields and increase water use efficiency and water productivity are needed.

Addressing rural poverty requires a focus on smallholders who make up majority of the rural poor. Improving irrigation productivity on large farms alone will not solve the continuing problems of rural poverty, which are getting worse in sub-Saharan Africa. Increasing agricultural productivity and income of majority of farmers who cultivate less than 2 ha in developing countries is a relatively untapped opportunity for finding practical solutions to rural poverty and household food security. Surface irrigation methods are utilized for more than 80% of the world's irrigated land, yet its field-level application efficiency is often only 40–50%. In contrast, drip irrigation may have field-level application efficiencies of 70–90% as surface runoff and deep percolation losses are minimized (Heermann *et al.*, 1990; Postel, 2000). Thus, drip irrigation may allow more crops per unit water to be grown and permit crop cultivation in areas where water is too insufficient to irrigate using surface irrigation methods.

While the drip irrigation system has higher water use efficiency of 70–90% (Postel *et al.,* 2001; Postel, 2000), the conventional drip irrigation (CDI) systems available commercially are unaffordable to majority of smallholder farmers (Polak *et al.*, 1997; Narayanamoorthy, 2003), Drip irrigation is a knowledge-intensive, technology-oriented operation, designed for larger landholdings (e.g., >4 ha), with capital cost ranging from $1500 to $2500 per hectare (Phene, 1995; Postel *et al.,* 2001). These CDIs are unavailable to many Tanzanian smallholder farmers who live in rural areas, have small landholdings, and limited financial resources (Postel *et al.,* 2001). Low-cost drip irrigation (LCDI) is an irrigation method that is suited for small fields and maintains the water-saving advantages, hence gaining the advantage of being a water-smart technology through its affordability, simplicity, easy maintenance and operation, and big water saving. The LCDI presents an opportunity to substantially improve the economy and food security of smallholder farmers.

Opening smallholders' access to affordable small-plot irrigation is a critical first step to wealth creation for the rural poor, particularly women. Low-cost drip irrigation systems not only open doors to a path out of poverty; they are also a path to saving water and doubling irrigation productivity on small farms as a water-smart agricultural strategy. For smallholder farmers, LCDI provides a means of maximizing returns on their crop land by increasing economic biomass production per unit of water and increasing cropping intensity by also growing crops during the dry season. The LCDI was therefore designed using locally available components, with preference given to local manufacturing that only requires relatively unsophisticated facilities, but not at the expense of performance and functionality. The system is simple and easily understood, and can be operated and maintained by average users, compared with conventional systems that are sophisticated and require expertise.

Low-cost drip irrigation system

Improving access to and adopting water-conserving practices can help irrigation systems cope with water scarcity. Water-conserving technologies can maintain cropping intensity and can provide opportunities to diversify, leading to production of high-value crops and reducing reliance on rainfed field crops. Technologies for achieving higher water productivity include existing LCDI technologies such as the "bucket and drip" system at prices that smallholder farmers can afford (Carruthers *et al.,* 1997). Drip irrigation systems are normally used for high-value cash crops (vegetables and fruits). These systems are common in some parts of Africa. For example, the Chapin bucket kits are being used in Kenya, Tanzania, Malawi, Zambia and Uganda (Phene, 1995; Narayanamoorthy, 2003).

The conventional pipes used for most of the outstanding schemes of drip irrigation are made mainly of polyvinylchloride (PVC) and occasionally asbestos-cement, while emission devices include point- and line-source emitters that operate either above or below the ground surface at discharge rates of 2 to 8 liters per hour (James, 1993; Yanbo and Fipps, 2003). These pipes and emitters are very efficient and adequate but are being imported and are thus beyond the reach of a rural farmer (Onilude, 2005), thus, the search for and use of a substitute technology. Therefore, fabrication and installation of LCDIs using locally available materials that are in the vicinity of smallholder farmers have become inevitable. To facilitate acceptability and adoption, LCDIs should be made simple for most smallholder farmers. LDCI can either be the bucket type or drum type.

The LCDI using drum irrigation systems operate under a low pressure head of water (0.5–5 m). Mounting the drums on block supports raised at least 1 m above the planting surface is recommended (Fig. 1). The higher the drum is placed, the greater the area that can be irrigated. An area of up to 1,000 m^2 can be covered by a drum system. The main advantage of drum systems is the bigger area that can be covered compared to the bucket system. The drum irrigation systems present an economic advantage because of the number of plants per drum system. A drum system covering five beds, each 1 m wide and 15 m long, can be used to grow 250 plants (tomato, eggplant, and similar plants requiring a spacing of 60 cm along plant rows); 500 plants (spinach, cabbage, kale, pepper and similar plants requiring a spacing of 30 cm along plant rows); or 1,500 plants (onion, carrot, and similar plants requiring a spacing of 10 cm). The drum system also offers water storage and control through a control valve, making it possible to fill the drum for irrigating at another time. The standard drum kit system comprises a drum, a control valve, a manifold, and drip lines. The drum should be filled with the valve in the closed position. To irrigate, it is important to open the valve fully. This allows the water to be distributed quickly through the drip lines and results in good water distribution.

Objectives

The main objective of the study was to evaluate the effectiveness of LCDI compared with CDI in terms of being a simple, cost-effective, and water-smart irrigation technology. The specific objectives were the following:

a) Evaluate water use and water productivity of LCDI compared with CDI

b) Evaluate crop growth performance and yield under LCDI

c) Evaluate the costs and benefits of LCDI compared with CDI system

Materials and methods

Study area

The study was conducted at Mkindo village (latitude 6°16' and 6°18' south and longitude 37°32'and 37°36' east) located in Mvomero District, Morogoro Region in Tanzania. Its altitude ranges between 345 and 365 m above mean sea level. The study area is about 85 km from Morogoro municipality. The average annual temperature in Mkindo is 24.4°C with a minimum of 15.1°C in July and a maximum of

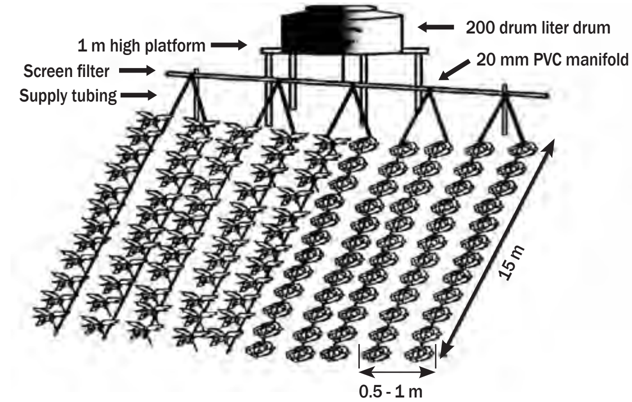


Fig. 1. Drum-type LCDI (Source: KARI Kenya).

32.1°C in February. The rainfall pattern is bimodal, characterized by two rainfall peaks with short rains from October to December with a mean value of 140 mm, and long rains from March to May) with a mean value of 500 mm. The groundwater table rises at a range of 80–140 cm from the ground surface during the wet season. Soil type on the experimental site was predominantly clay loam.

The experiment was done in randomized complete block design. The study involved pressure heads of 0.8 m (T1), 1.0 (T2), and 1.2 m (T3) of the LCDI with one punched hole, compared with the conventional drip irrigation (CDI) system at 1.0 m pressure head of the supply tank (T4). Calibrated tensiometers were used to monitor the soil moisture status. The discharge of the emitters was determined before planting to know hydraulic performance parameters that include Christiansen's uniformity coefficient (CUC), distribution uniformity (DU), and emission uniformity (EU). Irrigation water was measured at each irrigation event to determine irrigation water productivity (IWP). At harvest, aboveground biomass and grain yield were measured. Data were analyzed using the Genstat computer package.

Farmer field schools

Farmer field school (FFS) plots (4 m by 7) m were prepared and the LCDI systems were installed in collaboration with farmers. Farmers chose tomato as the test crop. Field visits were organized to monitor and evaluate progress. Regular on-site discussions were held with farmers on the practicability and limitations of the system. The performance of the low-drip irrigation system was also compared with typical farmers' practice of hand watering using water in the FFS plots. Three plots per each irrigation method was assessed and okra was the test crop used for both methods. The methods were

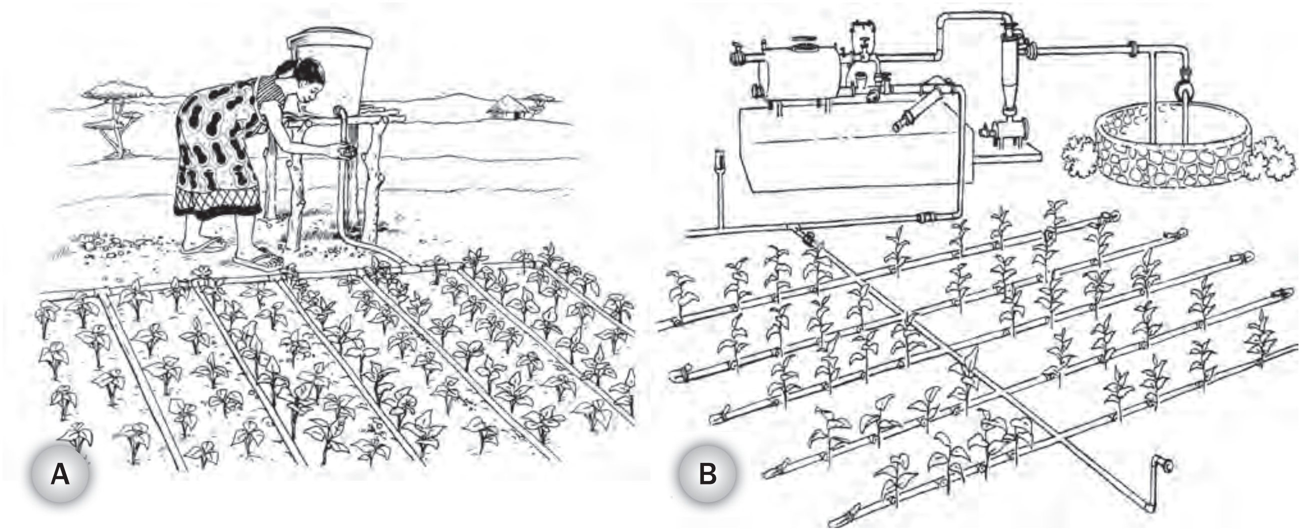


Fig. 2. (a) Low-cost drip irrigation system and (b) conventional drip irrigation system in Mkindo village, Morogoro region.

evaluated in terms of technical performance (water savings, labor savings, and yield increase), suitability, and marketability (perceived benefits and price). Water use was measured (in liters) by the number of buckets of known volume each time water was applied (Fig. 2).

Results and discussion

Water use and water productivity

The results on performance parameters for LCDI and CDI are presented in Table 1. No significant differences in terms of EU, CUC, CV and DU for treatments T1 to T4 ($p<0.05$) were noted. A comparison of average results from LCDI and CDI also indicated no significant differences in system performance. This means that the locally fabricated LCDI performed as well as the industrially manufactured irrigation system (T4). As to discharge, however, CDI had a significantly lower discharge than to LCDI due to better control provided by industrial emitters.

Yield and crop water use are presented in Table 2. For LCDI, the treatment with a pressure head of 0.8 m (T1) did not show any significant difference in yield compared with other treatments. However, it had the lowest water use and it gave higher water productivity than did other LCDI treatments. T1 is regarded as the best treatment in terms of water saving.

Average seasonal irrigation water use across constant-head, low-cost drip irrigation treatments was 5.9 m^3 for CDI (T4) and 11.13 m^3 for T3. Seasonal irrigation water use did not vary appreciably among these treatments but it increased with increase in pressure head. Optimum water use for LCDI was at a pressure head of 0.8 m (T1), which gave a water productivity of 1.023 kg/m^3. Statistics show a significant difference between T4 (CDI) and the other treatments ($p<0.05$) on the water used. This is due to variation in emission devices.

Table 1. Performance parameters of different treatments of a constant-head low-cost drip irrigation system.

Irrigation type	Treatment	EU (%)	CUC (%)	CV (%)	DU (%)	Discharge (L/h)
LCDI	T1	90.034a	61.292a	38.708a	99.508a	1.5345b
	T2	89.644a	76.013a	23.987a	99.695a	1.8472b
	T3	83.782a	73.814a	26.185a	99.667a	1.9372b
LCDI (avg)		87.820a	70.373a	29.627a	99.623a	1.773b
CDI	T4	87.528a	80.012a	19.988a	99.746a	0.6128a

Means followed by the same letters are statistically non-significant at the 5% probability level.

Table 2. Yield, water use, and irrigation water productivity under constant-head condition.

Irrigation type	Treatment	Yield (t/ha)	Water used (m^3/ha)	Water productivity (kg/m^3)
LCDI	T1	11.13a	10,850b	1.023ab
-	T2	11.10a	11,000b	1.009ab
-	T3	8.92a	11,550b	0.774a
LCDI (Ave)	-	10.38a	11,130b	0.935ab
CDI	T4	10.46a	5,900a	1.778b

Means followed by the same letters are statistically non-significant at the 5% probability level.

Nevertheless, the hydraulic performance did not significantly differ among the treatments ($p>0.05$) as stated earlier (Table 1).

Economic comparison

The gross returns of the two systems (LCDI and CDI) are presented in Table 3. There was no significant difference in terms of income gained from the two systems. A comparison of the production costs for LCDI and CDI is presented in Table 4. The investment cost for LCDI was less by 24.1% compared with that of CDI. Installation cost of LCDI was also 44% less than that of CDI because the latter needs expertise on installation while the former does not. Irrigation activities (filling water in the tanks) in LCDI were higher by 16.7% compared with CDI. This is because, in LCDI, many tanks have to be filled during irrigation. Cost of other activities in both irrigation systems did not vary. Generally, cost associated with LCDI was less by 24.1% that of CDI (Table 4).

Gross returns from soya bean cultivation under CDI were slightly higher than those under LCDI (Table 4). However, this gross amount cannot be treated as effective (real) profit under LCDI and CDI, because it does not take into account the capital cost of the drip set, its depreciation, and the interest accruing on fixed capital.

In the FFS demonstration plot trials, the benefits of LCDI—increased yield, decreased water usage, decreased labor usage, improved water and labor productivity—were observed. Net income from drip-irrigated crops was only 8% higher than hand-watered plots (farmers' practice), while yields were 61% higher, man-hour savings were 33%, and water savings were 33%. Considering total production cost per hectare, LCDI's is 24.1% less than CDI's. The water and time savings realized from LCDI compared with can-watering indicates that LCDI is more water-smart than conventional practice. Also, if female farmers were involved, the labor and time saved will enable them to do other activities for the well-being of their households. The lower total cost also shows that farmers adopting LCDI can save money without compromising crop yield.

Table 5 indicates that irrigation water productivity under LCDI was high (3.27 kg/m^3) compared with hand watering (1.37 kg/m^3). LCDI was thus more economical than hand watering (labor saving). Nevertheless, this comparison is limited to capital cost, seasonal investment input, and returns. There is a need to consider the lifespan of the two systems and determine the net present value and net profit, including depreciation and interest accrued on fixed capital. The longevity (duration of service) of the drip-set is an important variable to assess net present value, which, in turn, is a determinant of per–hectare profit.

***Table 3.** Comparison of soya bean production per hectare under LCDI and CDI.*

S.N Description	Unit	Under LCDI	Under CDI
Crop productivity	kg	10,384	10,463
Average harvest crop price	Tsh/kg	3,000.00	3,000.00
Total gross returns	Tsh	3,115,200.00	3,138,900.00

Table 4. Per-hectare costs (Tsh) associated with LCDI and CDI.

Description	LCDI	CDI	Gain over CDI	
			Amount	Percentage
Material purchase	10,990,000	14,666,800	3,676,800	25.07
Drip installation	150,000	270,000	120,000	44.44
Cultivation	75,000	75,000	-	0.00
Seed sowing	40,000	40,000	-	0.00
Pesticide application	30,000	30,000	-	0.00
Weeding and intercultural practices	360,000	360,000	-	0.00
Irrigation	140,000	120,000	(20,000)	-16.67
Harvesting	120,000	120,000	-	0.00
Total	11,905,000	15,681,800	3,776,800	24.10

Table 5. Yield, water use and water use efficiency of low-cost drip system and hand watering under farmer-managed conditions.

Irrigation method	Yield (t/ha)	Water use (m^3/ha)	Irrigation water productivity (kg/m^3)	Man-hours used
Low-cost drip system	13.214	4,035.71	3.27	149
Hand watering	8.214	6,000.00	1.37	224

Conclusions and recommendations

A low-cost drip irrigation system was introduced in Mkindo village and tested for its affordability, acceptability, and performance under farmer-managed environment. During season one, the treatment with one punched hole per emitter and the supply tank raised to 1 m elevation head (T1) was recommended for use among other treatments because it used less water. Further it was shown statistically that there were no significant differences in water productivity with T3 (higher WP). During season two, the treatment with supply tank at a pressure head of 0.8 m was found to be the best as it used less water than did other LCDI systems. Its WP had not significantly differed from that of CDI system.

An economic analysis of the LCDI system revealed better performance in terms of in payback period than CDI. However, further economic analysis using other crops should be done to get a more solid basis for recommending possible changes in the LCDI technology.

Farmers' testimonials

- *LCDI is simple to install, I don't need to hire an expert.*
- *We are getting the same yields just like commercial family drip systems, but these are much cheaper and affordable.*
- *I used to irrigate with watering cans and was taking quite some time. With LCDI I am spending less time irrigating my fields.*
- *The system can easily be installed and dismantled at the end of cropping season.*

Farmers reported high levels of satisfaction with the low-cost drip system and they were willing to pay for the equipment. With relative abundance of water in some areas in Mkindo, however, it is a challenge to motivate farmers to use it. It is better to promote drip irrigation among farmers for whom water is a key constraint—i.e., water is scarce and costly to pump. When integrated with improved crop management practices, low-cost drip irrigation can be a water-smart technology compared with conventional drip irrigation.

The labor and time saved through LCDI can give female farmers opportunity to engage in other activities for the well-being of their households. The lower total cost of LCDI indicates that farmers adopting this system can use 24.1% less money than when they use CDI while at the same time not compromising yield. There is therefore a need for government to promote LCDI.

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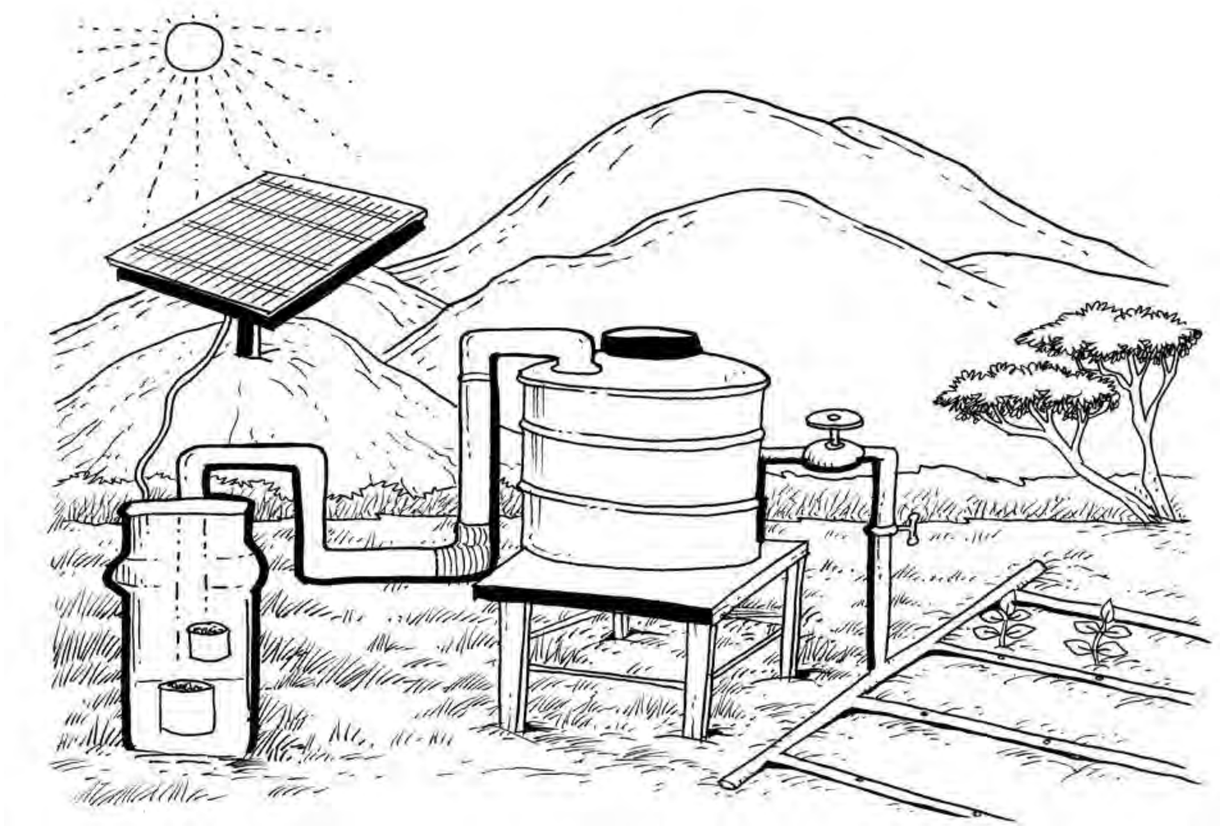
Exploring Groundwater Sources for Sustainable Smallholder Agricultural Production in Northern Uganda:

The Case of Agago District



When the Lord's Resistance Army insurgency in northern Uganda ended, relative peace returned and the internally displaced persons' (IDPs) and the camps for internally displaced persons (IDPs) had to be closed down. The people resisted returning to their homes because they were destitute. They had no means of livelihood after two decades in the camps. Forty percent of IDPs living in the Kalongo camp were extremely vulnerable, with no means of livelihood and mostly depending on direct aid (GOAL, 2009). Food production in the district was very low with only 28% of the population in Agago accessing food from their own produce, 63% from the market, and 9% from other sources (Kalebbo and C, 2010). After closing, the Kalongo IDP camps, the majority of returnees settled in Pakol parish in Parabongo sub-county, and started growing millet, potato, beans, and simsim for consumption. They also produced cotton and vegetables such as cabbage, onions, and tomatoes for sale. The community already had experience in vegetable production, mainly growing cabbage and tomatoes in the swarms during the dry seasons. Agricultural work was primarily done by women and children, who sold their produce in the Kalongo market (GOAL, 2009). The returnees had no other sources of income and depended entirely on the sale of their produce, but their production was characteristically low because of the erratic rainfall distribution and severe drought periods. Pakol parish is in the northern agroecological zone with a less pronounced bimodal rainfall pattern. The rainfall is often erratic with occasional dry spells; it cannot guarantee a satisfactory crop under rainfed agriculture.

Goal International, a nongovernment organization, initiated an irrigation project to help smallholder farmers during dry spells and long droughts. The project objective was to enhance the returnees' livelihoods and strengthen the community's capacity through provision of supplemental water for increased agricultural production. It targeted 100 households by piloting vegetable production under irrigation on 14 acres of land.

Implementation

To meet project objectives, the need to increase water availability and maximize water use to produce more with less water were the key elements considered at the design and implementation levels. The following tasks were accomplished.

- **Community mobilization and problem identification**
  The intended beneficiaries were mobilized in a brainstorming session so as to identify problems and propose interventions. The community proposed the provision of irrigation water to overcome water stress on crops that result from dry spells and unreliable rainfall.
- **Assessment of crop water requirement** The calculation of net irrigation water requirement was based on 80% dependable rainfall to cover periods of long droughts. The crop water requirement for cabbage and tomatoes, as analyzed using the Aqua Crop tool (FAO, 2012) was 5 mm per day. Considering drip irrigation for the project (because of its highly efficient of water application), it was estimated that only 20% of the area would be irrigated. Therefore, the net crop water requirement would be 1 mm per day, translated into 56 m^3 of water per day for the 14 acres of land under the project.
- **Assessment of water sources**
  The project analyzed the feasibility of rainwater harvesting, river damming, and groundwater abstraction, but the surface water option was immediately ruled out because there were only seasonal streams that also dry up during dry seasons. Roof-top catchment of rainwater was not feasible because most of the houses in the project neighborhood were grass-thatched. While the runoff catchment was feasible and had the potential to yield more water, the topography of the project area limited its successful exploration. Fortunately, an assessment of groundwater revealed a huge potential and was, therefore, adopted for the project. Empirical assessments of groundwater parameters found aquifer potential and yield adequate for the project. The drilled well had a sustainable yield of 7.5 m^3/day.
- **Power sources to operate groundwater pumps**
  The project area had no supply of electricity from the national grid and the option of diesel engine to run the pumps was not appropriate because its running costs would overburden the already poverty-stricken returnees. In the light of sustainability, a solar-powered pump was installed but because its performance is tied to sunshine, it would only be effective for at most 10 h daily. The capacity of the available solar-powered pump from the local market was limiting too. So, two pumps with a capacity of 2.4 m^3/h each against a head of 65 m were installed at depths of 40 m and 45 m below the ground level.
- **Storage reservoirs**
  The total capacity of the reservoir tanks was chosen to match the capacity of the installed pumps. It was estimated that the solar-powered pumps would effectively work for a maximum of 10 h on a good sunny day, thus delivering a total of 4.8 m^3/h. To achieve an adequate head (water pressure) to distribute water to the drippers, the 14 acres of land were divided into five subplots of equal size and each had a 10,000-liter capacity reservoir tank installed near it. The reservoirs were all raised 2 m above the ground so as to provide the necessary water head to run the drip irrigation system.
- **Water application methods**
  Considering the cost involved in water abstraction and water as a limiting factor in production, it is prudent to use methods that are efficient in application. The farmers, however, were trained on all irrigation methods, including furrow irrigation, drip irrigation, and sprinkler irrigation methods and how to reduce water loss during application. However, drip irrigation was recommended for use because of its high water

application efficiency. Five sets of drippers were installed but farmers were also provided with garden hoses to complement the drippers or in cases that they fail. The garden-hose method of water application is a cheaper alternative to drippers, but extreme caution is required when irrigating young and delicate crops. On-farm methods of water management such as mulching were encouraged to reduce evaporative water loss.

Results

The irrigation project gave returnees hope and a new beginning. It encouraged all the IDPs to return home and the Kalongo camps have since been closed.

The beneficiaries of the Pakol irrigation project are no longer depending on direct aid. They are able to buy seeds in the subsequent seasons and have now diversified their production, growing maize and beans on a larger scale. The farmers have also upgraded their group to establish a village savings scheme where they pool proceeds from their production and loan it to members with interests. This has played a vital role in financing small-scale farmers who have no collateral to access loans from financial institutions.

The technology of supplemental irrigation is now spreading with some households excavating small ponds near swamps to collect water for use during dry spells. From the ponds, they use treadle pumps to draw water and apply on their crops, owing to the training and experience gained from the demonstration plots.

Challenges

The communities were IDP returnees expecting handouts in the form of money, farm inputs, and in kind (food), which were beyond project deliverables.

The adoption of the technology is slower than anticipated. Many households are still depending on the demonstration field for production. The initial cost of the system is prohibitively high for returnees who have just started rebuilding their lives.

Lessons learned

Managing community expectations is very important to ensure delivery of project goals. This can best be achieved through effective engagement of communities, which allows meaningful participation. Communities should be involved right from problem identification, proposal generation and implementation, up until monitoring and evaluation. More importantly, during implementation, the community must be made aware about contributing some resources to enhance a sense of ownership to sustain the project.

Conclusion and recommendations

With all the benefits of restoring livelihoods of a destitute community (as was in Pakol) and the potential of doubling proceeds of smallholder farmers, irrigated agriculture is one of the most important tools for fighting food insecurity. In all instances, the yield and returns from irrigated agriculture are higher than those from rainfed agriculture. In Ethiopia, Fitsum *et al.* (2009) have shown that returns on irrigated agriculture by a smallholder farmer can be up to 200% higher than the returns from rainfed agriculture. With good agronomic practices, such as soil and water conservation, the economic returns of irrigated farming can transform farmers from being peasants to commercial producers within a short time.

Harnessing groundwater for supplemental irrigation takes away the fear of drought due to erratic rainfall. Many times, people have considered groundwater as a pure source of water that must be reserved for domestic purposes only, but it is high time we overcome the hurdle and explore all sources of water, including groundwater to improve agricultural production. For sustainable and successful harnessing of groundwater for irrigation for a community of smallholder farmers, the following are recommended:

- Formation of water users (beneficiaries) into groups with a management team: The management team would liaise with government agencies and development partners with a bid to mobilizing resources and technical support. This approach has successfully been applied in managing the rural community water supply and sanitation systems in Uganda.
- The management team would not only be in charge of operation but will also work out an agreeable formula for charging farmers for services rendered. A formula for charging can be based on the volume of water applied, the area irrigated, or a fraction of the final produce. This, however, has to be agreeable to all.
- The beneficiary community needs to be adequately sensitized on project benefits. The beneficiaries need to be made aware of their responsibilities and contributions to the project.

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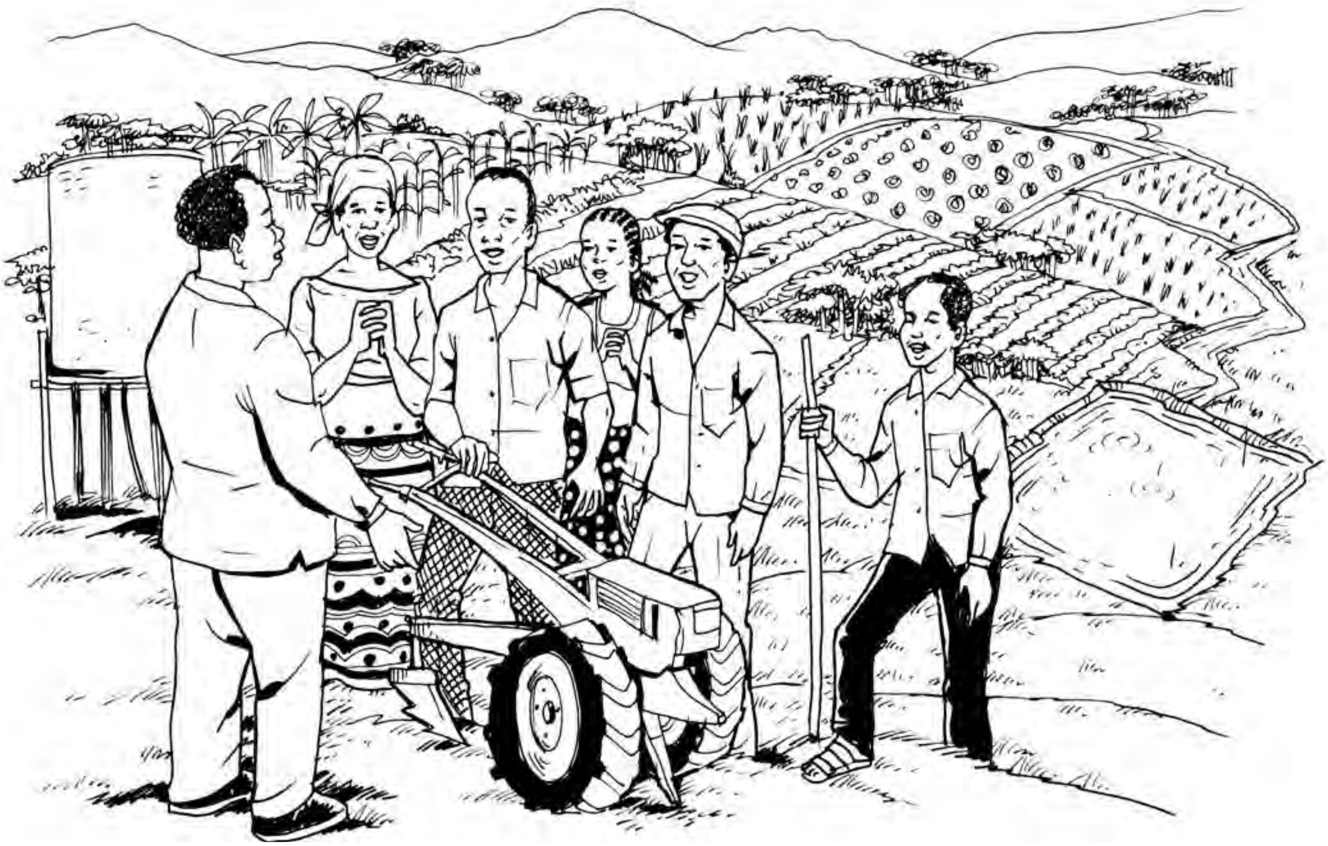
Conserving Soils

4

Economic Incentives for Soil Conservation in East African Countries



The effort to reconcile the three objectives of increasing agricultural production, reducing poverty, and ensuring sustainable use of natural resources has been a continuing battle in many developing countries. Many developing countries are confronted with problems of increasing population pressure on an already degrading land resource, worsening poverty, and declining per capita food production. With shrinking land frontier, increases in agricultural production need to come from improvements in land productivity (Eicher, 1994). However, significant increases in agricultural productivity cannot be attained if the land resource base is degrading.

Hence, the sustainable use of land resource constitutes the key constraint to agricultural growth in these countries. Land degradation, especially in the form of soil erosion, nutrient depletion, and soil moisture stress, is particularly severe in the highlands of the East African countries of Ethiopia, Kenya, Tanzania, and Uganda. These highlands have high agricultural potential but have been experiencing severe land degradation. Land degradation has been identified as the most severe environmental problem in these countries since the early 1970s (Jones, 2002; Mbaga-Semgalawe and Folmer, 2000; Gebremedhin, 1998; Stahl, 1993; Zake, 1992).

Use of economic incentives

Upon realizing the severity of land degradation in the early 1970s, the East African countries have embarked upon a series of initiatives for soil conservation (Stahl, 1993). Soil and water conservation and afforestation projects and programs have been widely used in Ethiopia, Kenya, Tanzania, and Uganda. Mostly supported by donor funding, these initiatives involved economic incentives to land users to conserve soil.

The use of incentives for soil conservation has perhaps been most widespread in Ethiopia, a country where land degradation is also most severe among the East African countries. The Ethiopian policymakers had largely ignored the problem of land degradation until the 1970s, after which national efforts for soil conservation expanded rapidly. Compensation for labor, especially in the form of food-for-work (FFW) and, in some cases, cash-for-work (CFW), has been the main direct economic incentive used for soil conservation in Ethiopia. Apparently, the 1974 drought provided the initial motivation for the mobilization of the rural labor force for conservation in the country using FFW programs. In addition to FFW and CFW programs, tree seedling distribution at minimal prices for private use and free of charge for use in community lands has been another direct economic incentive.

In spite of the rich indigenous knowledge of soil conservation throughout Ethiopia, the FFW-based soil conservation programs were aimed at promoting "new" or "improved" soil conservation practices, which were based on little prior research and scientific base. The programs were fundamentally top-down, with little involvement of local beneficiaries. Moreover, the programs focused on promoting conservation practices on community land, with minimal consideration given to individual farms. The lack of prior research and scientific base of the soil conservation programs was also manifested in the little consideration given to conservation needs at the watershed level. As a result, most farmers considered the FFW projects as sources of employment with little connection to the objective of soil conservation in the long run.

The difficulties encountered by the Ethiopian programs during their initial stage of implementation led to the realization of the need for beneficiary participation in the planning and implementation of conservation programs and projects, including the adaptation of conservation technologies to local conditions. As a result, several participatory approaches were used for soil conservation. However, the extent of farmer participation and the impact of these approaches on adoption of conservation practices were limited, as real involvement and participation of farmers could not be realized.

Alongside the effort by the government organizations, NGOs have also been very active in the area of soil and water conservation in Ethiopia. The approach used by the NGOs has largely been based on compensation for labor and technical assistance, which is basically the same approach used by the government programs. As in most government programs of soil conservation, beneficiary involvement and participation in the planning and implementation of the programs and projects run by NGOs have also been limited.

The use of indirect incentives for soil conservation in Ethiopia has been very low. Although the government extension service included sustainable natural resource management as one of its activities, in practice, the focus largely remained on improved crop and livestock production. The major bottleneck for soil and water conservation in Ethiopia has, perhaps, been the lack of land tenure security of farmers. Agricultural land in Ethiopia belongs to the state and farmers have only usufruct rights. Several researchers have documented that insecure land tenure is an important factor inhibiting farmer investment in soil conservation practices (Gebremedhin and Swinton, 2003; Gebremedhin et al., 2003; Alemu, 1998). However, no significant efforts have been made to improve land tenure insecurity in Ethiopia until recently.

Another indirect incentive that has been used since about 1996, especially in the northern highlands, is the distribution of communal degraded land for private tree plantation. This policy assumes that farmers would have better incentives to conserve the soil, and plant and care for tree seedlings, if the plantation is for private (rather than communal) use. The experience to date indicates that such policy can in fact produce encouraging results, perhaps reinforcing the argument of many researchers for the need to improve land tenure security of farmers as an incentive for farmers to invest in soil conservation.

As in Ethiopia, land degradation was identified as the most severe environmental problem in Kenya by the early 1970s. The Kenyan government soon set up a soil and water conservation branch in its Ministry of Agriculture, assisted by funding from the Swedish government. Kenya established a National Environmental Secretariat and a Permanent Presidential Commission on Soil Conservation and Afforestation in the mid-1980s. In 1989, the government established a Ministry for Reclamation and Development of Arid, Semi-arid and Wastelands (Stahl, 1993).

Alongside the focus on institutional development for soil conservation, Kenya started a soil and water conservation project with technical and financial assistance from Sweden in 1974. The project later expanded into a full-fledged National Soil Conservation Program covering the whole country (Mbegera *et al.*, 1992). The direct incentives used in the Kenyan soil conservation efforts included FFW, provision of hand tools, and materials for on-farm gully control. Unlike Ethiopia, the Kenyan approach to soil conservation emphasized indirect incentives such as training, technical assistance, and extension services, and it focused on private farms. By 1993, more than 18,000 agricultural officers were trained in soil and water conservation and it is reported that more than 1 million farmers had adopted conservation practices by then (Stahl, 1993). However, about two-thirds of Kenya's small farms that needed conservation were yet to be reached. The focus on individual farmers was later replaced by the catchment approach, since it was felt that the on-farm approach was slow and scattered. Earlier evaluation of the adoption of soil conservation practices at the farm level showed that the areas where adoption of soil conservation was higher were those where farmers had secure land tenure rights.

Several factors have contributed to the limited success of soil conservation in Kenya (Bryan and Sutherland, 1992). Despite the emphasis given to indirect incentives, these were deemed inadequate. Owing to the limited research on land management and soil conservation, the conservation practices suffered from lack of sound scientific and technical basis. Perhaps more important has been the lack of involvement of beneficiaries in the planning and implementation of conservation projects and programs.

The legacy of forceful implementation of conservation requirements in Tanzania during the British colonial rule resulted in the unpopularity of conservation efforts soon after independence in 1961 (Mbaga-Semgalawe and Folmer, 2000). Areas formerly prohibited from cultivation started to be cultivated, and agricultural development and research programs opted not to emphasize soil conservation. However, not after too long, the continued acceleration of soil erosion forced the Tanzanian authorities to refocus on soil conservation (Misana, 1992; Mndeme, 1992; Rugumamu, 1992). Hence, as in the other East African countries, soil conservation programs have expanded rapidly in Tanzania since the 1970s.

In 1979–80, the Tanzanian government, in collaboration with the Regional Integrated Development Program supported by the technical aid program of Germany (GTZ), initiated an integrated Soil Erosion Control and Agroforestry Program to promote soil conservation in the west Usambara mountains. In 1989, the Dutch government initiated an irrigation development program, which included soil and water conservation as a major objective. In 1992, GTZ initiated the Tanzanian Forest Action Plan in the Pare mountains, with soil conservation as its major component.

To encourage the adoption of soil and water conservation practices in Tanzania, these programs provided various types of incentives to farmers. The direct incentives used by the programs included the provision of implements and farm inputs such as improved seeds at subsidized prices. The indirect incentives used included revitalization of the traditional labor-sharing groups to reduce the problem of labor shortage; the establishment of village-level land use planning committees responsible for planning and implementation of soil and water conservation activities; the establishment of village tree nurseries for afforestation purposes; the provision of technical assistance for soil and water conservation; and field tours, training, and the provision of information. An assessment of the factors associated with the adoption of soil conservation technologies promoted by these programs indicated that awareness of soil erosion problem, participation in promotional activities of soil and water conservation, and participation in labor-sharing groups enhanced adoption (Mbaga-Semgalewa and Folmer, 2000).

As in Tanzania, efforts to conserve soil in Uganda started during the colonial period (Tukahirwa, 1992). The British Protectorate realized the need for soil conservation in 1940. Soil conservation bylaws were instituted at the district level in 1956, and chiefs were responsible for enforcing the by-laws (Zake, 1992). However, the extension services for soil conservation during this period were based on implementing compulsory, legally enforced requirements, which was highly resisted by farmers and led to the rejection of soil and water conservation practices soon after independence (Tukahirwa, 1992).

After independence, a number of soil conservation projects, mostly funded by donors, were implemented in Uganda. In 1986, Uganda established its Ministry of Environmental Protection with the mandate for soil conservation. While the establishment of this public body provided for a unified authority responsible for soil conservation, the lack of coordination among the activities of the different ministries related to soil conservation activities is said to be one reason for the lack of effective soil conservation in the country (Zake, 1992). Other national issues related to the ineffectiveness of soil conservation include ineffective extension service, lack of appropriate mix of soil conservation technologies (e.g., physical versus biological), and the difficulty to implement government policy on land across the diverse land tenure systems (customary, freehold, "Mailo," and leasehold systems) (Zake, 1992).

Conclusions

In the East African countries, direct incentives for soil conservation have been mainly aimed at mitigating the effect of the proximate causes of land degradation. The FFW and CFW projects and programs were targeted at constructing soil conservation structures or establishing biological means of soil conservation, in a direct attempt to curb soil erosion. Such an approach failed to realize the role of the more important causes of land degradation—the underlying factors. Hence, the mixed success of most incentives for soil conservation in the East African countries appears to arise from the use of inadequate and inappropriate use of incentives.

Perhaps the most important factor inhibiting farmer investment in soil conservation in the East African countries has been land tenure insecurity, since farmers cannot be expected to invest in long-term soil conservation structures such as stone terraces that have long-term pay-off, unless they are secure of their tenure for a long-enough period. However, improving land tenure security of farmers as an indirect incentive for soil conservation has not received due attention in these countries.

The low profitability of conservation practices and the absence of adequate short-term benefits from soil conservation have been important factors that detracted from the sustainable use of soil conservation practices. To encourage soil conservation at the farm level, several factors, which either raise the discount rate of farmers or reduce the profitability of conservation practices, need to be considered in designing incentives. Market infrastructure development or price support schemes could improve profitability. In this regard, cross-compliance measures that link price support with conservation would increase the profitability as well as the desirability of soil conservation. Economic incentives for soil conservation could be more effective if they are designed as part of the overall agricultural development strategy. The design of future incentives for soil conservation needs to depend on using the appropriate mix of direct and indirect incentives. While direct incentives could be useful for demonstration and technical support purposes, the sustainable use of soil conservation practices is likely to depend more on the appropriate use of indirect incentives.

Source

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Intensive Cultivation and Environment Use among the Matengo in Tanzania

This paper focuses on the agroecological background of an intensive cultivation system called *ngolo*, which has been practiced for more than 100 years among the Matengo people in southern Tanzania. The ngolo system is highly sustainable as it both conserves soil and water and matures the soil; moreover, the high productivity of this system ensures a steady food supply to the Matengo. The other cropping systems in Matengo agriculture, which are closely related to ngolo, economically support farmers. For example, coffee cultivation provides cash to support the local economy, and it also enables farmers to purchase chemical fertilizers. These fertilizers are applied to ngolo fields in the highlands, where fields cannot be left fallow because of high human population densities. Immigrants from the highlands to the woodlands practice a normal ridge system of cultivation called *mitumbila* and a slash-and-burn cultivation called *matema/malala*. These systems are the initial stages in the process of creating suitable soil conditions for ngolo cultivation, and they are major sources of income in new villages where coffee trees are too young to be harvested.

The Matengo and the origin of ngolo cultivation practice

The Matengo are a Bantu-speaking people who reside in the Mbinga District of the Ruvuma Region in southern Tanzania. They grow maize and beans as staple food crops and coffee as a cash crop. The Matengo are well known for their farming skills, and they practice a unique cultivation technique, called ngolo, in mountainous areas. Literally translated, ngolo means "pit" in the Matengo language. Since a ngolo field has many pits, the system has been referred to in the literature as "Matengo pit cultivation."

Ngolo fields are cultivated in March, toward the end of the rainy season. Men slash down the dense weeds that have grown during the rainy season and, after a week, arrange the stalks to form square grids of 1.5-2.0 m. Women then dig up the soil within the grids and use it to cover the stalks. The grid ridges produce many pits over an entire field. These pits conserve soil and water, while the buried weeds mature the soil (1) (Allan, 1965; Basehart, 1973; JICA, 1998). Older studies (Pike, 1938; Stenhouse, 1944) reported that ngolo cultivation was already in use in the early 1900s; thus the Matengo have sustained the system for over 100 years.

The origin of ngolo cultivation is related to the process of ethnic group formation. Around the middle of the 19th century, the Ngoni people invaded from southern Africa and drove the natives away. During this invasion, one party of refugees reached eastern Songea, the center of the Ruvuma Region, and became the Ndendeule; another group of refugees settled in the mountainous areas of the Mbinga District and became the Matengo (Gulliver, 1955; Ebner, 1959; Allan, 1965; Schmied, 1988). The Matengo farmers may have invented the ngolo system of cultivation in order to survive in the harsh mountainous regions while being threatened by the Ngoni (Stenhouse, 1944).

The western part of the mountainous area in the Mbinga District is called the Matengo Highlands and is characterized by steep slopes ranging from 1,300-2,000 m above sea level (asl). The indigenous vegetation of the Matengo Highlands is primarily evergreen montane forest, and this landscape differs from the woodlands found on the outskirts (JICA, 1998). Ngolo cultivation may have originated in these montane forests. Ngolo cultivation is labor-intensive, some of which are left fallow. In 1926, coffee was introduced to the Matengo Highlands and gradually spread throughout the area (Iliffe, 1979). Coffee is suited to the cool and moist conditions of Mbinga, and the cultivation of this crop may advance the sedentary lifestyle of the Matengo. According to the 1957 census, the population density of the Matengo Highlands was about 70 individuals/km^2 (Tanganyika, 1963), and in 1997 it was more than 100 individuals/km^2 (JICA, 1998). This density is considerably higher than the average 26 individuals/km^2 in Tanzania in 1988 (BOS, Tanzania, 1989).

Since the 1960s, the shortage of land has caused many farmers in the Matengo Highlands to migrate to the rolling hills in the south and east of the district. The Matengo named their original highland *itumbi* and refer to new destinations as *itutu*; they often comment on the differences in living conditions between the two areas. Aside from the shortage of land, there are also cultural and social aspects related to Matengo migration (Kato, 1996); however, this paper deals primarily with the agroecological aspect of their migration.

Basehart (1973) noted a tendency for the Matengo to maintain ngolo cultivation in densely populated villages, whereas those who migrated to sparsely populated villages adopted more extensive systems of cultivation. He interpreted this phenomenon in light of the Boserup assertion (2), which states that population density regulates the intensity of agriculture. According to Basehart, the ngolo system was formed under high population pressure; therefore, those who moved into sparsely populated areas abandoned ngolo cultivation and chose more extensive systems. However, this explanation based on the Boserup assertion does not ubiquitously fit into the context of the Matengo agricultural intensification.

In Matengo society, a patrilineally extended family or lineage generally owns one small mountainous ridge surrounded by streams. The land is called *ntambo*, which is an archetype unit of land tenure. The Matengo are polygamous and married women borrow fields in the ntambo from their fathers-in-law. Matengo men usually engage in growing the coffee, whereas women are responsible for the production of maize and beans, the daily staples. Many households raise a few goats and/or pigs, which are primarily used for rituals, in wedding and funeral ceremonies, and to supplement the income.

Ngolo cultivation

The archetype unit of the land tenure (ntambo) has influenced the unique pattern of land use in the study area (Fig. 1). The elevation ranges from 100 to 600 m and the size of the ntambo ranges from 10 to 70 ha. People build houses on any flat site, called *nnduwi*, within their ntambo and plant kitchen gardens for growing tomato, onion, amaranth, sweet potato, sunflower, pumpkin, and other vegetables. Coffee trees are planted around the kitchen garden. On the steep slopes, called *uheleu*, below the coffee gardens, ngolo fields are cultivated to grow the major food crops: maize and beans.

A narrow, flat, elongated plain along the streams, which remains wet throughout the year, is used to grow some vegetables and coffee seedlings. In these plains, locally called *kijungu* and *libindi*, fields of various perennial crops, such as sugar cane, banana, and taro are often planted, or the plains are kept in pasture during the dry season. The upper parts of the mountains are often kept covered in forest (*kitengo*). This place is used for firewood, grazing, or collecting wild plants for herbal remedies. Thus, the Matengo use the ntambo effectively to suit ecological conditions, centering the ngolo fields where the staple foods are produced. This section describes the features of the ngolo cultivation system, while paying particular attention to agroecological conditions.

Rainfall patterns

While the mountain zone has high agricultural potential that is supported by reliable rainfall, the topsoil on the slopes tends to be eroded by heavy rains. Figure 2 shows the amount of rainfall per day in the 1996/97 and 1997/98 seasons in the village of Kindimba. The annual total rainfall in the 1996/97 and 1997/98 seasons was 838 mm and 1,496 mm, respectively, and fluctuated greatly. Although there was not much difference between the two seasons in terms of number of days of rainfall, 0.5 mm (92 days in 1996/97 and 107 days in 1997/98), annual rainfall was 1.8 times higher in 1997/98 than in 1996/97. The results indicate frequent torrential downpours in years that have high rainfall. Under such severe conditions, ngolo cultivation has successfully conserved the soil for over a century.

Rainy-season tasks

A series of tasks in ngolo fields corresponds with rainfall patterns. Figure 2 shows the agricultural calendar of the ngolo system. In general, a household keeps one ngolo field for maize and one for beans, and the crops are grown in rotation. During the late rainy season, women dig pits (Fig. 3) and sow beans. After harvesting the beans in June, the field is left alone during the dry season. Maize is planted on the same ngolo ridges in December, just after the onset of the rainy season, and is harvested in August of the following year. Fields are then left without cultivation until late in the rainy season of the next cycle of ngolo preparation (i.e., a short fallow period of 7 months). Because of the two-crop rotation system with two fields, one household can always harvest both maize and beans every year.

The series of tasks performed by a household is closely related to rainfall patterns. The farmers classify the rainy season into three periods. The rain in December is called the “rain for field preparation.” Rain and clear weather alternate every few days at this time of year. Women sow maize in the ngolo fields that were cultivated during the previous season. Just before sowing, they weed with a hand hoe and re-form the grid ridges. They then use a hoe to make planting furrows on the ridges and sow maize seeds at 20-cm intervals, using their feet to cover the seeds with soil as they go. The plant

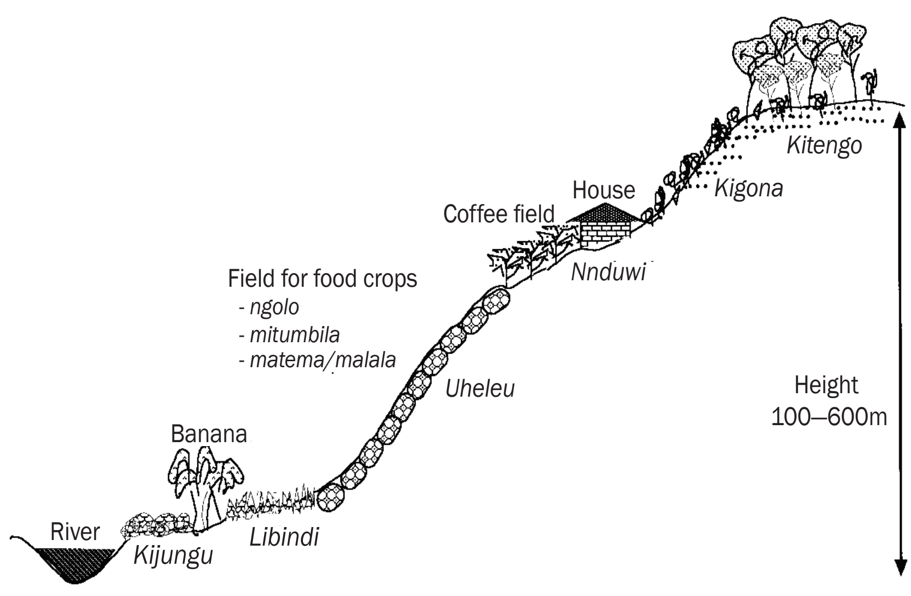

Fig. 1. *Use of ntambo (JICA 1998).*

density is about 10 plants/m^2. If the maize seeds or seedlings are damaged by pests, animals, or rain, they can be replanted.

Rainfall is usually heavy between January and February. The farmers engage in weeding (*kukulagalila*) and thinning (*kutukupila*) the maize fields; therefore, they call this rain the "rain for weeding." Women and men usually weed for several days in mid-January. By this time, the pits in the ngolo fields may be filled with soil that has been loosened from the ngolo ridges by the heavy and incessant rain. However, the soil rarely flows downhill because of the maize roots that effectively cover the soil surface.

From March to mid-April, the rains are intermittent. This corresponds to the period for cultivating another ngolo field, and this season is known as the "rain for the beans." When selecting dates for planting, women must consider the amount and intensity of rainfall because beans are sensitive to soil moisture conditions. Late in April, the rain decreases gradually, and this period is called the "last rain." Thus, the series of tasks in the ngolo fields corresponds to each type of rainfall pattern during the rainy season.

Making ngolo ridges

Ngolo fields are normally arranged on slopes of 5-30 degrees. The average size of a ngolo field is about 0.7 ha, and the average size of a square grid ridge is about 2 m. Therefore, there are more than 1,500 pits in a typical ngolo field. Preparation of the ngolo fields is based on strict gender division of labor, broadly divided into the slashing (*kukyesa*) and arranging of grasses into square matrices (*kubonga*) by men and the cultivating (*kulema ngolo*) and planting by women.

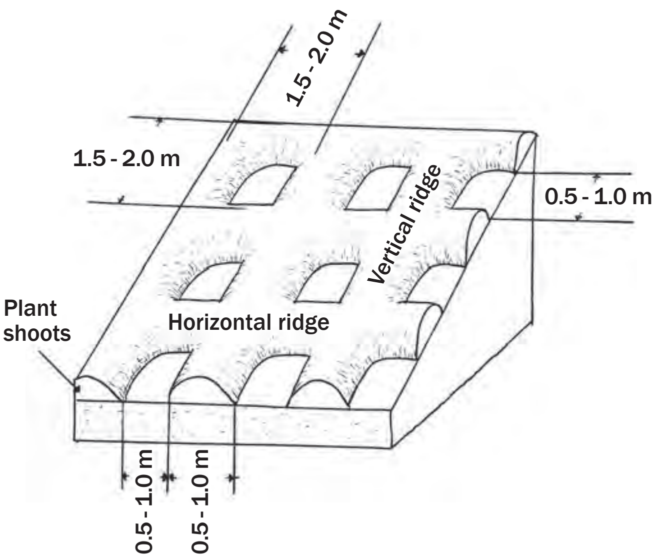

Fig. 3. A profile of ngolo ridges (Itani, 1998).

In February, late in the rainy season, several weeds, collectively known as *malumba* (including *Nidorella resedifolia* and *Conyza persifolia*) all flower together. At the beginning of March, men slash the malumba with a billhock (*gesela/mbopo*). In new villages, men sometimes struggle to slash *Hypharrhenia coleotricha* grass that grows about 2 m tall. Slashed grasses are left to dry in the fields for about a week, and the dry stalks are then collected and arranged into vertical and horizontal lines to form grids. The lines of grass stalks are called *mabongi*. When buried under the ridges, the mabongi have the same effect as green manure (JICA, 1998; Moritsuka *et al.*, 2000) and provide internal drainage (Itani, 1998). Men pile up excess grass in piles 2 m in diameter and 0.5 m high, which are later burned. The soil eventually deteriorates after continued cultivation for a long time, and *Pteridium aquilium* and *Imperata cylindrica* become dominant; thus, it becomes necessary to let the field lie fallow.

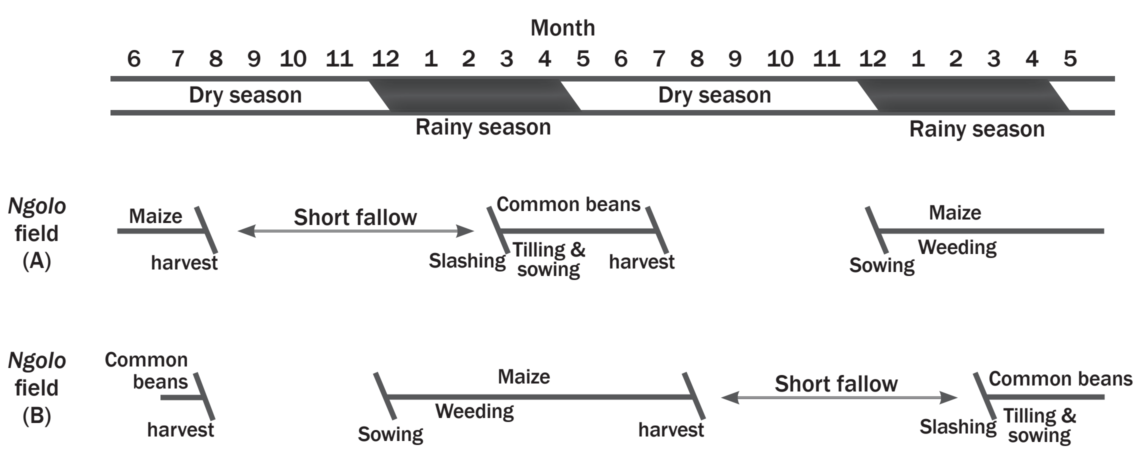

Fig. 2. Household cropping patterns of two ngolo fields.

After finishing kubonga, women cover the mabongi with small amounts of topsoil (about 8 cm) inside the grid (*kujalila*). Figure 4 shows the sequence of the work. Women evenly spread topsoil over the mabongi and then sow bean seeds onto them (*kukweta ngondi*). Finally, they cover the seeds with the soil in the pit (*kukulila*; Fig. 5). Kukulila looks like kujalila, but it involves deeper tillage of about 15 cm. According to the women, moving soil uphill (letters a–d and i–k in Fig. 5) is physically arduous. The women place some soil clods on a, b, and i before putting other clods on c, d, and j and the upper gaps between a, b, and i. The former clods are for ridge foundations and the latter are for linking larger clods. Thus, because the horizontal ridges are constructed more strongly, the ngolo can withstand heavy rains. Sometimes cassava cuttings are planted just after sowing the beans (point A, Fig. 5).

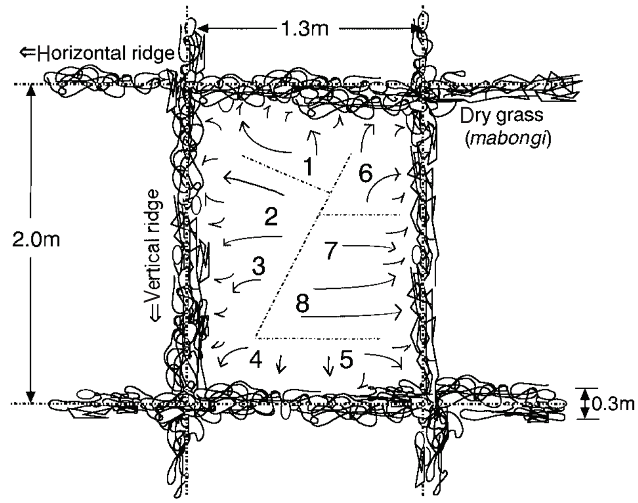

Fig. 4. Work of kujalila*.*

Soil maturing

The soil in the Mbinga District basically consists of clayey red soil, which the Matengo call *luhumbi lukeli*. Darker soil is formed in deeper layers by mixing the mabongi into the deep soil; dark soil rich in organic matter is called *luhumbi lujilo*. An important feature of the ngolo cultivation system is the formation of dark layers of luhumbi lujilo, which provides conditions favorable for high crop yields.

Although the ngolo cultivation system conserves surface soil on the slopes, by the middle of the rainy season, the pits are filled with sediment, and a small amount of soil is lost with runoff. In this system, the fertile soil from the pits is returned to the ridges every 2 years, while the subsoil that is dug up compensates for the soil losses. Therefore, some red soil (*luhumbi lukeli*) appears on the ridges, but it changes to luhumbi lujilo by being mixed with mabongi. The red soil is placed on the horizontal ridges to reinforce them (clods c, d, and j in Figure 5).

The position of the pits is shifted for each new cultivation (Fig. 6). New pits are placed where the previous ridges intersected. By changing the position of the pits during each preparation, the top and sub-soils as well as dry grasses are mixed or turned over (JICA, 1998). This process matures the soil. Although the function of soil and water conservation attracts the most notice in the ngolo system, soil maturing is also quite important to maintaining high productivity levels.

The change in soil nature by this cultivation is indicated at the following analysis. Topsoil of original vegetation (*miombo* woodland) and topsoil of a ngolo field were analyzed at Lupilo village, eastern side of the district (JICA, 1998). The results showed that clay occupied about 50% and 35% of the topsoil of ngolo field and the miombo woodland, respectively. This is mainly due to integrating part of the subsoil into the topsoil by ngolo cultivation. Moreover, the soil structure is stabilized through decomposing organic matter by bacteria and fungi (Russell, 1988). Topsoil forms water-stable aggregates suitable for cultivation through a process integrating organic matter.

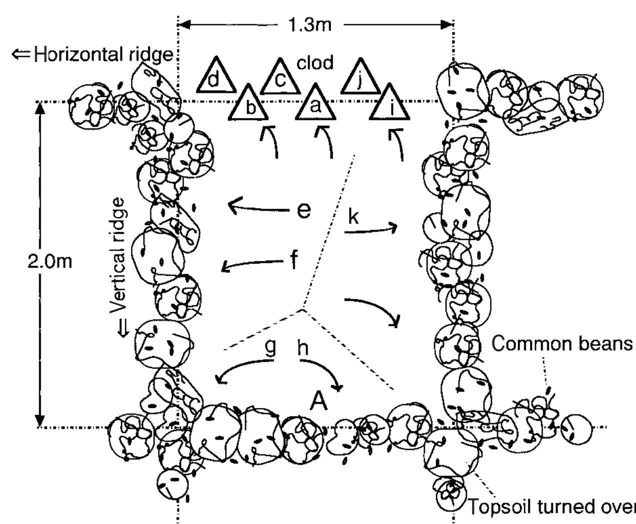

Fig. 5. Work of kukulila*.*

The Matengo define an ideal ngolo field as having pit dimensions of 3.5 m2 x 70 cm deep, with an adequate amount of buried mabongi. Under these conditions, ngolo cultivation effectively conserves

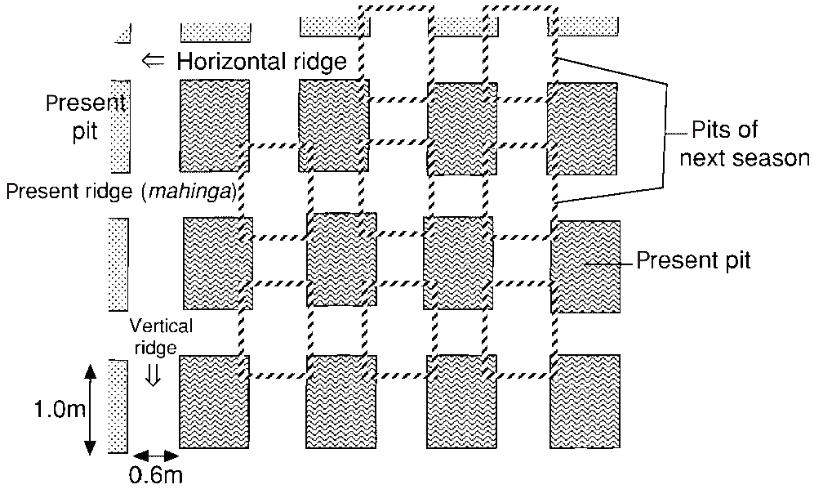

***Fig. 6**. Changing positions of pits in a ngolo field.*

soil and water and maintains soil fertility. Women must master the techniques of making the ideal and perfect ngolo. They are aware that the skill of cultivating the ngolo is an index of their socio-cultural status and recognition, particularly for unmarried women. Thus, the ngolo cultivation system has also been maintained by the common recognition of women's labor and integrity.

End note

Ngolo cultivation is an intensive system that contributes to soil conservation and sustains fertility of the arable land. It is quite rare among African indigenous cultivation systems, many of which are extensive. However, Pike (1938) and Stenhouse (1944) inspected the district during the first half of the 20th century and reported that coffee cultivation and mitumbila prevailed, and that intensive ngolo cultivation was declining. Basehart (1973), quoting Boserup's assertion, pointed out that those who migrated to sparsely populated areas practiced more extensive cultivation; hence he concluded that practicing intensive ngolo could be attributed to the high population pressure.

The system of ngolo cultivation was formed under social constraints. The Matengo were placed under duress by their rival, the Ngoni, and were forced to cultivate the steep mountainsides. In those days, they needed to increase the yield per unit area in order to obtain enough food, and consequently the Matengo cultivation system was intensified.

The high population pressure might have brought about the creation of the ngolo system and the land tenure system, and the intensity of Matengo agriculture may therefore be based on population pressure. However, the severe environmental conditions in the mountainous area may also have influenced the formation of this intensive but sustainable cultivation method. The Matengo have relied on the ngolo cultivation system, which has been able to support them, and may well have been a foundation of their culture.

Notes

1. In this paper, "soil maturing" means the process of accumulating organic matter and clay in the topsoil, with repeating cultivation.

2. Boserup (1965) insists that as the population density increases, changes occur in cropping techniques such as shortening fallow periods and increasing the labor input to satisfy the higher demand for food. According to her arguments, the agricultural intensification can be spontaneously attained under the high population pressure. This paper focuses on the following part of her assertion: *...cultivation who used intensive methods in their densely settled home districts give up these methods after they have been resettled in less densely populated districts and given more land per family* (Boserup, 1965: 63).

Source

This article is a considerably shortened version of the original article. *Intensive Cultivation and Environment Use Among the Matengo in Tanzania* by Masahiko Kato. Graduate School of Asian and African Area Studies, Kyoto University. African Study Monographs 22(2): 73-91, July 2001.

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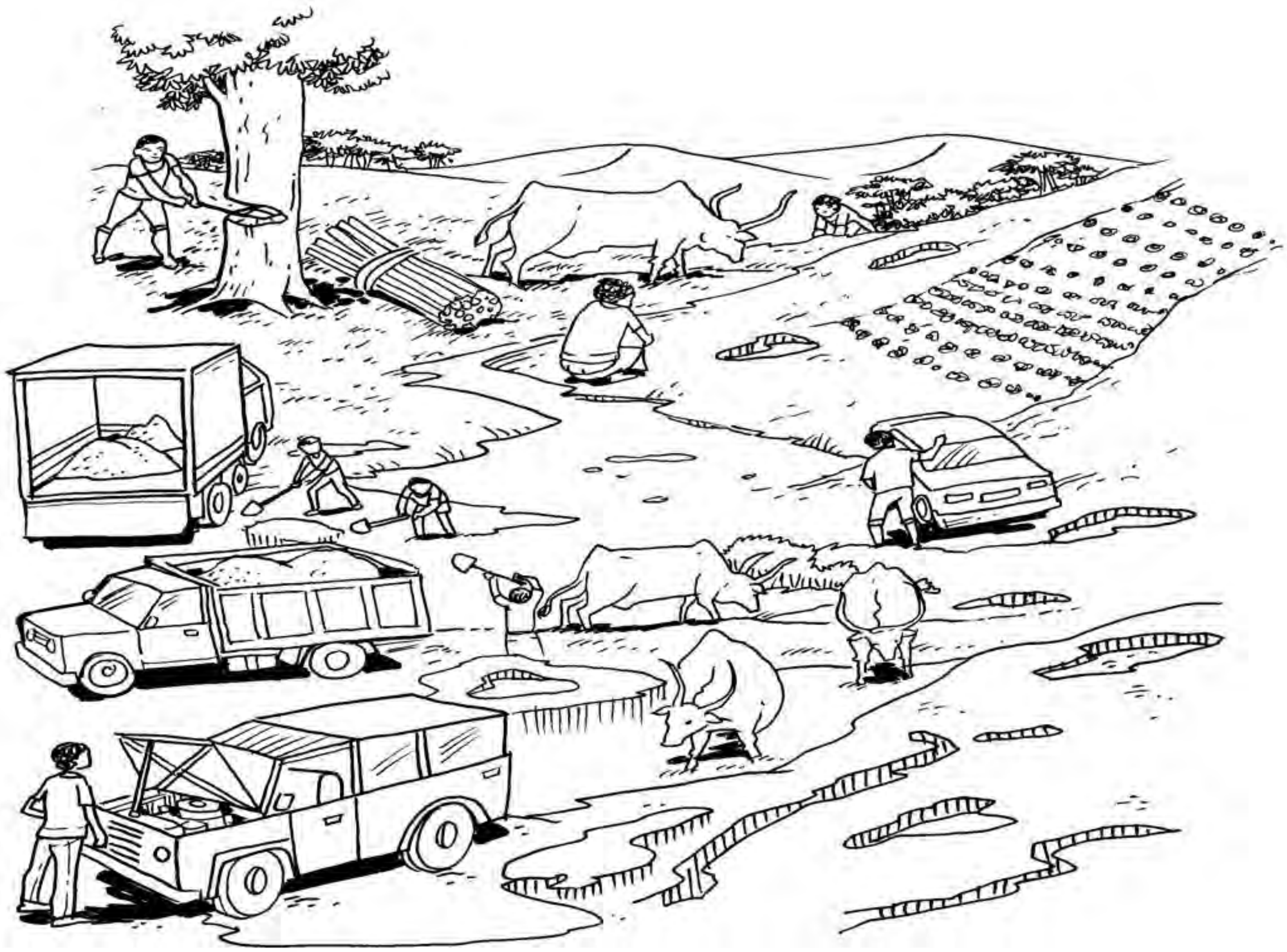
Soil and Water Conservation Technologies in the Upper Rwizi Micro-catchment of Southwestern Uganda



The continuing decline of agricultural productivity in many areas in Uganda, particularly in the Lake Victoria Basin (LVB), has been attributed to land degradation and, as a consequence, farmers encroach on forests, wetlands, and marginal steep slopes (NEMA, 2009; Mugonola, 2013c). Cultivation of these areas using unsustainable agricultural production methods contributes to increased soil erosion, loss of buffering capacity, sediment deposition, and pollution of water bodies. Degradation of farm and rangeland has on-farm and off-farm effects. On-farm, it leads to reduced current and future land productivity and land values, while off-farm, soil erosion results in environmental degradation, desertification, siltation of waterways, and flooding, among others.

The rapid land-use changes taking place in the LVB, including the upper Rwizi micro-catchment, continue to contribute to land degradation. For instance, banana production in the Rwizi-micro catchment of southwestern Uganda is expanding rapidly in response to increasing demand for cooking banana in urban places in Uganda and neighboring countries. This rapid expansion leads to changing land use and conversion of marginal areas (wetlands, steep slopes, valley bottoms) for agricultural production. However, these new areas may not sustainably support crop production because they are prone to land degradation through soil erosion. Soil losses through erosion leads to loss of the topsoil, organic matter, and inadequate water penetration and retention. The resulting effect is crop failure and reduced productivity due to nutrient and moisture stresses.

To abate soil erosion and the associated land degradation, smallholder farmers need to adopt water-smart technologies that include mulching, grass strips, runoff diversion, agro-forestry, and water harvesting, among others. These approaches, grouped into soil and water conservation (SWC) technologies, include biological, physical, and management-related techniques (WOCAT, 1992). Soil and water conservation is the rational use of land resources, application of erosion control and water conservation technologies, adoption of appropriate cropping patterns, and prevention of land degradation (Hudson, 1987). Adoption of SWC technologies will enable smallholder farmers to utilize resources such as land and water in ways that promote water-smart agriculture (WaSA).

SWC in the Upper Rwizi micro-catchment

Many technology dissemination and technology uptake pathways exist in Uganda—these include the research-extension farmer linkage, demonstration plots, progressive farmers' approach, Zonal Agricultural Research Development Institute (ZARDI), and exposure visits, among others (Mugisha *et al.,* 2012). In addition, various environmental management committees at different levels of local government are expected to oversee the wise use of natural resources.

New technologies, including SWC technologies, are taken up using these dissemination and uptake pathways. Once smallholder farmers get the right information, they act on it for as long as it is perceived to improve their economic and/or social conditions. These individual actions to conserve soil and moisture in the farm land that collectively lead to conservation of the Rwizi River through reduced deposition of sediments and nutrients, thus contributing to WaSA.

The upper Rwizi micro-catchment is drained by the River Rwizi, which originates from the Buhweju hills in present-day Buhweju District. The river flows eastward, dissecting a number of papyrus swamps and finally discharges into Lake Victoria through River Bukora, the Sanga plains, and Lake Mburo National Park. River Rwizi is drained by the Itojo wetland systems in Ntungamo District, the Bujaga/Nyaikaikara wetlands in Mbarara District, the Nyakambu wetlands in Buhweju, Buhweju District, and the Kooga wetland systems in Sheema, Bushenyi and Mbarara districts (NEMA, 2009; Wanyama, 2012). These wetland systems are naturally replenished by the water sources in the ridges of Buhwa and Bucuro (in Buhweju and Kashari), Ryengoma in Ibanda District and Rubindi. The Rwizi River is the main source of water for domestic, livestock, and industrial consumption in five districts (Bushenyi, Ntungamo, Mbarara, Kiruhura and Isingiro) of southwestern Uganda (NEMA, 2009).

The River Rwizi has a catchment area of 2,282 km^2 (228, 200 ha^2); altitude ranges from 1,262 to 2,168 m asl, with a bimodal rainfall of 1,000–1,500 mm per annum in most of the catchment area. However, the upper Rwizi micro-catchment is an area of high population density (ranging between 96.7 and 323.6 persons per km^2 of land area (NEMA, 1997), and high agriculture potential, supplying mostly banana and livestock to the urban areas of Uganda and neighboring countries (Wanyama, 2012). The predominant farming system in the upper Rwizi micro-catchment is the western banana-cattle system (Wortmann and Eledu, 1999; Wanyama, 2012) from which majority of the population derive their livelihood (NEMA, 1997). The major sources of income is the sale of crops and livestock. Major crops include banana, coffee, pulses (beans and peas), cereals (millet, maize, and sorghum), root crops (potato) and vegetables (Mugonola, 2013c). The annual crops require clean tillage practices, which expose the fields to water erosion and nutrient loss through leaching and nutrient mining at harvest (Wortmann and Kaizzi, 1998; Isabirye et al., 2007). Banana production is a major economic activity in this area and therefore takes up a considerable portion of farm-level resources (Bagamba, 2007). Bananas are planted along the hill slopes mainly as monoculture, but sometimes intercropped with coffee and beans.

Many of the valleys have been either fenced off as grazing paddocks or are used to cultivate crops, especially vegetables and potato. The wetland vegetation, especially papyrus, is cut and used for various purposes such as mulching banana plantations, thatching houses, and making arts and crafts, among others (NEMA, 2007). Since the hilltops and slopes have become unproductive due to overgrazing, loss of fertility, and degradation, agricultural activities have shifted to the valley bottoms and wetlands (Mugonola, 2013c). This change in land-use impacts on the catchments as bare hilltops and slopes are prone to massive soil erosion and the buffering capacity of the wetlands is eventually overwhelmed. For these reasons, the upper Rwizi micro-catchment is often described as land degradation 'hot spots' (Isabirye, 2005; NEMA, 2010). The river system receives all the eroded sediments and sediment-fixed nutrients from hillsides and agricultural land unabated, which eventually end into Lake Victoria (Isabirye, 2005; De Meyer et al., 2011).

Sample selection

The study used multi-stage sampling strategies involving purposive selection of districts and subcounties, where the extent of degradation was highest, "degradation hot spots," random selection of villages (bearing in mind the distance from the river), and clustering of respondents by economic activity (intensity of banana production and livestock density). A household survey was conducted among 271 households drawn from Mbarara, Bushenyi, and Ntungamo districts in selected subcounties of Bukiro, Bubaare, Rwanyamahembe, Rwengwe, Bugamba, Kyangyenyi, Rugando, Ndeija and Itojo (Mugonola et al., 2013a). In addition, sediment measurements were taken in selected subcatchment areas along the river, targeting areas with intact, medium, and completely degraded wetland vegetation.

The adopters of SWC technologies were 45% while the nonadopters were 55%. The adopters were small-holder farmers that had any or a combination of mulching, retention ditches, grass strips, and runoff harvesting channels, among others. This implies that majority of the respondents had not taken up any measures to conserve their soils and water, thereby increasing the risk of soil erosion and sediment deposition into the Rwizi river system. The demographic characteristics of the adopters and nonadopters of SWC technologies in the Rwizi microcatchment are presented in Table 1.

Conceptually, this analysis assumes that smallholder farmers optimize the benefits that accrue from the adoption or nonadoption of SWC technologies. However, as smallholder farmers seek to optimize the benefits of SWC, they may be affected by a number of factors, which may hinder them from taking favorable decisions toward adopting SWC technologies (Fig. 1). The observed differences in the decisions of the smallholder farmers toward

Table 1. *Demographic characteristics of adopters and nonadopters of SWC technologies in the Rwizi microcatchment.*

Dichotomous variable	Adopters (N = 122)	Nonadopters (N = 149)	Pooled (N = 271)
Male-headed households	47.9	52.1	78.6
Female-headed households	34.5	65.5	21.4
Presence of SWC technology	45.0	0.0	45.0
Absence of SWC technology	0.0	55.0	55.0
Severe signs of erosion	44.8	55.2	92.3
Absence of signs of erosion	47.6	52.4	7.7
Agriculture main income	47.2	52.8	84.5
Non-agriculture income	33.3	66.7	15.0
Belongs to farmers' group	47.5	52.5	29.5
Not members of farmers' group	44.0	56.0	70.5
Access to agric extension	58.1	41.9	38.7
No access to agric extension	36.8	63.3	61.3
Access to agric credit	50.4	49.6	42.0
No access to agric credit	41.0	59.0	58.0
Off-farm agricultural income	43.6	53.0	57.6
No off-farm income (%)	47.0	56.4	42.4

Source: Mugonola *et al.,* (2013a).

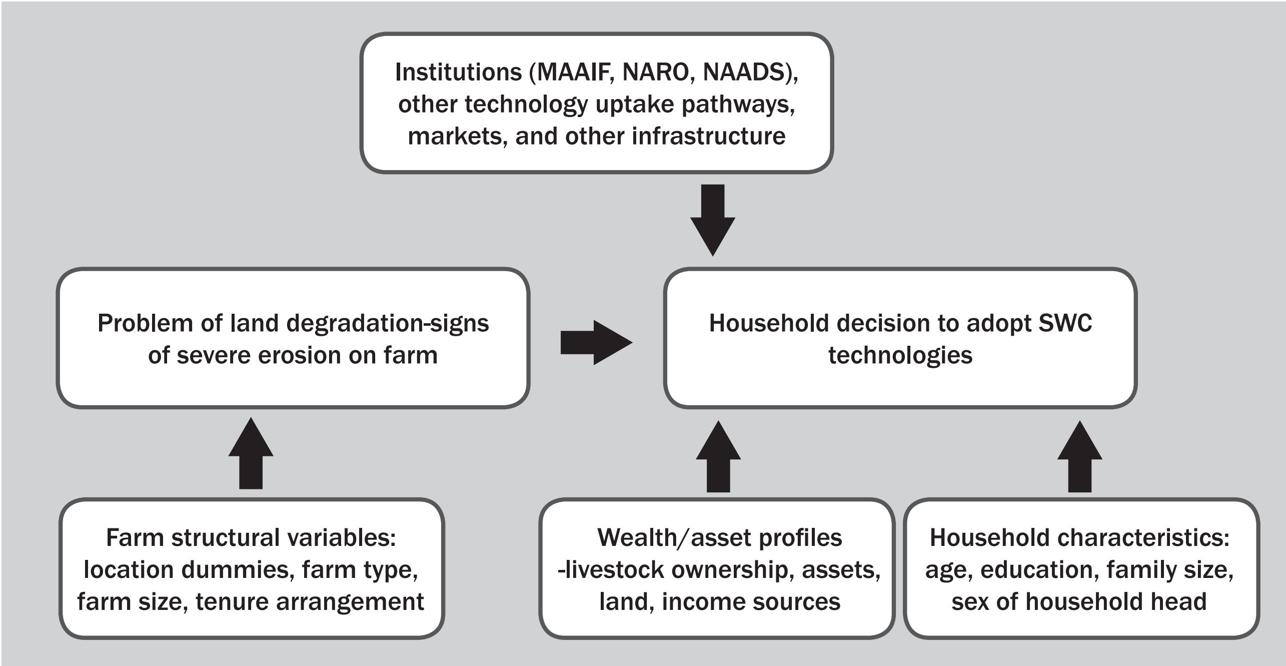


***Fig. 1**. Conceptual framework of land degradation and smallholder decisions in the Rwizi micro- catchment (Mugonola* et al., *2013a).*

adoption may be explained by the differences in socioeconomic characteristics, asset endowments, farm structural characteristics, perception of land degradation problem, and access to institutional support (Mugonola *et al.,* 2013a).

Results

As indicated in Table 1 and Figure 2, most of the adopting smallholder households were male-headed, had access to extension message, belonged to a farmers' group, had agriculture as main source of income and had access to credit facilities. As a result of the adoption of SWC technologies, a number of observations have been made as a result of this initiative: increased banana yields, reduced soil erosion and deposition of sediments into the Rwizi river system, finding a market for grass as mulching materials, integration of livestock and banana production in the form of using the manure to replenish soil fertility and using banana residues to feed livestock, among others. The results further indicate that only 45% of the farmers have adopted SWC technologies in the upper Rwizi microcatchment. In addition, these adopters were shown to be more technically efficient than their nonadopting counterparts. Average technical efficiency values of about 70% were reported for the adopting farmers (Mugonola *et al.,* 2013b). This implies that adopters obtained higher output (banana) per unit of inputs used. However, the fact that technical efficiency was only 70% implies more room for improvement only in the upper Rwizi microcatchment.

Sedimentation of River Rwizi

Soil erosion of bare land leads to generation and transportation of sediments. In the upper Rwizi catchment, average suspended sediment yield (SSY) in a year is 465 tons/km^2 the range is from 40 to 1,152 tons/km^2 per year in the sub-catchments (Wanyama, 2012). The amount of SSY is influenced by the type and extent of land-use/vegetation cover change. (Land-use/cover change in the upper Rwizi catchment refers to conversion of grassland to cropland with no SWC measures on the hill slopes and the elimination of the natural sediment filter system of papyrus swamps, which impacts on the land degradation and catchment sediment dynamics). Cropland (bananas) on the steep slopes is very sensitive to gully incision when there is runoff producing land-uses upslope of it (e.g., degraded grasslands) (Wanyama, 2012). Gully channels in the catchment increase sediment transportation and are responsible for the delivery of runoff and new coarse sand and rock fragments to rivers. As an adaptation

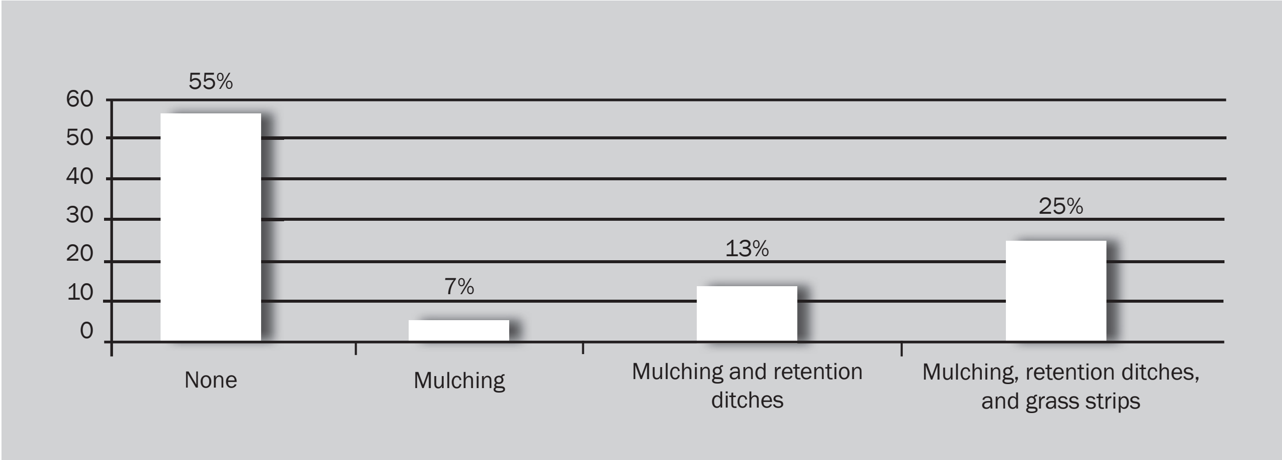


Fig. 2. *Adopters and nonadopters of SWC technology in the upper Rwizi micro-catchment (N = 271) (Mugonola* et al., *2013c).*

to the new conditions created by the flash floods and sediment deposits, the river channels are eroded and widen in cross-section.

Key challenges

The challenges with project-supported work include the following:

- Interventions normally end with the end of the project and therefore no resources are left to scientists for follow-up activities.
- The farmers have also learned to position themselves to seem to be doing something right to entice the project teams and hence tap some resources but not to build their capacity to carry on with the interventions.
- The local populations in these communities were hostile to the research team due to the fact that, at the time of the study, there had been clashes with the National Environmental Management Authority (NEMA) officials over encroachment on the wetlands.
- Measurement of sediment transportation and deposition in the river, especially following the rainfall episodes, was challenging as the volume of the water was high.

Conclusions

This research concluded that for sustained adoption of SWC technologies to take place, there is need for institutional support. For instance, the extension system needs to be supportive of the technology dissemination and awareness creation programs. The extension system in Uganda involves both the public system and nongovernment organizations. Institutional support in terms of markets, farmer groups, infrastructure, and financial institutions, among others is very important in fostering technology adoption. In addition, land ownership came out as a strong factor suggesting a land-area threshold for farmers to adopt these SWC technologies. This represents the importance of asset ownership in technology adoption. Equally important was gender consideration. Male-headed households were more likely to adopt SWC technologies probably due to the drudgery of some practices, security of tenure, and access to financial assets.

This study revealed that the extent of adoption of SWC technologies is limited to only 45% of the farmers, yet, the River Rwizi micro-catchment is the lifeline of a significant proportion of the population in the five districts of southwestern Uganda. Urgent attention is therefore needed to reverse the level of degradation by enforcing adoption of SWC technologies and other WaSA principles. It is further recommended that catchment management initiatives be geared toward “wise use” of land resources to promote WaSA. This will reconcile the need to meet the increasing demand for food resulting from rapid population growth and the general concern over widespread degradation of the resource base and sedimentation of water resources.

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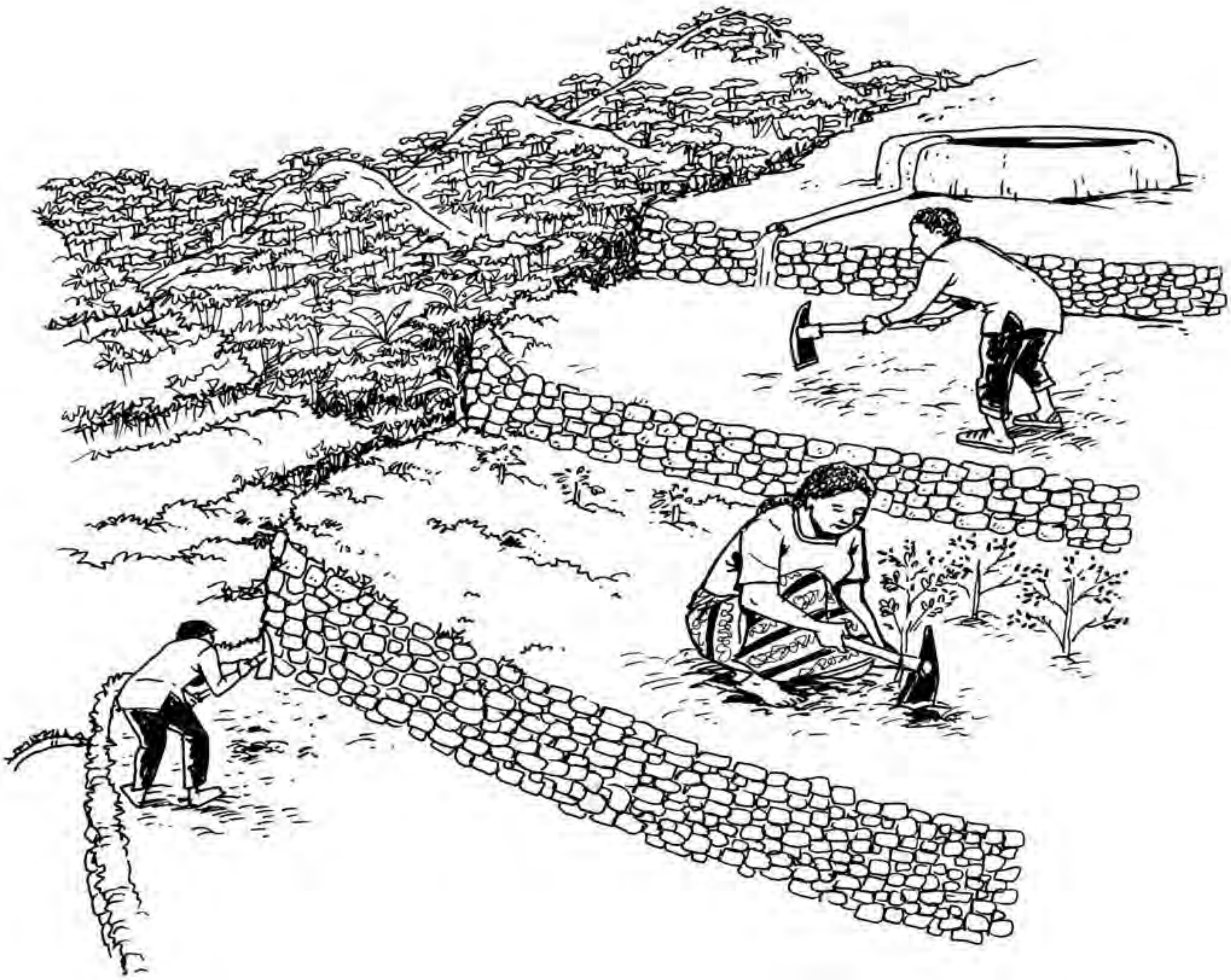
Bench Terrace Construction: Ensuring Sustainable Land Management and Creating a Source of Income for the Youth



In 2009, the Ethiopian government initiated a 5-year Sustainable Land Management (SLM) Program to rehabilitate degraded land and improve land management. Part of the program involved the introduction of improved bench terracing practices. Bench terracing is one of the oldest means of saving soil and water on the steep slopes in Ethiopia, dating back 400 years in the Southern Nations, Nationalities, and Peoples' Region in Konso special woreda in Ethiopia (Besha, 2003). A bench terrace is defined as level or nearly level steps constructed or formed on a contour and separated by an embankment known as a riser. They are typically constructed on steep sloping farmland (average of 12-58% slope) in order to reduce soil erosion and increase water infiltration.

Members of the Ministry of Agriculture (MoA) traveled to China to receive training on improved bench terracing methods. They then returned to Ethiopia and trained a set of experts to teach woredas in the six regions of Ethiopia, with a particular focus on southern Tigray.

Southern Tigray is mountainous with many pockets of degraded land, providing an ideal setting for the implementation of bench terracing. In 2012, the MoA supported a pilot intervention in one watershed in the Endamehoni woreda in southern Tigray.

The intervention was so successful in the pilot area that 16 of the 18 kebeles in the Endamehoni woreda, in addition to the surrounding communities outside of the woreda, have adopted bench terracing. This study documents the woreda's successful practices in order to scale up implementation in other appropriate landscapes and communities in Ethiopia.

The Kebele Pilot

About 8 km of bench terraces were constructed and on 4.5 ha of land. This created about 2.7 ha of new land distributed among 26 landless young beneficiaries established as a user group. The group created a plan indicating short-term, medium-term, and long-term perennial crop activities on the restored land. This group managed to cultivate vegetables, mainly garlic, integrated with apple and 'gesho' plantations.

Background

The Endamehoni woreda in southern Tigray has a population of slightly more than 100,000. The woreda is located 120 km south of the regional capital Mekele and 660 km north of Addis Ababa. It is composed of forestland, agricultural areas, grassland, settled areas, and enclosures.

Originally, bench terraces were built in the region on a limited area with poor design standards and high construction and maintenance costs, resulting in limited use and benefits. However, through improved practices gained from MoA staff's visit to China, it was recognized that bench terraces have the potential to provide significant benefits. In 2011, staff from the Endamehoni woreda visited the bench terrace sites in the Ofla woreda and they were convinced to adopt bench terraces in a pilot site (Endamehoni Woreda Agricultural Office, 2013).

The pilot bench terracing intervention was supported by the MoA in one of the watersheds of the Endamehoni woreda. The intervention started in December 2012 with the Embhasty kebele as the first demonstration site. An expert was appointed to survey the selected site and determine the method of construction. Bench terraces can be constructed from the bottom of the slope to the top of the mountain (bottom-up) or it can be the other way around, from the top of the slope to the bottom of the mountain (top-down). While the farmer approach is more common, the expert chose the bottom-up approach. It would be more appropriate in this watershed, as the farmer approach produced berms or small landslides in each terrace. The latter approach necessitated that it be finished before the rainy season; otherwise, terracing will collapse.

Since work has to be completed during the dry season, a down period for farmers, government officials and community members enabled them to contribute more freely. Experts also provided training and supervision. In the pilot site, farmers brought manure from their backyards to improve soil fertility.

The bench terraces were built mainly by the youth. The woreda agreed to adopt a bylaw that includes a provision that the youth will provide the labor required to build the bench terraces. In return, they will obtain the right to cultivate the land.

After this intervention proved successful, the other kebeles in the watershed began adopting bench terracing with support from the MoA.

The key components of the intervention included the following:

Training

One of the MoA experts trained a member from the woreda on bench terracing, along with the DAs from each kebele (there are 18 kebeles in the Endamehoni woreda). The youth in the watershed were then mobilized as manual labor.

Financial support

The MoA, under the SLM project, shouldered 80% of the cost in the form of capital requirements. The youth were paid in cash for 80% of the labor required to build the terraces; the remaining 20% was provided in kind.

Water storage structure

Along with the bench terrace construction, the MoA supported the construction of a water tank that captures water from an upstream spring. The water is stored in a tank and made available to farmers engaged in bench terracing to use for canal irrigation.

Farmers were trained by the MoA on irrigation scheduling in order to operate and maintain the water tank and implement irrigation practices.

Scaling up

The project was implemented in one watershed that included five to six kebeles. The youth from each of these kebeles helped in the construction of the bench terraces beginning in one micro-watershed and then scaling throughout the watershed. After this approach was adopted in the watershed, other kebeles in the Endamehoni woreda began adopting this practice with support of the of the MoA.

Successful implementation practices

To scale up this initiative among other woredas and regions of Ethiopia, the study team has detailed a number of conditions and practices that contributed to the success of this particular intervention.

Method

The study team held discussions with members of the woreda leadership and responsible technical staff from the woreda on how they can convince communities to implement bench terraces successfully and on how monitoring and evaluation can be done. The team held similar discussions with zonal level implementers. Field visits were conducted in five kebeles where bench terraces were being constructed along with an assessment of the activities under implementation at the micro-watershed level to gather information on implementation processes and approaches. At each kebele, the study team facilitated a group discussion with development agents, kebele leaders, and farmers.

Conditions for adoption

Severals important factors contributed to the acceptance of bench terracing at the woreda level:

- **Appropriateness of the technology.** Bench terraces are suitable for the mountainous areas. This is regarded one of the best technology choices for the mountainous woreda.
- **Demand for arable land.** Due to growing population pressure on existing farmland, community members are interested in rehabilitating degraded land to increase the amount of arable land available.
- **Employment opportunities for the youth.** Currently there are around 15,000 unemployed youth with little access to arable land in the woreda. As a result, many young people migrate to find jobs. The woreda has considered developing and redistributing rehabilitated mountain land to unemployed youth. So far, 12,000 young people (often landless) have been given rehabilitated degraded land. Bench terracing can be undertaken by the youth as a tool to rehabilitate the land for economic benefit.
- **Technical and financial support.** Technical support from the GIZ-SLM project experts and financial support from the World Bank were critical in the success of the pilot project.
- **Feedback.** Encouraging feedback was given by high MoA officials who visited the woreda's pilot site and encouraged the communities to continue bench terracing over the woreda.

Lessons from the pilot case

- **Critical support from woreda leadership and experts.** Both the woreda leadership and technical experts were highly committed to implement sustainable natural resource management activities, especially bench terracing, which greatly contributed to positive adoption rates and implementation.
- **Labor availability.** The woreda previously assumed that bench terrace construction would require a large amounts of labor and therefore chose not to implement terracing. However, through the pilot study, the woreda realized that there is enough available labor either through community contributions or paid labor, when funds are available.
- **Quick economic and environmental returns.** If designed and implemented properly, bench terracing can have immediate environmental and economic benefits.
- **Social acceptance.** The majority of communities within the woreda developed positive attitudes toward bench terracing and became interested in adopting this practice.

- **Return on investment.** Through a cost-benefit analysis, the study found that, after 3 years, investment will be recovered, but only if perennial crops are grown, such as fruits. In this case, bench terraces began producing financial gains during the second year, after establishing apple and gesho.

Challenges

- Initially, farmers were reluctant to adopt bench terracing because they were currently using this land for free grazing. Since land is communal, the community initially preferred to keep the land for grazing. However, after understanding the benefits, the community agreed to support the terraces for the youth to grow perennial crops. They may also grow fodder and forage on the terraces to provide feed for the animals that no longer have this grazing land.
- A water tank structure must be built with the bench terraces in order to secure a water source for crop cultivation. While many additional kebeles and communities have adopted the bench terracing practice, they have not been able to secure sufficient funds to build water tanks. This is a challenge that must be addressed to maximize the benefits of bench terrace farming.
- The youth would like to receive compensation for the manual labor they provide to build the bench terraces, as the government has mandated that the youth in the woreda will give 40 days of free labor each to implement this technology. The woredas should reconsider the work norm or wage rate of the young workers.
- Building the bench terraces requires a significant amount of manual labor, which the youth are able to undertake. But they would like to receive monetary compensation for it.
- Fertility management requires farmers to bring manure to the terraces. The supply of manure should be secured.
- It is recommended that the terrace is constructed from the bottom-up. However, the construction must be completed before the rainy season starts.

Conclusion and recommendations

Based on the successful implementation and adoption of bench terracing in the Endamehoni woreda in southern Tigray, the MoA recommends that this practice be scaled up throughout the region and in other similar landscapes in Ethiopia. Bench terracing may continue to be promoted by; the government in phase II of the SLM Project that started in 2014.

It is advised that communities that implement bench terracing follow the best practices implemented in the Endamehoni woreda. Communities should ensure the following: sufficient support from woreda leaders and experts, a willing labor force, appropriate land and soil on which to construct the bench terraces, agreement over the transformation of communal land into bench-terraced agricultural land, and sufficient funds to support the installation of the bench terraces and water-harvesting structures.

But there is little scientific research in Ethiopia to support bench terrace interventions, it is recommended that additional research be undertaken.

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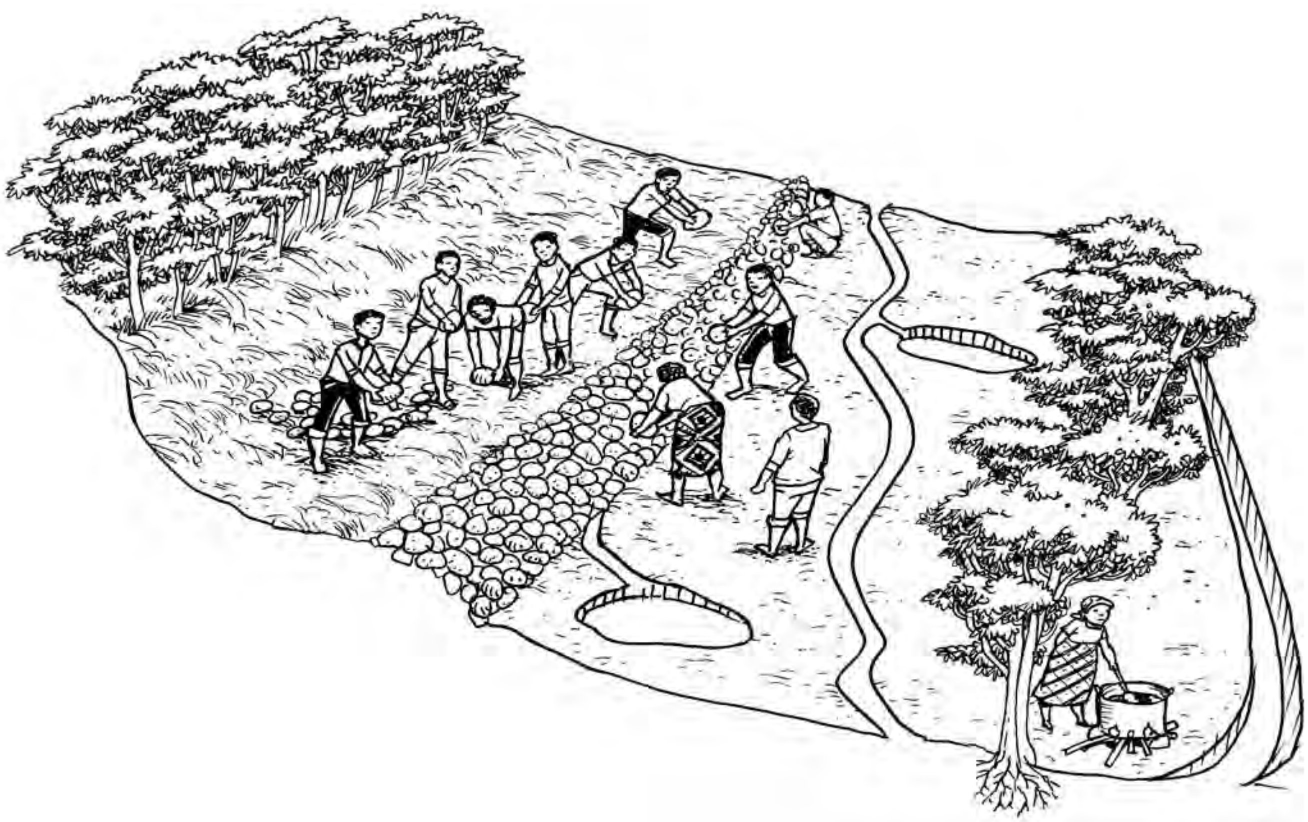
Integrated Soil and Water Conservation through the Use of Stone Bunds, Percolation Pits, and Trenches in Rwambu Wetland Catchment Area



Rwambu wetland borders the Kamwenge and Ibanda districts in the Rwenzori Subregion, western Uganda. It lies between latitudes 0°01'0" N and 0°02'0" N and longitudes 30°24'0" E and 30°25'30" E. Covering a population of 2,714 (Kamwenge District- Portal, 2014), Rwambu wetland is drained by Rwambu River, which meanders through Nyabbani Subcountry in Kamwenge District, and Ishongororo Subcounty in Ibanda District.

The Rwambu wetland forms part of the feeders for the Mpanga River, a permanent river system that drains into Lake George. From a conservation viewpoint, the Mpanga ecosystem is home to the threatened and endemic cycad trees (*Encephalartos whitelokii*) (UWA, 2003). This puts the Rwambu wetland at the center of conservation focus in the entire Mpanga River catchment area. The wetland and its neighborhood support local livelihood by providing land for agriculture, fish, water, and raw materials for crafts, among others. It also provides other ecosystem services such as flood control and micro-climate modification. The main economic activity in the area is agriculture where the major food crops include maize, beans, and potato and cash crops include banana and coffee. A small percentage of the population is engaged in pastoralism.

The problem

Rwambu wetland is surrounded by steep sloping hills with V-shaped valleys. According to the Kamwenge District Development Plan (2004), more than 90% of the population in Rwambu is engaged in subsistence rainfed agriculture as their main source of livelihood. With the increasing population, decreasing land for agriculture, soil erosion reducing soil fertility, and climate variability, farmers around Rwambu wetland continue to register increasing incidents of crop failure that threaten their food security. More so, the eroded soils from the hill slopes finally settle in the wetland, thereby causing water contamination and silting of wetland water reservoirs (NEMA 2012). The situation in Rwambu requires adoption of strategies and measures that can address the above challenges, in an integrated approach, in order to improve the hydrological status of the catchment through intercepting and trapping of runoff water, while allowing it to slowly percolate through the soil and reduce erosion. Consequently, this would in turn improve soil moisture content and sustain agricultural production for household food security and income needs.

Getting started

Stakeholder mapping

Project design and implementation took a participatory approach to ensure full involvement of the primary project targets. Stakeholder mapping was the initial project activity that brought on board different stakeholders critical to project success. Key stakeholders that were identified at this stage were the district water officers, district natural resource officers, district agricultural officers, subcounty authorities, Rwambu catchment management organizations, the community, technical support units, and the private sector. These stakeholders were specifically selected so their experiences, technical skills, and support can be tapped in drawing the project implementation plan. It is at this stage that the project objectives, rationale, and expected outcomes were identified and agreed on.

The role of Joint Effort to Save the Environment (JESE) was to enable stakeholders to identify strategies and measures to adopt and use in their land to address the challenges of erosion, declining soil fertility, and reduced agricultural production and to achieve overall conservation of Rwambu catchments. Discussions on the control measures focused mainly on physical soil and water conservation (SWC) technologies. Selection and prioritization of the technologies were based on criteria such as slope gradient, ease of construction, cost implication, availability of materials for construction or their substitutes, complementarity, and perceived effectiveness. The final selection of the technologies was done through show of hands by the farmers; those with more support were selected. From this process, three technologies were selected: stone bunds, percolation pits, and trenches. These were further integrated with agroforestry along the hill slopes to enhance soil structure stability and modify the micro climate.

The rationale for the integration was that, if the three technologies were applied in an integrated manner, they would complement one another and ensure effective trapping of runoff that would eventually percolate slowly into the soil. The reduction in erosive power of the runoff would also improve soil moisture content and increase agricultural production in the long run.

Establishing the Implementation Committee

A committee comprising seven people was selected with two representatives from the community, one representative from the district technical personnel, an engineer and a social worker from JESE, and two representatives from the Rwambu catchment management organizations.

The responsibilities of the committee included offering technical support and making key decisions on project implementation and management. Specifically, it was required to mobilize the community, to develop the criteria for tracking and evaluating progress, and to make reports. This committee further took center stage in reviewing final construction designs and work timeframes, selecting host farmers, and handling materials and logistics.

Implementation

This phase started with a survey and confirmation of actual sites of interest and host farmers. The survey further showed the slope gradients, valley shapes, soil types, and assessment of soil vulnerability to erosion.

Further discussions with farmers focused on land ownership. This process was followed by the drafting of a memorandum of understanding (MOU) between the Implementation Committee and the host farmers. The MOU clarifies that the technologies to be implemented on their land would benefit the entire community and affirms that the participating community would have free access to these technologies for learning, progress monitoring, and reporting purposes.

Technology design and construction

A total of 265 community members (142 females and 123 males) were directly involved in the actual construction of the soil structures and integrating them with agroforestry activities.

Design and layout

Stone bunds and trenches were designed in uniform dimensions of 30 x 3 x 4 ft along the identified hill slopes with the capacity to retain about 10,200 liters of runoff water. The width and depth were customized based on the slope gradient, type of crop in the garden, and available labor for excavation of trenches and placing of stones along the slope. The percolation pits, on the other hand, were designed in the dimensions of 10 x 10 x 7 ft with the capacity to intercept about 19,800 liters of runoff water and allow it to percolate into the soil.

The three technologies (practices) were placed across the slope, one after another, depending on the intensity of perceived erosion. For instance, the upper hill slopes with high perceived water velocity had all the three technologies with stone bunds appearing at the top, followed by percolation pits and trenches at 15-m intervals, while the medium and lower slopes had two practices being integrated at 20-m intervals. The integration was further determined by the availability of construction materials and labor.

Importantly, trenches and percolation pits were preferred because they were easy to excavate compared with stone bunds that required lots of stones for alignment along the slope. Later, the stone bunds were planted with local grass to strengthen them against erosion. However, outside this study, the three technologies can be randomly placed across a slope as an alternative integration, with or without any further integration besides using each singly.

Most materials, equipment, and labor for the construction and planting of Grevillea trees were locally mobilized, which was a milestone for the project. On average, each participant contributed 3 man-hours a day. The community further provided food and water during the project working days.

This was important as the implementation team was not constrained by logistical issues and they just concentrated on giving technical support in terms of planning, review, and overall implementation.

Grevillea trees spaced in lines at intervals of 17 ft were planted at the middle and lower parts of the hill slopes. This species was selected by the community because of its fast growth rate, strong rooting system, high biomass accumulation, and multiple uses for wood fuel, timber, and poles. To quicken this process, JESE procured seeds of Grevillea, potting materials, wheel barrows, spades, and watering cans, which were given to the farmers who established three community nursery beds. These nursery beds were maintained by the farmers themselves, contributing labor, meals, and other logistics, while JESE offered technical support on nursery bed management and other technical backstopping. The community took it upon themselves to supervise seedling distribution and actual planting.

Monitoring and progress tracking

Participatory monitoring and review meetings were organized at community, subcounty, and district levels to track progress and ensure accurate reporting of successes, challenges, opportunities, and insights emanating from the project.

Table 1. *Cost involved in constructing the different structures.*

Technology	Average cost (UGX)	Dimension	Remarks
Stone bunds	22,442 per meter	3.3x3x4 feet	Cost of stones and labor
Trenches	5,050 per meter	3.3x3x4 feet	Excavation cost
Percolation pits	89,100 per pit	10x10x7 feet	Excavation cost

The Implementation Committee played a key role in the technical assessment of the progress by offering advice with regard to performance of established technologies. It is important to note the pivotal role played by the host and participating farmers in assessing progress and suggesting means for improvement, especially in overcoming the labor intensiveness involved in the establishment of the three technologies.

Key results

A total of 4,000 m of linear length of stone bunds were constructed. The stone bunds matured and stabilized land uphill for agricultural productivity. This has resulted in reduced soil erosion, thus minimum loss of fertile soil downhill and less water runoff, an indication of increased water infiltration. Also, 3,000 m of "Fanya chini" trenches were constructed. The trenches intercept surface water runoff, thus allowing it to seep through the soil and retain the eroded soil. This contributed to ground and surface water recharge, slowed runoff velocity, and increased agricultural production. Percolation pits collected water runoff and allowed it to infiltrate slowly into the ground. These further intercept water and make it available for agricultural re-use.

Approximately 60,000 Grevillea tree seedlings from the community nursery were planted. The trees have matured and stabilized the soil on the hill slopes, improved the aesthetics, and enhanced the micro-climate in the area. Other observed results include reduced siltation of the wetland and contamination of water points and reduced pressure and encroachment on wetland and downhill resources.

Key challenges and limitations

The major challenge faced was the slow decision of all stakeholders to get involved in project activities, which affected the implementation time frame.

Several limitations were encountered:

- The practices were labor-intensive, which made it hard to complete assignments on time. This also affected the adoption of technologies at the household level. Looking at all three technologies, a great deal of energy is required to construct them. If labor is to be hired, it would be too costly for a poor household to do. Adoption therefore is limited.
- It was difficult to assess the short-term hydrological outcomes.

Addressing limitations

- The community was encouraged to engage in collective action through pooling of labor. They agreed on work dates, although sometimes adherence to this was low. However, those who regularly reported for work were committed and did a commendable job.
- Qualitative hydrological indicators to ascertain effectiveness of the structures were used.

Lessons

- An integrated approach to SWC requires effective stakeholder involvement to ensure success and sustainability of the results. Strategies to achieve this should be carefully planned before the project is begun.
- The community takes a long time to adopt new technologies. However, when comprehensively sensitized and their capacities built, their adoption rates can increase.

Conclusion

The three technologies, when well-planned and integrated with agroforestry practices, can effectively retain water on hilly landscapes. This has been observed in the Rwambu catchments where runoff water was retained. This has reduced soil erosion, improved soil moisture conditions, stabilized soil physical conditions, and minimized the siltation of wetland water resources. It has contributed to improved agricultural productivity and water resource management as well.

Strategies for scaling

- The technologies must be shared in different fora for awareness creation, replication, and modeling.
- More community members must be mobilized to ensure adoption of the technologies on their farms.

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Water-Smart Agriculture through Integrated Soil and Water Management: The Uganda Experience

Agriculture is a major source of livelihood for more than 80% of Uganda's population (Mundi, 2014). However, water shortage and soil degradation constraints, among other things, are increasingly hampering smallholder farmers' activities, thereby threatening agricultural sustainability. This is evidenced through rainfall uncertainty, increasing frequency of droughts, extreme weather events, changing growing seasons and soil exhaustion (Ssali, 2002). These challenges result in frequent crop failures, leaving many farmers vulnerable.

With most agriculture in Uganda being rainfed, there is increased risk of crop failure due to extreme weather events (Mubiru *et al.,* 2012). Water-smart agriculture (WaSA) addresses this risk and builds farmers'' resilience by combining rainfed farming with sustainable, small-scale soil and water management (http://wle.cgiar.org/blog/2014/07/30/water-smart-agriculture-initiative-east-africa).

This review presents examples of WaSA practices that have worked in Uganda through integrated soil and water management.

Integrated soil and water management and water-smart agriculture

Integrated soil and water management (ISWM) is the use of soil and water management practices that enable users to maximize economic and social benefits from soil and water resources, while maintaining or enhancing their ecological support functions (FAO, 2009).

ISWM ensures that productivity and ecological integrity of soil resources are maintained over time. It is key for improving land resource productivity and resilience and is critical in coping with devastating effects of climate change and environmental degradation.

Soil organic matter, especially the more stable humus, increases the soil's capacity to store water (Bot and Benites, 2005). Practices that increase soil organic carbon content will contribute to WaSA. These practices keep the soils productive, have a rich biodiversity, require less chemical inputs, and sustain vital ecosystem functions.

Soil productivity and water-smart agriculture

Soil productivity depends on the soil's physical, chemical, and biological properties. Soil properties most important for WaSA include texture, structure, organic matter content, nutrient content, soil organisms, pH, and cation exchange capacity.

These properties influence the soil's ability to retain water and nutrients. Degraded soils are vulnerable to moisture stress due to serious loss of soil organic matter, nutrients, biodiversity, unfavorable soil physical properties (e.g., compaction), and high soil erosion rates.

Steps in managing soils for water-smart agriculture

Assess soil status

Knowing the soil status and condition helps in decisionmaking regarding suitable management practices for WaSA. The process involves field soil assessment and survey supplemented by laboratory testing to determine critical soil properties (texture, structure, water-holding capacity) crucial to their sustainable management. Sandy soils retain less moisture and nutrients, and therefore, can be managed by providing water, organic matter, and fertilizers.

Local field indicators can also be used to assess the nature of soils. Studies in Masaka District show that farmers use indicator plants/weeds to identify good soils from poor ones. Weeds such as Katabuteme, Sekoteka, Kafumbe, and Lusenke indicate fertile soils, while black jack, couch grass, Kakuuku, Eteete, and Muwugulaomunene grow on poor soils. Similarly, crops such as banana do well on good soils, while mango can grow on poor soils (Tenywa *et al.,* 2014).

Control soil erosion

Soil erosion is a serious land degradation process, particularly for cultivated land on moderate to steep slopes and areas with sparse ground vegetative cover. Runoff and soil erosion can be reduced using mechanical, biological, or a combination of methods (Magunda and Tenywa, 2001).

Mechanical means comprise soil and water conservation structures (terraces, contour bunds, stone bunds, etc.). Terraces are made by digging a trench 60 cm wide along the contour and throwing the soil upslope (or downslope) to form an embankment. This, in turn, reduces slope length, and hence soil erosion from steep cropland (Thomas and Biamah, 1991). The soil bund retains water and thereby safeguards crop yield even during drought. The bunds may be reinforced by planting grass or agro-forestry trees on them, to make them more stable.

Contour bunds are constructed by excavating a channel and creating a small ridge on the downhill side (Mati, 2005). They drain excess runoff from steep cultivated lands. They may be reinforced using grass or agro-forestry trees to make them more stable. In Rakai District, runoff, and soil and nutrient loss decreased significantly following construction of contour bunds on banana, coffee, annual crop, and rangeland fields (Majaliwa *et al.,* 2004). Construction of contour bunds on rangeland resulted in higher biomass, ground cover, and species diversity (Table 1).

Improve soil water storage

Soil water storage depends on rainfall amount and distribution, soil depth, texture, and structure.

Practices such as runoff water harvesting (Mugerwa, 2007), mulching, minimum tillage, and deep tillage in compacted soils increase water infiltration, reduce evaporation, and store water in soil. Practices that improve soil organic matter, structure, porosity, and aeration and reduce bulk density can reduce soil erosion and increase water infiltration, water storage, and availability to plants.

Table 1. *Effect of contour bunds on production of a degraded rangeland (2 years after).*

Property	No contour bunds	With contour bunds
Soil physical and chemical properties		Improved
Rangeland biomass (t/ha)	7.1	27.2
Ground cover (%)	51.0	86.1
Plant species diversity (Shannon index)	3.93	4.46

Stone lines are structures where stones are arranged in lines across the slope to form a strong wall. The stones slow down the speed of runoff water, filter it, and spread the water across the field, allowing it to infiltrate into the soil and reduce soil erosion (Critchley and Siegert, 1991). Stone lines are commonly spaced about 15-30 m apart, with narrower spacing on steep slopes. They may be reinforced with soil or crop residues to make them more stable (Duveskog, 2001).

Biological methods such as conservation agriculture (CA) (minimum or no tillage), grass strips, strip cropping, crop rotation, agro-forestry, woodlots, use of green manure, crop residues, shrubs (e.g., tithonia), trash lines, and planting vegetation across slopes can improve water infiltration into soil. Conservation agriculture is a tillage system based on (i) minimum soil disturbance (reduced soil tillage), (ii) maintenance of soil cover most of the year, and (iii) crop rotation. This system improves soil cover and reduces soil and water loss. Studies in Uganda show that CA, using permanent planting basins, increased maize grain yield by 30% (Mubiru, 2014).

Grass strips are patches of dense grass planted in strips of about 0.5 to 1.0 m wide, along the contour. The strips create barriers that minimize soil erosion and runoff, through filtering. Silt builds up in front of the strip, and with time, benches are formed. On gentle slopes, the strips are more widely spaced (20-30 m), while on steep land, spacing is 10 to 15 m.

For sandy soils in hot areas where permeability, evaporation, and organic matter decomposition rates are high, practices that reduce soil disturbance (e.g., mulching, minimum tillage) should be promoted to conserve soil moisture. Soil conditioners (e.g., calcium bentonite, a type of clay) also improve moisture content, resulting in higher crop yields (Semalulu *et al.,* 2014).

Improve soil structure with organic matter

Soil compaction reduces water infiltration and lowers moisture content. In large mechanized farms, continuous use of heavy equipment leads to soil compaction; in grazed areas, overgrazing leads to soil compaction; in smallholder farms, continuous cultivation may compact soil. Practices such as minimum tillage, mulching, use of manure, compost plus alternate growing of shallow-rooted with deep-rooted crops (e.g., pigeon pea) can improve soil organic matter while reducing soil compaction. This in turn improves water infiltration and available soil moisture.

Boost nutrient management

Combined application of organic with inorganic fertilizers improves soil plant nutrient content, and physical and biological properties. In addition, less inorganic fertilizers are applied and, as a result, the risk of nutrient losses to the environment is reduced.

Combined application of organic with inorganic fertilizer increased maize grain yield by nearly 100% and improved fertilizer use efficiency compared to where either of the fertilizers were applied singly (Kaizzi *et al.,* 2002). Similar results were reported with P and farmyard manure on groundnut (Semalulu *et al.* 2014).

No tillage using cover crops can recover the would-be lost N. Cover crops take up N and reduce its loss from the soil. On killing the cover crop, N is recovered and made available to subsequent crops, increasing yield. However, where no-till is used without cover crops but with herbicides used to kill weeds, effects on N uptake and reduced leaching and on yields are less observed.

Recycling plant and animal residues (cow dung, poultry litter, compost manure) and biological nitrogen fixation using legumes can improve nutrient availability. Traditional practices (e.g., natural or improved fallows using legumes, relay cropping) can also improve nutrient availability.

Increase water use efficiency and irrigation

With growing scarcity for agricultural water, there is need to use water more efficiently. Practices that reduce evaporation and improve organic matter management (*e.g.,* mulching, minimum tillage, manure and crop residue recycling, use of cover crops) can enhance infiltration and moisture retention, thereby improve water use efficiency. Choosing crops/varieties that match the agro-ecology (Mubiru, 2010) can also increase water use efficiency. Crops such as sorghum and millet require less water to grow than does maize.

Using proper agronomic practices (cultivating along contour lines, early planting, optimum plant population, intercropping, early weeding) contributes to WaSA. Crop-livestock integration, zero grazing, and optimum stocking rates can also improve water use efficiency.

Water scarcity in smallholder farming can also be addressed through irrigation. In Uganda, the total area under formal irrigation is 14,418 ha out of an estimated 560,000 ha with irrigation potential (Republic of Uganda, 2011). In addition, an estimated 53,000 ha is under informal irrigation for rice in Tororo, Buteleja, Pallisa, Budaka, and Iganga. Irrigation development will enable farmers to improve their farming practices, mitigate against decreased or intensified precipitation, and reduce the yield gap in traditional producing areas, and thereby address emerging regional market opportunities (Republic of Uganda, 2011).

Respond to water stress

To cope with increasing water shortage in agriculture in the face of rainfall variability, it is important to increase the farming system's buffer capacity by increasing the amount of water stored. Options include roof and runoff water harvesting for domestic and crop/livestock use, enhancing soil water infiltration and storage, on-farm water retention, utilization of groundwater, and supplementary irrigation during critical periods (FAO, 2013).

Cost and benefit of integrated soil and water management

Some ISWM technologies are costly while others are labor-intensive, and their suitability also varies for different areas. Adoption of a particular practice in a given area must therefore be economically justified. On gently sloping land, farmers should use less expensive/less labor-intensive options such as grass strips or trash lines for soil erosion control. Use of locally available materials (crop residues, animal manures, and shrubs such as tithonia) and agro-forestry to improve soil fertility, plus runoff water harvesting could also be considered.

Investment in ISWM technologies should be done preferably on more profitable enterprises and farmers should be linked to markets. Increased access to markets in Uganda resulted in increased adoption and investment in soil management (Delve and Roothaert, 2004).

Facilitating activities that strengthen the entire value chain (e.g., support to water management committees, innovation platforms, value addition and agro-processing, strengthening farmer-market linkages) can serve as incentives to investment in ISWM.

Studies in Uganda show that investment in ISWM technologies is profitable. In Rakai, adoption of contour bunds and mulch improved profitability by more than 200% for banana, coffee, and beans. Farmer adopters were much better off than nonadopters (Kalyebara, 2005). According to Semalulu *et al.* (2014), use of 17 t ha^{-1} coffee husks mulch in pineapple production significantly improved fruit weight and resulted in a fivefold increase in gross margin.

Policy interventions

Many areas require these policy interventions:

(i) Enforcing the adoption of appropriate technologies for controlling soil erosion on various types of land—rangeland, crop land, both gentle and steep slopes.

(ii) More effective by-laws and incentives for enforcing use of improved soil management technologies.

(iii) Improved land tenure systems for management of communal lands, lands belonging to absentee landlords, and wetlands. More effective policies and by-laws to reduce land degradation.

(iv) Introduction of market-led incentives, e.g., market value chain approach to stimulate resource conservation.

(v) Guidelines and bylaws that empower communities to protect and manage their natural resources and the environment.

(vi) Scale up sustainable land use planning on all agricultural land countrywide.

Conclusion

Water scarcity is increasingly affecting Uganda's agriculture. A number of soil and water management technologies exist and have successfully been demonstrated in Uganda. In order to maintain agricultural sustainability, there is a need to scale up these technologies in different agroecological zones, through participatory catchmentwide approaches, supported by a conducive policy environment. For ease of uptake, however, these technologies must be profitable to the farmer.

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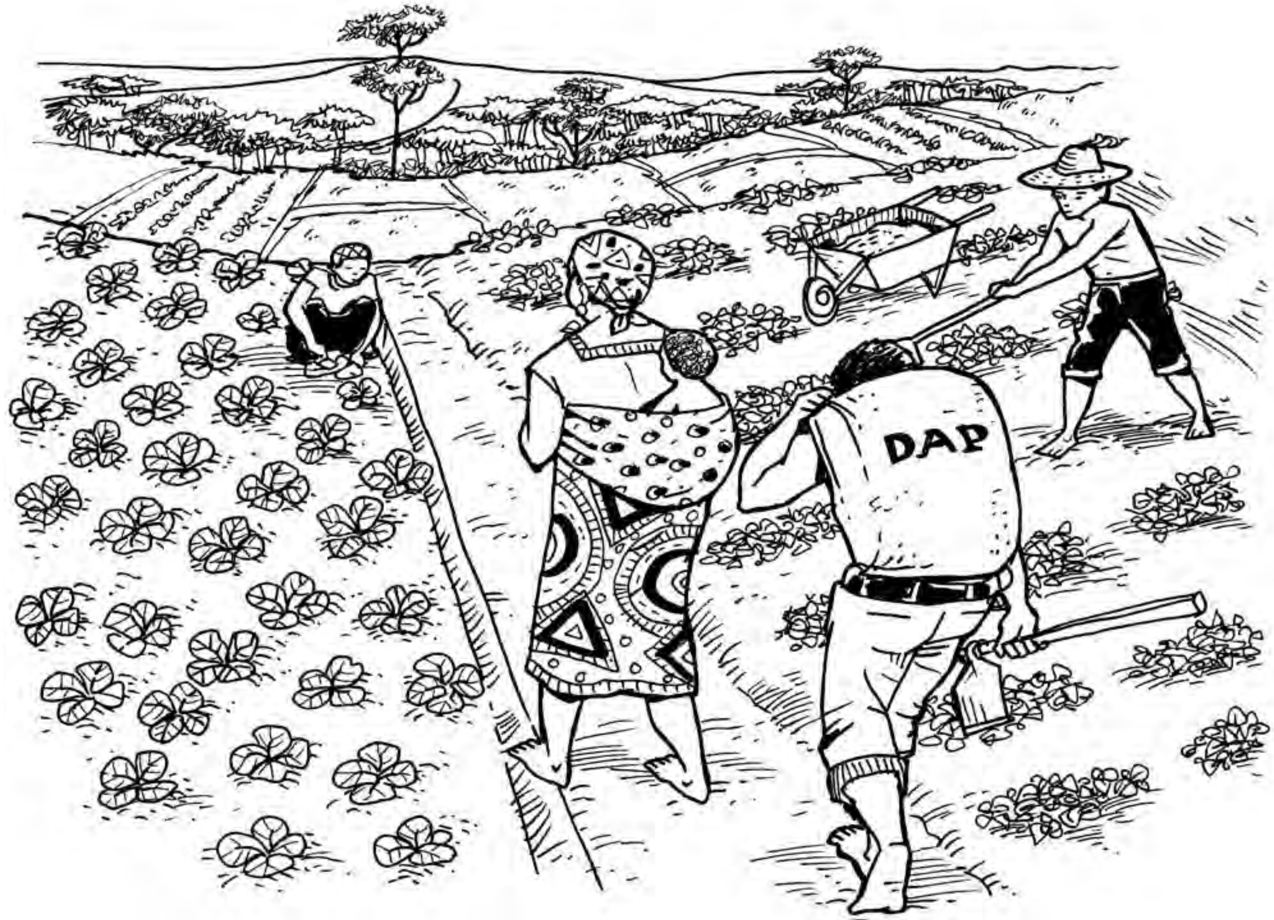
An Assessment of the Cost Effectiveness of Soil and Water Conservation Techniques in Otuke District, Uganda



An action research study was conducted by stakeholders in Otuke District under the Learning and Planning Alliance (LPA). The study aimed to increase awareness and equip farmers with knowledge and skills in using selected agricultural soil and water management practices and technologies. Otuke District is one of the districts in the Lango Subregion located in northern Uganda. Facilitated by the Global Water Initiative East Africa (GWI EA), the study identified the most cost-effective soil and water conservation (SWC) practices that can be adopted in Otuke and in similarly semiarid areas in Uganda. Working with champion farmers, demonstration plots were established to host soil and water management techniques and practices by focusing on rainwater harvesting using rooftop and runoff, construction of shallow wells for supplementary irrigation, mulching, minimum tillage (planting basins), raised planting ridges, and use of compost manure. These were complemented by growing high-value vegetable crops to demonstrate the benefits of adopting such practices by farmers.

The problem

Farmers in Uganda and in Otuke District rely on rainfed agriculture. The district receives an average annual rainfall of 1,197 mm with a unimodal distribution. Peak rainfall occurs in July/August and a secondary peak occurs in May. The period between December and February is the driest, with evaporation significantly exceeding rainfall by a factor of 10.

According to Oxfam (2008), rainfall (water supply) has become increasingly unreliable, and it is the biggest threat to food security that affects mostly small-scale farmers. Otuke farmers only realize 15–20% of potential crop yield, and the June-July dry season often results in significant crop failure (GWI EA, 2013). Extreme heat usually experienced in most semiarid areas leads to high evaporation rates. This reduces the moisture content in the soil profile available for use by the plant root systems as well as the quantity of water available for irrigation. Adversely, this increases incidences of crop failure, which, in turn, increases the vulnerability of farming households to effects of seasonal variability such as food insecurity and high risk of becoming poorer (Mubiru, 2010).

To the smallholder farmers, conventional irrigation is relatively expensive to operate and maintain and therefore uneconomical. Also, these farmers mainly grow food security crops such as cereals and tubers—these crops do not justify heavy investment in conventional irrigation. Thus, there is a need for alternative low-cost, easily adoptable agricultural water management technologies (AWM) in the semiarid regions. These enable farming households to diversify their income sources as a way of increasing household resilience to effects of changing weather patterns.

Given the above, the LPA, in collaboration with Welthungerhilfe, supported the champion farmers to promote soil and water management technologies. The results helped in identifying the most cost-effective practices that are instrumental in reducing farmer vulnerability caused by unreliable rainfall. These techniques and practices, when adopted, will improve farm productivity and result in greater food security.

Methodology

Study design and scope

An action research approach was used to execute the study. The approach is cyclic, participatory, and qualitative (Richard, 2009). More so, the study is intended to bring about action (improvement and development) as well as research knowledge and understanding as illustrated below.

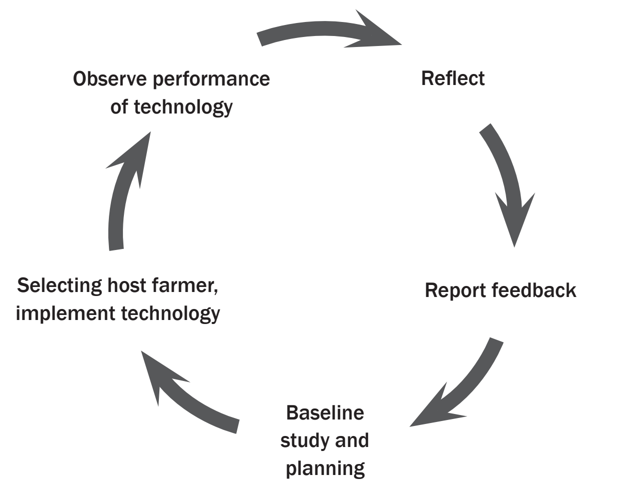


Fig. 1. The action research approach (Adapted from Atherton, (2009) with modifications).

This approach supports learning by doing: jointly identifying a problem, exploring and testing solutions, and disseminating lessons of both successes and failures of an improved learning. The study was performed collaboratively with the farmers, local authorities, researchers, and other key stakeholders to test various technologies and practices on soil and water conservation.

At the onset of the study, stakeholders jointly developed the criteria for selecting champion farmers to host demonstration sites. Among the critical criteria were ability to avail of at least 2 ha of land, capacity and the will to train others, commitment of support from the spouse, readiness to invest (time and input) in demonstration plots, and consideration of women farmers.

Based on the above, eight farmers were selected from each of subcounties Olilim, Ogur, and Orum. This brings the total to 24 champion farmers (F=15, M=9). These subcounties had previously benefited from GWI phase 1, and phase 2 was built on lessons from the earlier phase.

The 24 farmers were trained and supported to prioritize and select enterprises to implement with the technologies in line with the national agriculture advisory guidelines on enterprise selection. Farmers selected tomato and onion. These are high-value crops assessed to have a ready market within the northern region. In addition, they were supported to select a third crop: cabbage, banana, or pineapple.

Onions and tomatoes were planted on two plots. On the first plot, farmers strictly applied improved agronomic practices, including soil and water management techniques and practices. On the second plot, farmers used their traditional farming practices. In this case, mulching, planting on ridges, use of permanent planting basins (PPBs), and supplementary irrigation were not applied.

The plot sizes differed according the farmers' capacity (range was from 240 to 1,000 m^2). In order to standardize this information, data were extrapolated for 1 acre.

Soil and water conservation technologies were promoted under improved practices and were used in combination. Variously, a farmer would plant tomatoes on ridges, use compost and mulch, and supplement rainfall with water harvested from surface runoff, hand-dug well, or rooftops. Maize and bananas were planted in PPBs. These basins are sunken surfaces that trap water and allow precise application of manure and inorganic fertilizers in the basins for crop utilization. The other technologies included madala terrace and kitchen gardens, conservation farming, and action research implementation approach.

The action research team under the leadership of the district agricultural officer (DAO) was composed of district technical staff, researchers from Gulu University and NARO-Ngetta (ZARDI), and the civil society (Welthungerhilfe, IUCN, ACF, and CARE International). This team developed study concepts and data collection tools, provided guidance to the implementing team, monitored the performance of the demonstration plot, analyzed the data, and produced the research report.

The project implementation process was structured in four phases: (1) studying and planning (problem identification and solutions); (2) taking action (farmer selection, profiling and citing technologies, enterprise selection, input distribution, setting up technologies, and M&E; (3) reporting on preliminary findings; and (4) reflection on challenges and coming up with remedies.

Data collection and analysis

The methods used in this assessment included questionnaires, observations, yield measurements, and focus group discussions at the subcounty level. Data were collected on households, farming systems, yields, and input-output. The collected data were processed and analyzed using SPSS and MS Excel.

Results and discussion

The cost effectiveness of a combination of SWC technologies (improved practices) was measured by the level of crop yield achievements and returns. The average yield of tomatoes produced by all the champion farmers under the improved practice was 3,079 kg/acre, the highest was 8,040 kg/acre and the lowest was 670 kg/acre.

Under control plots (farmers' practice), average yield was 1,340 kg/acre. The highest harvest was 3,788 kg/acre and the lowest was 20 kg/acre. The huge gap in the data is explained by external factors such as hailstorms, bollworms, and shrimps whose response to pesticide treatment was very poor.

Olilim farmers obtained the highest yield per acre (3,160 kg), followed by Ogor (3,138 kg) and finally, Orum (1,771 kg). The poor performance in Orum is partly explained by the delayed onset of rainfall and the effect of the short June-July dry spell, which affected the flowering and fruiting of tomato (Fig. 2).

Average yield per acre of tomatoes under farmers' practice in Otuke varied in the three subcounties. Ogor had the highest average yield (2,764 kg), followed by Olilim (2,247 kg) and lastly, Orum had 662 kg.

It must be noted that the average farmers' yields are still lower than the potential yield of 20,000–40,000 kg/acre (East Africa Seed, 2012). This was mainly because farmers were trying out the technology and the crops for the first time. More so, it was a learning process. The research team adopted a flexible approach that allowed farmers to make mistakes so as to learn from them in the second cycle. In addition, the champions had limited capacity to access and use all the recommended inputs such as pesticides and inorganic fertilizers.

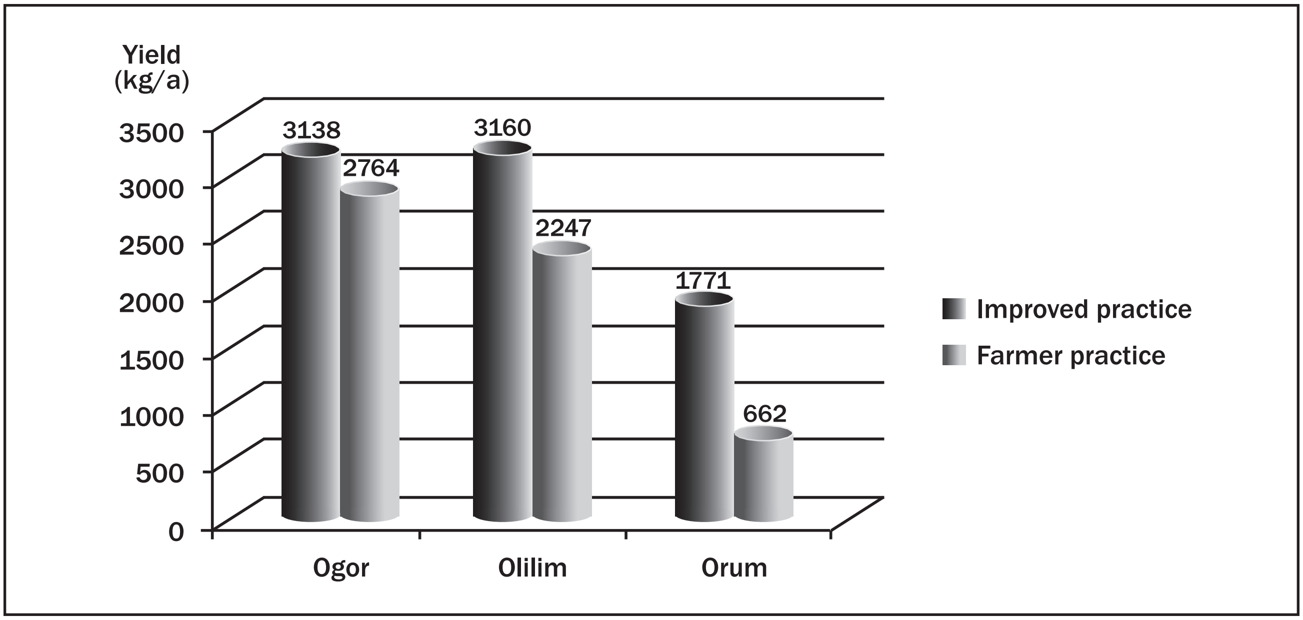


Fig. 2. Yield per acre of tomato under improved practice and farmer practice across the three subcounties.

Table 1. Establishment and maintenance cost (UGX) of each identified technology.

Technology	Labor requirement	Cost		
		Set up cost	Unit	Maintenance
Mulching	Collecting/buying the mulch Spreading the mulch	150,000	Acre	Replacing mulch that is displaced
Planting ridges	Digging of ridges	150,000	Acre	Only labor needed to heap back washed off soil
Minimum tillage (only planting hole dug)	Clearing of vegetation Spraying herbicide Digging permanent planting basins	174,000	Acre	-
Water runoff harvesting	Excavation of ponds Covering of ponds	2,690,000	35,000 liters	Cleaning of pond
Use of hand-dug shallow wells	Excavation of shallow wells	7,000,000	1 unit	Spare in case of a breakdown
Rooftop water harvesting	Procurement and installation of 11,000-liter plastic tanks	6,182,000	11,000 liters	Cleaning of tanks
Subsurface tanks	Excavation of pits Building up the tank walls	4,000,000	11,000 liters	Cleaning of tanks
Drip system	Procurement of a 1000-liter tank Procurement of drip lines	2,385,000	¼ acre ($1000 m^2$)	Prevention of clogging (filtration system)
Treadle pump	Procurement of money maker pump and its accessories	660,000	1 unit	Routine servicing

Table 2. Champion farmers' views on water management technologies.

Variable	Response (%)				
	Strongly disagreed	Disagreed	Undecided	Agreed	Strongly agreed
1. Water harvesting is a user-friendly technology.	0	0	0	58.8	41.2
2. Farmers in Otuke can afford to harvest water.	5.9	5.9	0	70.6	17.6
3. Water harvesting can be done by all farmers in our community.	0	52.9	29.4	17.6	0
4. Water harvesting is a labor-demanding technology.	0	5.9	5.9	23.5	64.7
5. The water harvesting technology introduced to us by CARE can also be done by women.	0	5.9	11.8	52.9	29.4
6. Water harvesting technology(ies) promoted in our community is culturally acceptable.	0	5.9	0	70.6	23.5
7. Mulching gardens is useful for crop growth.	0	0	0	17.6	82.4
8. It's very easy to mulch gardens.	5.9	23.5	0	29.4	41.2
9. Getting mulch is very easy in our community.	11.8	35.3	0	29.4	23.5
10. We have always been doing mulching in our gardens.	70.6	23.5	0	0	5.9
11. Use of planting ridges for planting crops improves crop performance.	0	0	0	35.3	64.7
12. It is very easy to make planting ridges.	17.6	23.5	0	41.2	17.6
13. Construction of ridges can also be done easily by women in our community.	0	5.9	0	52.9	41.2
14. Making plant ridges is very cheap in our community.	5.9	29.4	0	23.5	41.2
15. Minimum tillage technology is very good.	0	0	11.8	76.5	11.8
16. Crops under minimum tillage yield very highly.	0	0	82.4	17.6	0
17. Treadle pumps are very easy to use (user friendly).	0	0	41.2	41.2	17.6
18. Most farmers in our community can afford to buy a treadle pump.	35.3	0	41.2	17.6	5.9
19. Even women can use a treadle pump without any difficulty.	5.9	0	41.2	41.2	11.2

Source: Primary data

Table 3. Estimated cost and gross margin analysis for tomato production on an acre of land using a combination of soil and water conservation technologies.

Subcounty	Cost to produce 1 kg of tomato (UGX)	Average yield/acre (kg)	Total sales (UGX)	Gross margin (UGX)
Olilim	272	3160	3,096,800	2,237,300
Ogor	274	3138	3,074,914	2,215,414
Orum	485	1735	1,735,254	875,754

Source: Primary data assumptions: farm gate price of tomato is 1,000 shs/kg; postharvest losses are 2%.

These results demonstrate that SWC technologies, when used in combination, are very important for farmers in Otuke as shown in the level of gross margins attained from tomato production. This concurs with the FAO argument to focus on investments (FAO, 2003) that improve food security, nutrition, and livelihood of the most vulnerable people through a combination of improved water management in rainfed agriculture and improved soil fertility management.

Lessons learned

During the first cycle, farmers were overwhelmed by the many activities on the farm and this affected their performance because they had to distribute their time to other off-project activities. The team then decided that, in the second cycle, selected technologies should focus on high-value crops (vegetables) so that the farmers can have time for the demonstrations.

Key challenges and limitations

- Fake pesticides in the market affected farmers' yields. The first batches of pesticides bought were ineffective. This affected seedlings in the nursery beds, thereby leaving farmers with fewer seedlings for transplanting.
- Hailstorm was also a challenge.

Conclusion

The results have clearly shown the benefits of using a combination of SWC technologies (improved practices) compared with farmers' practices. It is evident that further improvement can still be made in the next cycle through better crop management, e.g., pruning, maintaining optimum plant population, and introducing integrated nutrient management.

However, it is important to mention that SWC technologies must be used in combination with the right crop varieties and integrated with agronomic practices. In our study, the average cost of producing 1 kg of tomatoes in the three subcounties, for instance, in Otuke was UGX 343. According to the East Africa Seed Growers' Guide (2012), studies in Kenya show that the cost of producing tomatoes was as low as UGX 20/kg. This implies that there is room to improve yield per acre and reduce production cost per kilogram.

An action research approach with champion farmers is an appropriate method for experiential learning for both farmers and implementers. The farmers tend to own these technologies since they are developed and improved by both farmers and the action research team. For example, implementers learned from the farmers that applying salt to rocks could soften them and enable easy excavation of ponds.

Also, government needs to come out strongly to regulate activities of agro-input dealers in the private sector. The issue of fake inputs is a reality and should not be tolerated.

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Reversing the Negative Impact of Excess Water on Smallholder Farming

In the Ethiopian highlands, where there is moderate to high rainfall, waterlogging is a major constraint to crop production. The problem prevails in about 7.6 million ha of land covered with vertisols. Vertisols are fine-textured soils characterized by poor infiltration. Due to this waterlogging problem, less than 2 million ha of the highlands are cultivated in any one season (Debele, 1985). In addition, the problem renders smallholder farming not climate-friendly. In most cases, the fields remain waterlogged in July and August. As a result, farmers either resort to late planting or they simply abandon the fields. Late planting entails repeated tillage as farmers try to control weeds. Repeated tillage causes higher losses of soil organic carbon and soil erosion. In addition, waterlogged fields create anaerobic conditions, which enhance the production of methane gas. Once the rains stop and the soils dry out, this gas is emitted. This is considered to be a more potent greenhouse gas (GHG) than carbon dioxide.

One solution to waterlogging is the construction of broad beds and furrows to drain excess water from the fields. The operation requires a special equipment called broadbed and furrow maker (BBM). The development of animal-drawn BBMs began in 1984 (Jutzi and Abebe, 1986). However, farmers' adoption of the BBM prototype was low because of its high draft power requirement and heavy weight; also there are other issues related to the assembly and field operation of the implement.

The Aybar BBM

To address the problem of adoption of the BBM prototype introduced earlier, a new type of prototype was developed following a different approach to design the soil-engaging components. The new prototype is called Aybar BBM (Fig. 1).

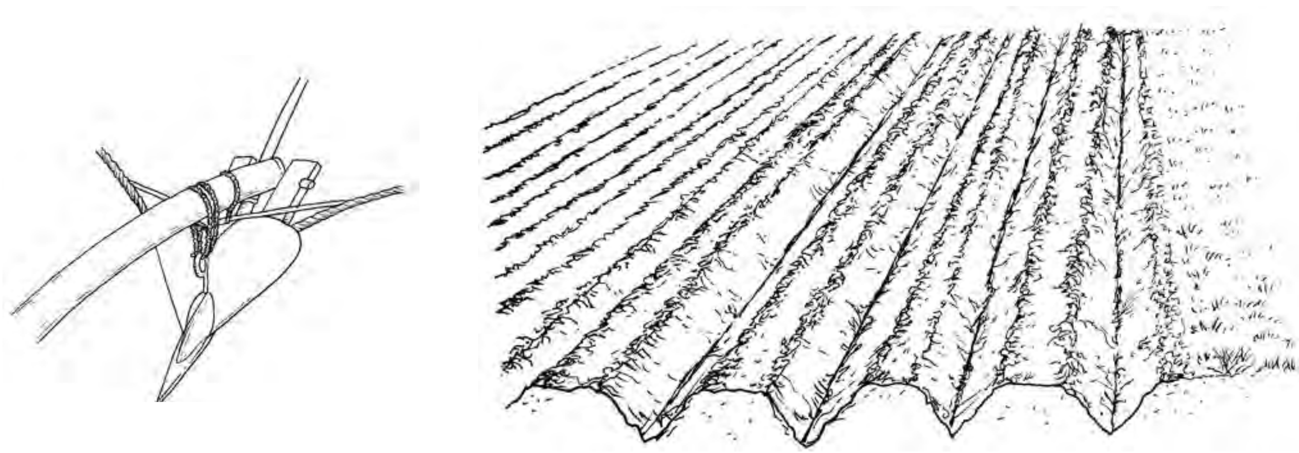

***Fig. 1**. Aybar BBM as assembled (left) and the broad beds that it constructed (right).*

The Aybar BBM was demonstrated in 60 farmers' fields in 2012 at selected sites of the Oromia administrative region in Ethiopia. Field days were organized and farmers were asked to compare the two prototypes. Farmers compared the two prototypes based on 10 criteria and stated that Aybar BBM is superior in all aspects. The following are the most important comparisons.

- The old BBM weighs 7 kg, while Aybar BBM weighs 3.5 kg. In addition, the old BBM carries on it a lot of mud, which makes it difficult for the operator to lift it at the end of the plot. The old BBM therefore required a higher draft force than what a pair of oxen can sustainably exert. Field tests have shown that the former requires 50% more draft power than the latter.
- The old BBM makes kinky beds because the oxen react to the high draft force requirement by moving in a zigzag direction. Kinky beds are less efficient in draining excess water. On the other hand, the Aybar BBM produces straight furrows, which gave higher grain yield.
- The old BBM becomes loose and thus unstable during operations, whereas Aybar BBM remains stable.
- The old BBM requires very friable soil, whereas Aybar BBM can be operated in relatively wet soils, thus extending planting time by up to 1 week.
- The old BBM bends and breaks, whereas Aybar BBM does not.
- The Aybar BBM can also be used as a tie ridger to conserve soil moisture in dry areas.

The advantage of the old BBM is that its features are a lot simpler than those of Aybar BBM. However, because less material is used for fabrication, the total cost of manufacturing of Aybar BBM is lower than that of the old BBM.

In early 2012, the Ethiopian Institute of Agricultural Research and the Federal Ministry of Agriculture (MoA) conducted a joint assessment of the Aybar BBM by interviewing farmers who used the implement. In June 2012, based on the findings, the MoA circulated a letter to the four major administrative regions urging the respective agricultural bureaus to disseminate Aybar BBM among farmers, citing the technology as a success after many years of failure. Mass production of the Aybar BBM began in 2012.

In 2013, the MoA conducted a survey to assess the performance of Aybar BBM. Farmers in Oromia region confirmed that the drainage of excess water by the Aybar BBM made it possible to increase crop yield threefold. Farmers reported that, before the introduction of the BBM, they used to get a maximum of 1,500 kg/ha. When conditions were suitable for field operation, the old BBM could give a maximum of 2,800 kg/ha, whereas Aybar BBM gave a minimum of 3,800 and a maximum of 5,700 kg/ha. (See www.aybareng.com for the interviews.)

Recent reports also show that some farmers produced as much as 8,200 kg of wheat/ha using Aybar BBM (A.G. Keneni, Oromia Agricultural Bureau, pers. commun.). Farmers also reported growing a second crop, usually chickpea, using the residual moisture. So far, a total of 45,000 units of Aybar BBM have been distributed in different regions and have been used not only to drain excess water from vertisols but also to construct tied ridges in dry areas to prevent runoff (and thereby increase moisture availability), to prepare fields for small-scale furrow irrigation, and even to harvest potato.

The Aybar BBM costs about 239 birr (US$12). The cost is lower than prices farmers pay for other agricultural inputs. For example, farmers pay up to US$ 80 for a 100 kg sack of fertilizer, which can only be used on 1 ha and only for one season, whereas Aybar BBM can be used on several hectares and for many years. The tool is also durable. For example, farmers who started using Aybar BBM for testing 5 years ago are still using the same tool and it does not show any sign of wear and tear other than removal of the paint.[1]

Case study

Farmer Berhanu Angassa, from Awash Bule kebele, southwest Shoa, Oromia region, reported that he used to produce 800 kg of wheat/ha from his field. The use of Aybar BBM enabled him to harvest 4,400 kg of wheat/ha. He planted chickpea using the residual moisture and harvested 800 kg. He also stored the drained excess water in a pond and later used it to grow vegetables.

The BBM technology reversed the negative impact of water on both crop production and the environment. It did so by moving away excess water that would have reduced yields, increased soil erosion and GHG emission and by making it possible to use that same water to grow another crop. Therefore, the technology not only helps increase crop production but also protects the environment. Early planting with the help of BBM allowed early soil cover with live crops, which means reduced soil erosion as the soil is protected by the crops instead of being cultivated during the rainy season that would cause higher soil loss. On the other hand, tillage increases carbon dioxide emission, while live crops absorb carbon through photosynthesis. Moreover, growing three crops per year results in an extended period of soil cover with live crops, which is in line with one of the main principles of conservation agriculture. In addition to reducing soil erosion, retention of rainwater in the field makes more water available for the crops, thereby increasing crop production by up to 60–73% (McHugh *et al.*, 2007).

Conclusion

Drainage of vertisols using Aybar BBM makes it possible to reverse the negative impact of water on smallholder farming by removing excess water. Consequently, the negative impact due to water-logging is avoided, while storage of excess water in a pond allows farmers to use that same water to grow more crops later through irrigation. These practices help farmers use water for agriculture in a smarter way and can triple their income, while reducing soil erosion and carbon dioxide and methane emissions. They also increase carbon absorption through an extended period of soil cover with live crops. Aybar BBM can also be used in dry areas to construct tied ridges that minimize runoff, which would have caused soil erosion, while allowing more water to infiltrate into the soil horizon for increased crop production. Farmers can also use Aybar BBM for small-scale furrow irrigation and other agricultural operations such as potato planting and harvesting.

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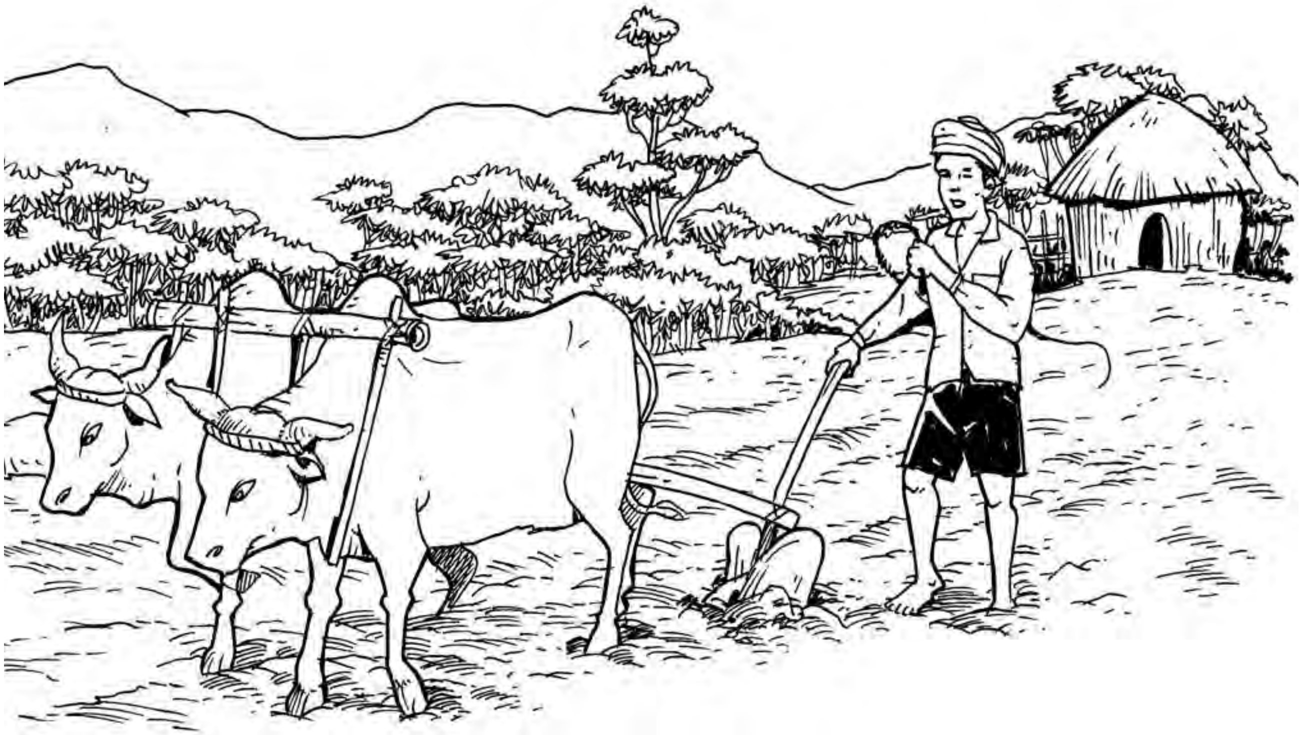
Arashogel: A Simple Oxen-drawn Tillage Implement for Soil and Water Conservation



Conservation agriculture (CA) is introduced to tackle the problem of land degradation as a result of intensive tillage. Conservation tillage is a tillage practice that involves minimum soil disturbance aimed at conserving soil, water, and labor and traction requirements (Rockstrom *et al.,* 2009).

In tractor-drawn commercial farms, the main cause of land degradation is soil inversion with tractor-drawn moldboard and disc plows. In addition to soil inversion, movement of soil at higher speeds with tractors causes significant soil pulverization. Such tillage practices speed up soil organic carbon losses. Loss of soil organic carbon causes land degradation (Reicosky, 2001). In addition, the use of tractors for tillage makes weed control more expensive than zero tillage combined with the application of nonselective herbicides. These factors and the fact that higher soil temperatures caused by intensive tillage jeopardize seed viability (Diaz-Zorita *et al.* 2002) led to the introduction of zero tillage.

When it comes to Ethiopia, oxen-plowing is the dominant method used by most farmers. It is also, however, the main cause of soil erosion and land degradation because of repeated cross-plowing. Cross-plowing is the practice of orienting the directions of two consecutive tillage operations perpendicular to each other. Farmers in Ethiopia are forced to undertake cross-plowing because of the geometry of the traditional tillage implement, *maresha* (Fig. 1a). Maresha creates V-shaped furrows (Temesgen *et al.,* 2008), while leaving strips of unplowed land between consecutive passes (Fig. 1b). During the next tillage, farmers cannot easily access the unplowed strips without resorting to cross-plowing. The situation calls for a locally adapted conservation tillage system that can achieve the main objectives of CA (Giller *et al.,* 2009).

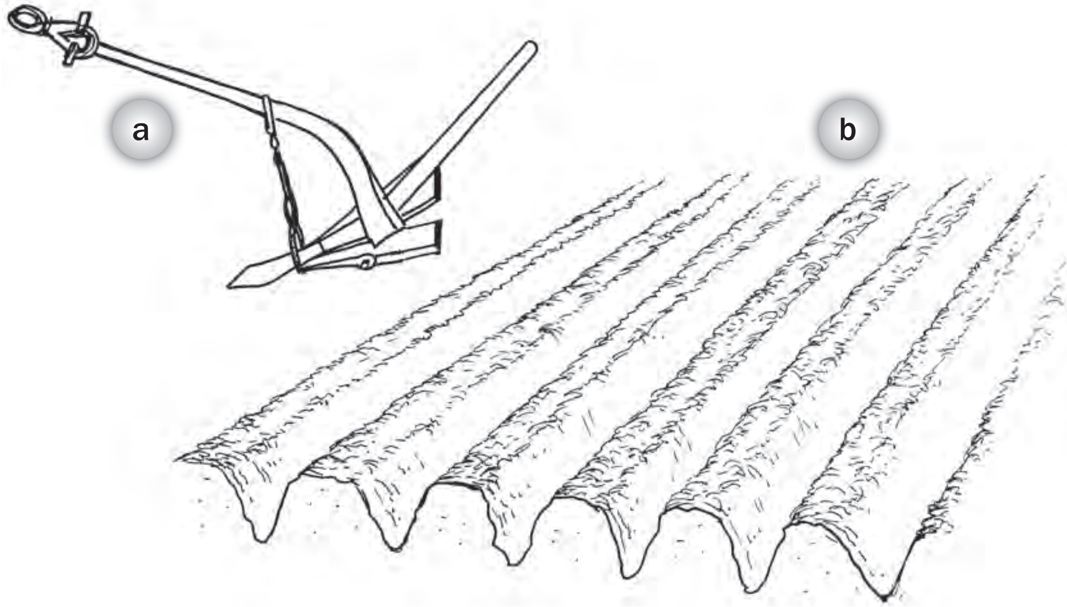


Fig. 1. *(a) Maresha, the traditional tillage implement of Ethiopia; (b) V-shaped furrows left after plowing by maresha. The land between passes can only be disturbed through repeated cross-plowing, the main cause of soil erosion and high tillage frequency in the country.*

The problem

Most Ethiopian farmers use oxen-drawn plows and practice cross-plowing. However, there are many disadvantages of cross-plowing:

- Cross-plowing wastes time and energy. During the second plowing, the plow is run across the already plowed furrows in order to access the unplowed strips of land. This wastes close to 50% of the time and energy of both the oxen and the farmer. Even after the second tillage, spots of unplowed land are left between pairs of crossing furrows. These spots of land carry weeds that have to be controlled. Additional tillage operations are required to fully disturb these spots during which the farmer has to spend most of the time running over the already plowed land. This is the main reason farmers in Ethiopia have to plow so many times. Moreover, where there are slopes, walking up and down these slopes puts an extra burden on both the farmer and the oxen due to gravity effects, while the variation in the inclination of the plow makes it difficult to maintain the depth of tillage while alternating between up-slope and down-slope plowing.
- Cross-plowing leads to high surface runoff and soil erosion. It rules out contour tillage, which is highly recommended in moderate to steep slopes. With cross-plowing, one of any two consecutive tillage operations falls along or nearly along the slope. Orientation of tillage directions along the slope provides channels for rapid flow of water, which causes higher surface runoff. Consequently, in addition to loss of soil moisture in dry areas, higher surface runoff is generally associated with higher soil erosion. Soil erosion is the main cause of land degradation in Ethiopia.
- Cross-plowing is inconvenient in fields treated with soil conservation structures. On moderate to steep slopes, much of the land is treated with soil conservation structures. However, farmers usually destroy the soil conservation structures due to the difficulty of undertaking cross-plowing between the structures, which are usually constructed in short intervals. Some farmers plow the field parallel to the structures but they have to employ more labor to manually dig the strips of land left between two consecutive passes.

An appropriate conservation tillage system

To help farmers avoid cross-plowing, a different type of plow called *Arashogel* has been developed (Fig. 2). Arashogel is attached to the traditional tillage implement, maresha, by replacing the connecting ring of the traditional maresha, which is called *wogel*. The arashogel functions as the connecting ring for different parts of the maresha and it is redesigned with parts that cut the soil. Thus, these parts cut the strips of the land left undisturbed during the first pass, thereby enabling the farmer to finish plowing in two passes as opposed to three to five passes and to undertake tillage in the same direction (e.g., along the contour). The cutting parts are designed to operate with minimal pulling force requirement.

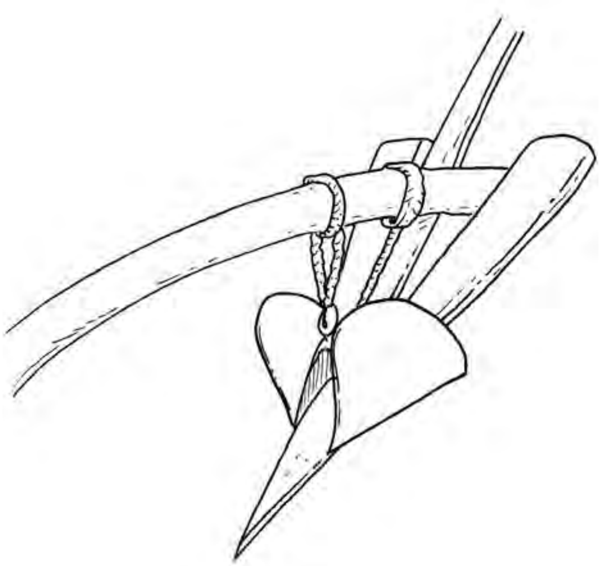


Fig. 2. *The* arashogel *is designed to avoid cross-plowing during consecutive tillage operations because of its wings, which cut the unplowed strips of land left by the* maresha.

Field test results

Field experiments were carried out to assess the effects of the new tillage system at a site known as Enerata in the upper Blue Nile Basin (Temesgen *et al.,* 2012). The experiment compared traditional tillage (TT) with conservation tillage (CT), which avoided cross-plowing, on fields treated with soil conservation structures. Both biomass and grain yield were consistently higher in CT than in TT in both crops, wheat and teff, with 35% and 28% increment in grain yield of wheat and teff, respectively, although the differences were not statistically significant ($\alpha = 0.05$) (Temesgen *et al.,* 2012). This is due to high variation in soil fertility as replications were made in different farmers' fields.

Participating farmers noted the differences in biomass and grain yield. Farmer-interviewees, believe the reasons could be (1) reduced soil erosion, (2) better weed control, (3) extended period of soil wetness, and (4) reduced waterlogging. They believe that reduced soil erosion in CT led to reduced loss of soil nutrients, whereas retention of soil moisture in deeper layers extended the growing period. Consequently, farmers harvested the CT plots, on average, 1 week after harvesting the TT plots. They believe this resulted in more biomass and grain yield. Reduced waterlogging and, hence, better aeration in CT made the crop greener compared with waterlogged strips behind soil conservation structures under TT.

Arashogel has been demonstrated on farmers' fields in Semen Achefer and Gonder Zuria *woredas* of the Amhara Regional Administration during the main season of 2014. Nature Conservation Alliance (NABU) conducted the demonstration. During field days organized by NABU in collaboration with the woreda agricultural bureaus, farmers who used arashogel mentioned several advantages of the implement. They stated that their oxen pulled the implement easily; they were able to save time on tillage; the runoff in fields plowed using arashogel was significantly smaller and, hence, there was less soil loss compared with fields plowed with the traditional method. Farmers and experts also commented that, based on crop growth and other visual assessments, they expect higher crop yields (sorghum and teff) from fields plowed with arashogel. Data are yet to be analyzed and reported after the crop is harvested.

Reduced tillage reduces loss of soil organic carbon, and reducing the loss of soil organic carbon is one of the main objectives of CA (Reicosky, 2001). Tillage with arashogel creates invisible barriers along the contour that retard the movement of water along the slope, thereby significantly reducing soil erosion and conserving water through increased infiltration. Moreover, arashogel makes it more convenient to plow between soil conservation structures. The invisible barriers left between passes allow more infiltration by reducing surface runoff toward the soil conservation structures. It also prevents waterlogging behind the soil conservation structures and possible damage to the structures that would have had detrimental effects downstream. The results of the field experiments have shown that crop yield and the life span of the soil conservation structures can be increased by the application of such a tillage system (Temesgen *et al.,* 2012).

Currently, arashogel is sold at US$ 15. Further reduction in price is expected with increased sale volume. Added together, the reduction in tillage time plus the increased crop yield as a result of using arashogel are equivalent to several times the current price of the implement. Soil conservation as a result of using arashogel is an added advantage. The implement can be used for more than a year, though the exact working life of the tool has not been determined yet.

Conclusion

Conservation tillage, based on the use of arashogel to avoid cross-plowing, has been found to be an effective and appropriate system to achieve the objectives of CA. It reduces soil and water losses, while reducing labor and traction requirements for tillage, which is the immediate benefit that attracts smallholder farmers. In moisture-stressed areas, the tillage system also conserves soil water, thereby increasing crop yield, which is another factor to motivate farmers. Unlike other types of CA that focus on long-term benefits, the arashogel-based conservation tillage achieves both short-term and long-term benefits, while being simple and cheap

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Evidence-based Soil Conservation Measures that Improve Soil Physical and Chemical Properties and Barley Yield

Soil degradation can be described as a reduction of resource potential by a combination of processes, such as soil erosion by water and wind, acting on the land and bringing about deterioration of the physical, chemical, and biological properties of soil (Maitima and Olson, 2001). Land degradation is a major environmental problem in Ethiopia and it is manifested mainly in the form of soil erosion, gully formation, soil fertility loss, and crop yield reduction. Some forms of land degradation are the result of normal natural processes of physical shaping of the landscape and high intensity of rainfall.

The scale of the problem, however, has dramatically increased in Ethiopia because of increase in deforestation, overgrazing, over-cultivation, inappropriate farming practices, and increasing human population pressure. The dependence of the Ethiopian rural population on natural resources, particularly land, as a means of livelihood is an underlying cause of degradation of land and other natural resources (EPA, 1998). Removing vegetative cover on steep slopes for agricultural expansion, firewood and other wood requirements as well as for grazing space has paved the way for massive soil erosion.

Forest cover in the Ethiopian highlands as a whole is estimated to have decreased from 46% to 2.7% of the land area between the 1950s and the late 1980s (USAID, 2004). It is also estimated that more than 1.9 billion tons of soil are lost from the highlands of Ethiopia annually (EHRS, 1986). These highlands have, for millennia, been major centers of agricultural and economic activity. It has been estimated that around half the area of highlands (about 27 million ha) has been significantly eroded and over one-fourth has undergone serious erosion. Moreover, 2 million ha are considered permanently degraded and incapable of supporting cultivation (EHRS, 1986). In the Amhara Region, more specifically, soil loss due to water erosion is estimated to contribute 58% to total soil loss in the country (Tesfahun and Osman, 2003). This has already resulted in a reduction in an estimated agricultural productivity loss of 2% to 3% per year, taking a considerable area of arable land out of production. The situation is becoming critical because increasingly marginal lands are being cultivated, even on very steep slopes (Tesfahun and Osman, 2003).

The present study was conducted to investigate the effects of integrating physical and biological conservation measures on some soil physical and chemical properties and subsequently on the yield of crops in the Absela watershed of Banja Shikudad District in the West Gojjam Zone of the Amhara national regional state of Ethiopia.

The catchment and research approach

The catchment area was delineated in 1998 and different soil and water conservation (SWC) activities have been carried out since then. Soil bunds made at different times and stabilized with biological measures such as vetiver grass (*V. zizanioides*), tree lucerne (*C. palmensis*), sesbania (*Sesbania sesban*), and phalaris grass (*Phalaris* spp.) can be found in the catchment.

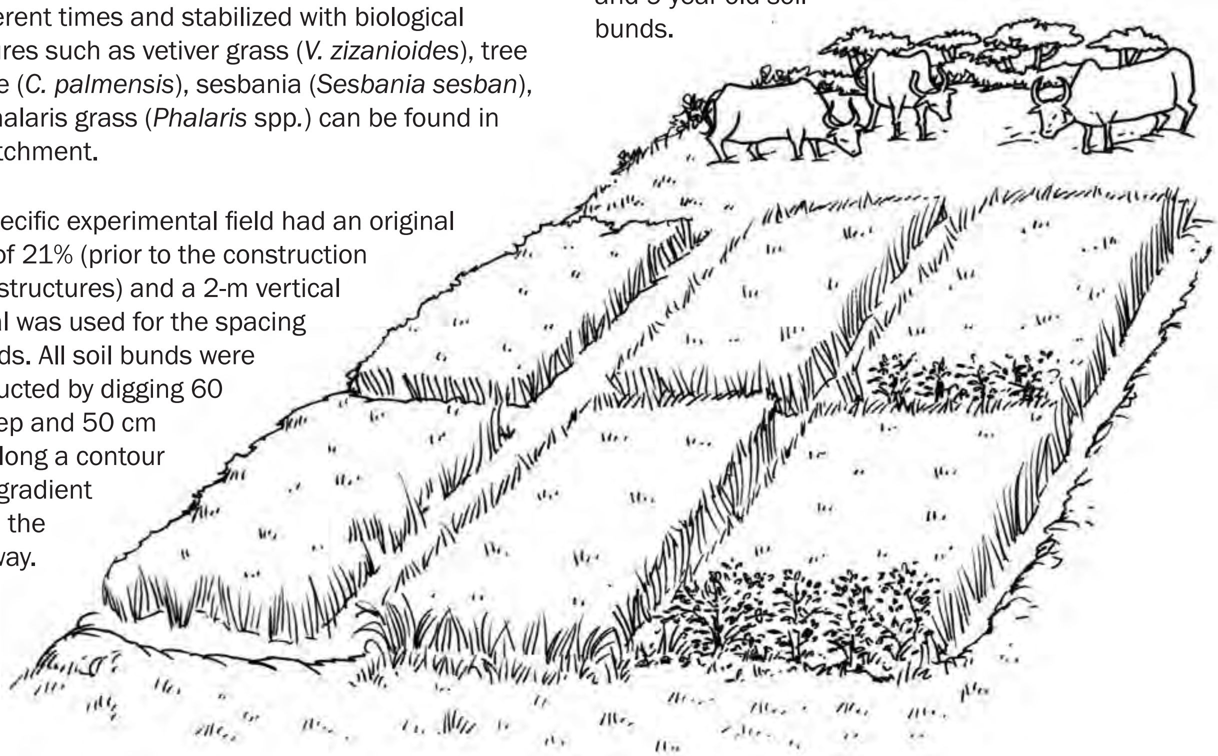
The specific experimental field had an original slope of 21% (prior to the construction of the structures) and a 2-m vertical interval was used for the spacing of bunds. All soil bunds were constructed by digging 60 cm deep and 50 cm wide along a contour at 1% gradient toward the waterway.

The soil that was thrown downhill was used to make embankments having a bottom width of 75 cm and a top width of 50 cm. Where the bunds were stabilized with vetiver, tillers of the same were planted at the upper position of the soil bund with a spacing of 30 cm in a single row, and where it was stabilized with lucerne tree, seedlings were planted at the top of the soil embankment with 50-cm spacing in a single row (Tadele *et al.*, 2011).

The vetiver tillers and lucerne seedlings were planted in the main rainy season in the same year as the structures were installed. The trees used to stabilize the bund were pruned each year before the onset of the main rainy season to avoid the shading effect after they mature. The pruned materials were largely used as fuel wood, fodder for cattle, and sometimes as fencing material. Some of the fallen plant parts were sometimes added to the soil. However, there were also some bunds with no trees planted around them and some areas of land that were not terraced. The latter were used as control plots for the experiment.

The research approach consisted of an analysis of plots with five different treatments, replicated four times.

These were control (non-conserved plots), 6-year-old soil bunds with lucerne tree, 9-year-old soil bunds with lucerne tree, 9-year-old soil bunds with vetiver, and 9-year-old soil bunds.



Results

Organic matter and total nitrogen

The non-conserved plots had the lowest mean value of organic matter when compared with all the other plots with some kind of treatment. Conserving soil using soil bunds or integrating soil bunds with biological measures significantly improved soil organic matter (Table 1). The major reasons for the buildup of organic matter in the conserved plots were the reduction in slope height, the significant decline in the speed of runoff, and the accumulation of organic matter in the interterrace space. Moreover, the addition of biomass from the bunds themselves improved the soil. Soil treated with conservation measures become an important sink of carbon, which, in turn, improve the soil physical and chemical properties and supply nutrients to the plants.

The result for total nitrogen content was similar and is linked to the finding on organic matter, since this is its major source. Generally, the inclusion of leguminous plant species on farmland improves soil fertility by improving the organic matter and total nitrogen contents of the soil through the addition of leaf litter and other parts of trees on top of the deposition of the nutrients in the interterrace spaces.

Bulk density and infiltration rate

The plots without any conservation were found to exhibit significantly higher mean bulk density than those with conservation measures. This could be attributed to the presence of higher organic matter in those soils (Table 1). Soils with high bulk density tend to restrict root penetration and hinder water and air transfer in the soil system. The 9-year-old soil bund and the 9-year-old soil bund stabilized with lucerne tree and vetiver had higher mean infiltration rates than the younger soil bunds and the untreated plots. Low infiltration rates are causes of exacerbated surface runoff and removal of nutrients from the soil system. This will eventually reduce soil organic matter, soil nutrients, and crop yield.

Interterrace slope and bund height

Sole soil bunds and soil bunds treated with biological measures reduced the interterrace slope more significantly than did the untreated fields (Fig. 1). The deposition of soil materials and debris on the upper position of soil bunds (usually called accumulation zone) increased the height of the bunds year after year, thereby reducing the interterrace slope between two successive structures. Differences in the length of time since the bunds had been installed also brought about a variation in interterrace slope. This meant that older bunds had a lower interterrace slope than younger ones. Specifically, the 9-year-old soil bunds had significantly lower interterrace slope than the 6-year-old soil bunds stabilized with similar plant species and the nontreated plots.

Similarly, the older soil bunds treated with or without vegetative measures had higher bund heights than the non-treated fields (Fig. 2). It was apparent that bund height was negatively correlated with interterrace slope.

Barley yield

Barley grain yields were higher in plots that were treated with soil bunds or soil bunds treated with biological measures compared with the untreated plots (Table 2). This could be associated with the accumulation of organic matter, total nitrogen, and probably other nutrients in the interterrace space, coupled with other desirable changes in the soil's physical and chemical properties brought about by the implemented conservation measures. Looking at the field yield performance, there was also a fertility

***Table 1**. Effects of SWC measures on physical and chemical properties of soil.**

Treatment	Organic matter (%)	Total nitrogen (%)	Soil bulk density (g cm^{-3})	Infiltration rate (cm h^{-1})
Control (nonconserved land)	1.577 d	0.125 c	1.38 a	0.24 b
6-yr-old soil bunds + lucerne tree	2.470 c	0.173 bc	1.26 b	0.28 b
9-yr-old soil bunds + lucerne tree	5.017 a	0.277 a	1.29 b	0.73 a
9-yr-old soil bunds + vetiver	3.306 b	0.215 b	1.25 b	0.82 a
9-yr-old soil bunds	5.478 a	0.284 a	1.27 b	0.88 a

**Means in a column followed by the same letter are not statistically different at $p \leq 0.05$.*

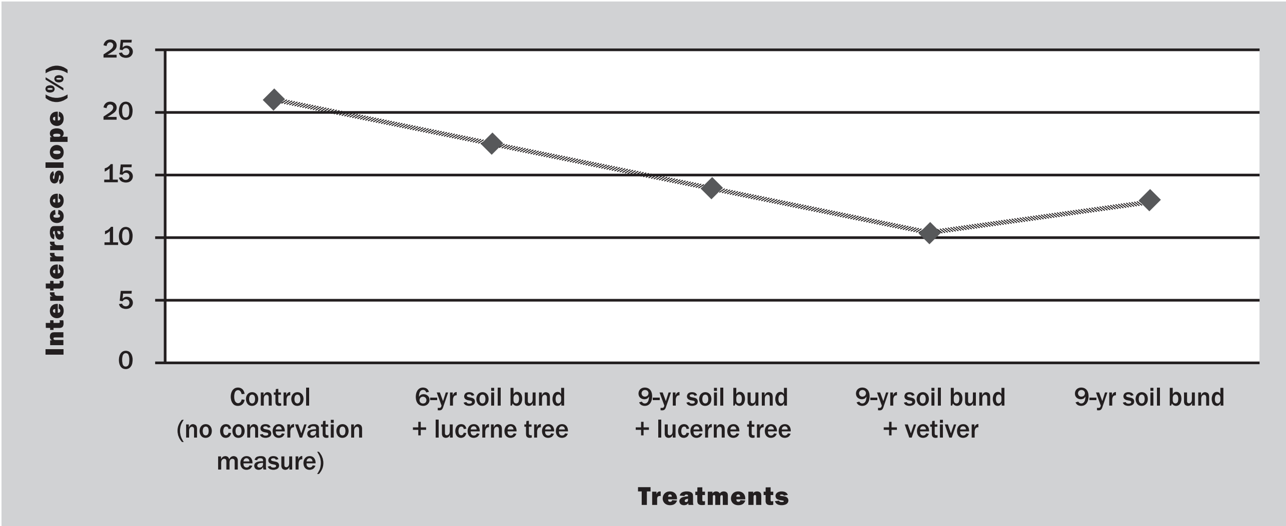


Fig. 1*. Effect of SWC measures on interterrace slope.*

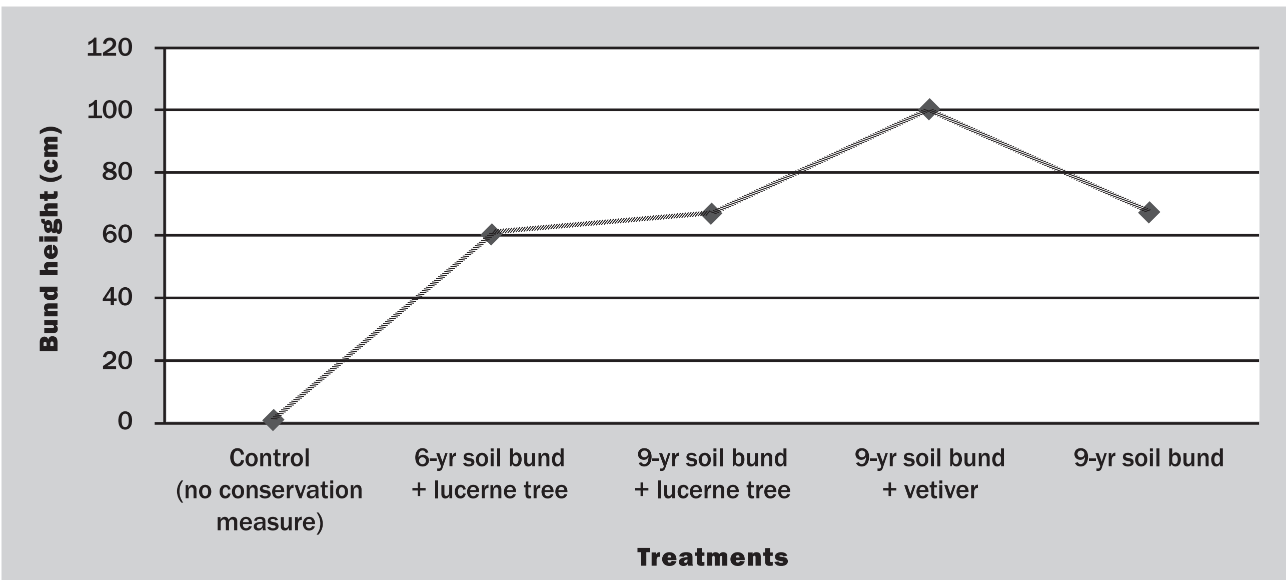


Fig. 2*. Effect of SWC measures on bund height.*

gradient within the interterrace space, and higher yields were recorded in the deposition zone than in the loss zone.

Challenges in implementing conservation measures

Not all farmers who lived and worked in the watershed were convinced of the benefits of the intervention. The result was that not all the fields were consistently treated with the conservation measures planned. Ironically, the lack of a consistent implementation provided the opportunity underlying this study of control plots. The other major challenge

Table 2*. Effects of conservation measures on grain yield and yield components at the soil deposition zone.*

Treatment	Grain yield (kg ha^{-1})*
Control (nonconserved land)	561.25 d
6-yr-old soil bunds + lucerne tree	1284.25 c
9-yr-old soil bunds + lucerne tree	1878.75 a
9-yr-old soil bunds + vetiver	1187.50 c
9-yr-old soil bunds	1712.50 b

* *Means in a column followed by the same letter are not statistically different at $p \leq 0.05$.*

was maintaining the structures, even those initially convinced sometimes damaged the bunds because they could not see any benefits directly in the short run. This is beginning to change as farmers in the neighborhoods of conserved land start to see the benefits over time. Similarly, free grazing, which was previously a major problem in maintaining biophysical structures, has recently decreased in importance as a constraint.

Conclusions and recommendations

Bund construction, integrated with biological measures, led to a reduction in slopes and generated a number of improvements in the soil. The study also recorded that the older bunds showed greater benefits. However, the bunds do not necessarily ensure the improvement of land productivity in the entire area unless agronomic and vegetative soil management practices are employed on the bunds. The highest yields were obtained in areas in which the soil settles—i.e., the accumulation zone—which shows the presence of a fertility gradient within the interterrace space. Among the benefits were improved nutrient content in the soil (i.e., organic matter and nitrogen content) and an increased ability of the soil to absorb rainfall (i.e., its infiltration rate). The conservation measures also decreased soil density.

Overall, the recommendations of the study are that degraded agricultural land should be rehabilitated through the implementation of integrated SWC measures (physical and biological). These will reverse degradation and increase the productivity of the land. Ideally, bunds should be stabilized with tree species, which should be pruned and the plant material incorporated into the soil for better effect. However, SWC measures will only be successful if farmers are involved at all stages, starting from planning through to monitoring and maintenance. In particular, bylaws that restrict the cutting of trees and free grazing are critically important if the benefits are to be sustained in the long term.

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Soil and Water Conservation Practices and their Potential for Outscaling in Semiarid Areas of Tanzania

Shortage of water for agriculture causes food insecurity among populations living in semiarid areas, (those characterized by low and erratic rainfall) worldwide (Barry *et al.*, 2008). This has serious implications in sub-Saharan Africa (SSA), where poverty is rampant and agricultural production is primarily rainfed (Sanga *et al.*, 2013). The region's vulnerability to food insecurity is underscored by the severe droughts experienced in the Horn of Africa, which killed human and livestock in 2011 (Sarr, 2012). To reverse the situation, the use of soil- and water-conserving (SWC) practices (bench terraces, grass strips, *fanya juu,* double digging, cover crops, micro basins and mulching) that have been proven scientifically to be water-smart agricultural practices with double dividends, reducing soil erosion and retaining soil moisture, is emphasized. However, the outscaling (i.e., increasing the number of users) of these technologies is quite low, despite the important role they play in the lives of smallholder farmers in semiarid areas (Oduol *et al.*, 2011; Ndjeunga and Bantilan, 2005). For example, in East Africa, outscaling is less than 10% of the farming communities living in semiarid areas (Kangai *et al.*, 2002).

Tanzania presents a compelling case, especially in semiarid areas where crop failure due to drought is severe and the use of water-smart agricultural technologies is very low (less than 6% of the farming communities are adopters) (Hatibu *et al.*, 1995). As a result, smallholder farmers in these areas are poor and suffer from food insecurity (Hatibu *et al.*, 2000). Realizing this grave situation, many programs geared toward increasing the use of SWC practices have been initiated and implemented since the colonial era (Tenge *et al.*, 2004; Hella, 2002). Yet, the outscaling of practices has continued to be low and the SWC structures, which are already in place, are not well-managed by smallholder farmers.

Considering the need to improve food security and livelihood of the people living in these areas, CARE International, through GWI2, initiated a project designed to advocate investment in water-smart agricultural practices from the rural to the national level. The project seeks to outscale the use of these practices by engaging key stakeholders in supporting smallholder farmer practices (CARE, 2012). Therefore, a study on the actual factors limiting outscaling is imperative. It involves gathering scientific evidences at local levels and getting farmers' point of view and using them to build consensus at the local and national levels.

Objectives

The paper aimed to present evidence on factors that prevent smallholder farmers from adopting SWC technologies and to evaluate the potential for outscaling them.

Specifically, the study aimed to

- Investigate factors limiting smallholder farmer adoption of SWC at the farm level in Same District.
- Identify opportunities for outscaling the use of SWC in the area.

Research approach and methodology

Study location

Same District is situated between 4°S to 4°45´S and 37°5´E to 38°5´E. The district is divided into three ecological zones: highlands, middle lands, and lowlands. These zones differ in topography, availability of water for agriculture, and use of water-smart (i.e., soil- and water-conserving) farming systems.

The highlands

The highland plateau zone lies between altitudes 1100 and 2462 m above sea level and is densely populated with 650 people per square km. The area receives between 1250 and 2000 mm of rainfall per annum. The temperature ranges from 15°C to 25°C. Because of reliable rainfall, the arable land in this area is fully utilized for agriculture. The crops grown in this zone include coffee, timber trees, banana, maize, beans, cardamom, and fruits such as pear, pawpaw, and avocado. The zone is also famous for producing vegetables such as tomato, onion, spinach, lettuce, okra, and pepper.

The middle lands

The middle lands lie between altitudes of 900 m and 1100 m above sea level. The area is relatively densely populated, with 250 people per square km. Rainfall is between 800 mm and 1250 mm per annum. Temperature ranges from 25 °C to 39 °C. Most crops produced in this zone include maize, coffee, and timber trees.

The lowlands

The lowland zone lies between 500 m and 900 m above sea level and receives 400–600 mm rainfall per annum. This zone is semiarid and is dominated by pastoralists with farming activities conducted in areas where irrigation is possible. Water is diverted from the Pangani River or harvested from runoff from the uplands. Crops that are commonly grown in this area include paddy, maize, cotton, sisal, vegetables, sesame, millet, sorghum, groundnut, beans, sunflower, sugarcane, and fruits. This zone is also characterized by the development of rapid urban settlement.

Data collection

The study benefited enormously from both secondary data collected through review of related literature and primary data collected through focus group discussions (FGDs) and structured questionnaire surveys. The FGDs were meant to gather general information on the current situation of soil- and water-conserving farming practices in the area, the actual limiting factors to adoption of the systems, and conflict lines among the various smallholder farmers. Participants in the FGD were selected purposively based on their experience and knowledge regarding soil- and water-conserving farming systems in the area. To get information with historical quality, people aged 40 years and above and who have lived in the village for more than 10 years were selected and involved in the FGDs. Six people (three men and three women) were chosen in each village.

Other primary data were collected through a household survey that was conducted in seven villages (Vudee, Bangalala, Mgwasi, Mwembe, Makanya, Ruvu Jiungeni, and Ruvu Mferejini). A total of 210 small-scale farmers were randomly selected from the seven villages and interviewed by using a structured questionnaire.

Results and discussion

Soil- and water-conserving practices

The survey results indicate eight main soil- and water-conserving practices commonly used in the area. Figure 1 indicates that bench terraces and fanya juu terraces are practiced more in the upper and middle zones, while micro-basins, double digging, and ridges are practiced more in the lowlands. According to Hatibu *et al.* (2000), the distribution of these structures is influenced by topography. The upper and middle zones are characterized by steep slopes, which require structures that can serve two purposes at a time: reducing runoff and conserving soil moisture. The lower areas have gentle slopes and flat plains, a feature that favors micro-basin, double digging, and ridges. Such structures hold water for a relatively longer period and allow it to percolate slowly.

Cover crops and mulching are not popular in the area; very few are found being practiced in the highlands and middle zones. This can be attributed to the fact that the area is semiarid, receiving low rainfall per annum, and that many varieties of cover crops need enough rain; the upper and middle areas receive relatively more rain than the lower zone. Nonetheless, mulching is also not popular in the area because the area does not produce much litter and the dead plants, mainly grasses, are used as animal feed.

Factors limiting outscaling of SWC structures

The shortage of land suitable for construction of SWC structures emerged as the main factor limiting outscaling of soil- and water-conserving practices in the upper and middle zones. This can be attributed to these zones' undulating topography, with very small areas that are good for constructing soil- and water-conserving farming systems, rapid population growth and in-migration, especially in the lower zones. Lack of labor and tools needed to build the structures are the other constraints. Figure 2 indicate that

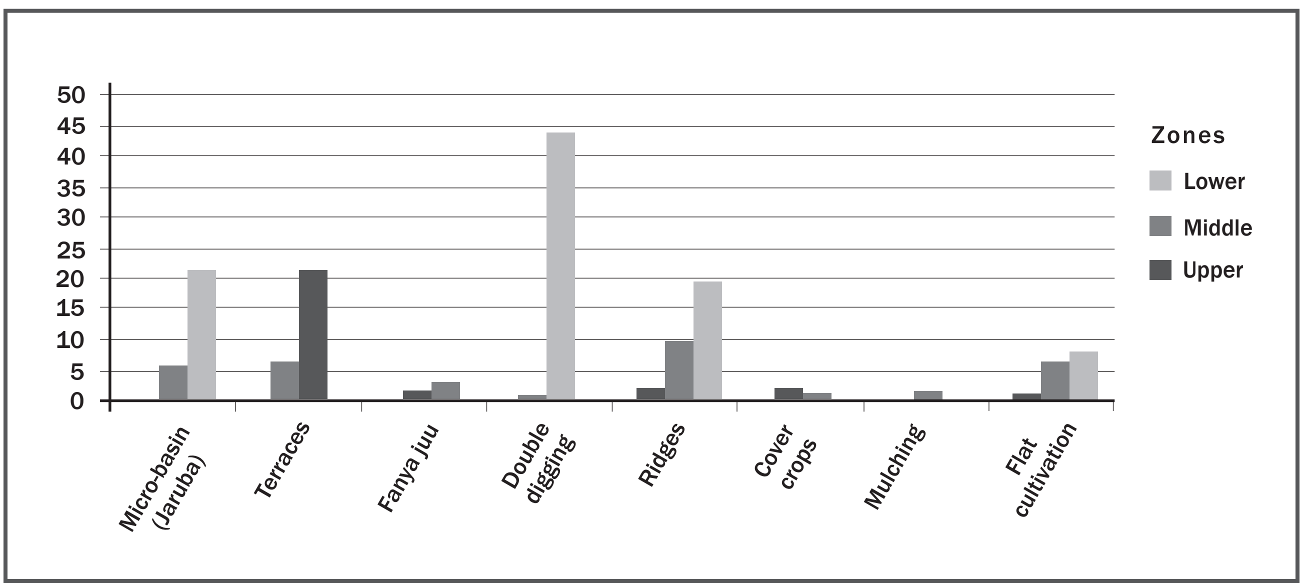

Fig. 1. *Distribution of SWC structures currently available in the project area.*

these are the major limiting factors in the upper and middle zones. Topography and type of soil pan also present problems. Many parts of these zones have rocks and hard pan; therefore, much labor is needed (a maximum of 40 man-days for an acre) to break the rocks and the pan to get to a level suitable for construction of the structures.

Equally important was the less priority given by weak governing institutions. In these areas, there are no regulations that force a household to practice soil and water conservation on its farm plot. Observations on the ground and testimonies from key informants and FGD participants also corroborated these results. It was pointed out that use of soil- and water-conserving structures is an individual decision. Therefore, smallholder farmers make decisions mutually exclusive of each other, something that leads some farmers not to practice SWC.

Lack of knowledge on how to build the structures is another limiting factor to outscaling in all the three agroecological zones. Smallholder farmers revealed that the currently used approach of selecting and training a few farmers is not effective in spreading the knowledge. Those involved in the program fail to disseminate the knowledge they have acquired to others due to lack of resources and platforms for training others. Finally, the lack of funds for constructing and maintaining the structures also hindered outscaling activities (Fig. 2). Some SWC structures such as bench terraces are too costly for a single smallholder farmer to construct and maintain, given his or her limited resources.

Lessons learned

- The potential for outscaling SWC practices that constitute water-smart agriculture exists in the area. Smallholder farmers are aware of the importance of SWC technology on their livelihood, and they know the factors that constrain them.
- Unstable land tenure arrangements and labor and tool unavailability are disincentives to smallholder farmers, thus hampering outscaling efforts.
- Weak governing institutions and lack of regulations that govern households as to WSC practice limit the outscaling of SWC technologies in the area.

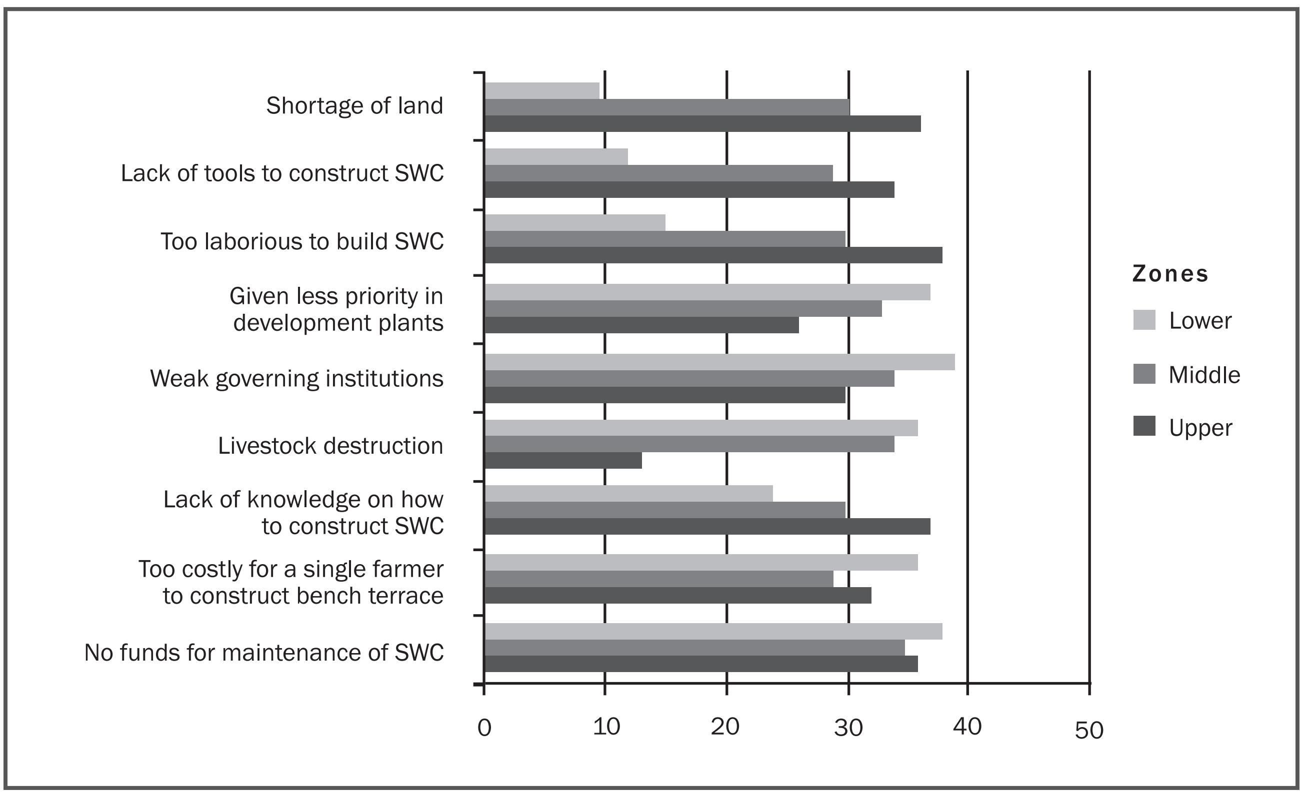

Fig. 2. Factors limiting outscaling of soil- and water-conserving structures in the project area.

Conclusions and recommendations

Outscaling SWC practices is the centerpiece of water-smart agriculture in semiarid areas. Therefore, understanding the factors that prevent smallholder farmers from adopting SWC practices is imperative. Results have shown that smallholder farmers in the area are aware of the practices and of barriers to adoption at a wider scale. The awareness angle not only creates the potential for outscaling but also identifies the focus of intervention. Poverty, lack of knowledge about WSC structures, high labor demand, and poor governance are important areas to focus on in order to achieve successful outscaling of the practices.

Policies play a vital role in the adoption of SWC practices. Results have shown that a weak legal system operates. In the lower zone, laws are not enforced, especially those that prohibit grazing of livestock in farmland.

Land, labor, and tools for constructing SWC structures are critical in the outscaling of SWC practices. Land shortage here means two things: tenure and availability. Insecure land tenure discourages a smallholder farmer from adopting SWC practices. Similarly, a household that has inadequate labor and no means of hiring labor will not adopt these technologies. Finally, implementation of SWC requires appropriate tools and equipment. Majority of smallholder farmers are too poor to afford these tools and this becomes a big constraint to adoption.

In view of these findings, the following recommendations are made:

- Establishing SWC structures is laborious and can be too much for a single farmer; an approach that promotes working together should be emphasized and strengthened among smallholder farmers.
- Tools and technical knowhow need to be available to smallholder farmers; the local government, through the Department of Agriculture, should be able to ensure this.
- Laws that can be used to settle disputes among smallholder farmers, enforce the practice of SWC technology, and maintain already existing structures should be established.

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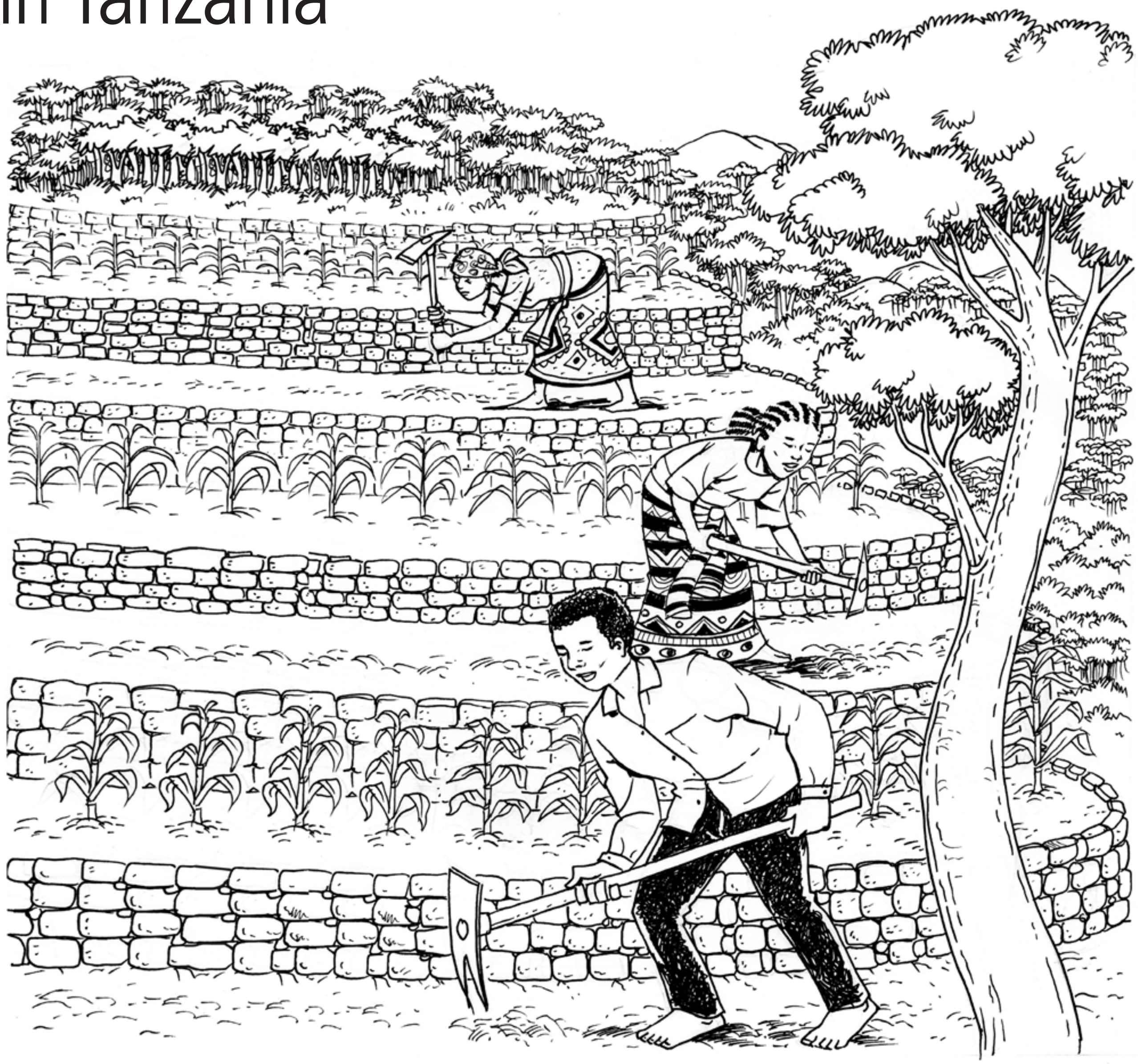
Hillside Conservation Agriculture for Improving Land and Water Productivity in Tanzania



Tanzania has a total area of 945,000 km^2 (MARI, 2006). Its inland lakes cover 59,000 km^2 (6% of total area) and the remaining land covers 886,000 km^2 (94% of total area). Despite its complex climatic and topographic setting, the country has sufficient land to allow substantial growth in agricultural production. However, land degradation due to soil erosion and decline in soil fertility caused by continuous cropping with no attempt to replenish the soil with mineral and organic manure are the major setbacks to agricultural production in the country. Any attempt to improve and expand agriculture in the country should invest in the betterment of land and crop husbandry practices.

On the other hand, there is shortage of water for agricultural production in the country due to inadequate rainfall in various parts of the country

(Mutabazi *et al.* no date). In general, nearly two–thirds of Tanzania, which covers a total area of 939,701 km^2, can be described as semi-arid on the basis of having a less than 25% probability of receiving 750 mm of rainfall per year (Mascarenhas, 1995; Bourn and Blench, 1999). Such areas, including Same District, are known to be less productive in agriculture. As Mutabazi *et al.* (no date) indicate, this is the reason why semiarid areas of sub-Saharan Africa (SSA), including Tanzania, where water is the most critical constraint to development, manifestations of poverty such as food and income insecurity are apparent. The question is: 'How can agriculture continue under such situations of soil degradation and insufficient water for agricultural production?' Answering this question becomes even more difficult, given the fact that some attempts by smallholder farmers in various places are strictly constrained by lack of efficient technology and capital. This, therefore, calls for a new, inexpensive approach that smallholder farmers can easily use. Conservation agriculture (CA) is thus considered for improving land and water productivity in Tanzania.

Conservation agriculture is any system or practice that aims to conserve soil and water by using minimum soil disturbance (conservation tillage) and crop rotation/association to minimize soil evaporation, which reduces runoff and erosion and improves conditions for plant establishment and growth. It involves planting crops and pastures directly into land, which is protected by mulch using minimum or no-tillage techniques. It is also used to increase organic matter content by improving soil structure and fertility, reduce reliance on cultivation, and achieve viable and sustainable productivity (Fig. 1a).

Fig. 1a. *Conservation agriculture is an option to improve land and water productivity in Tanzania.*

Fig. 1b. *A degraded hillside landscape results from poor land and crop husbandry.*

Other components and practices of CA comprise agroforestry, trap cropping, cover and green manure cropping, alley cropping, contour farming and strip cropping, organic and biodynamic farming, stubble mulching, integrated pest management, and crop and pasture rotation.

Conventional tillage, on the other hand, which is most commonly practiced in the country, involves the use of hand hoes, ox-drawn moldboard plow, tractor-drawn disc plow and harrows, combined with straw collection and burning during land preparation (Fig. 1b). During the operation, the soils are cut, inverted, and pulverized while most of the residues are buried underneath. The practice frequently causes soil compaction, affects soil physical properties, provokes biological degradation, and results in lower crop yields. With fine dust on the surface and compaction below, a lot of soil is washed away by the first rains. Soil losses of up to 30 tons/ha have been reported in Kilimanjaro region in conventional flat cultivated fields at a slope of 5% (Kaihura *et al.,* 1998).

Why conservation agriculture?

Land degradation has been a growing problem in Tanzania because of increased human activity and the growing demand for land as the population grows. Deforestation, overgrazing, and inappropriate tillage practices are contributing heavily to land degradation. It has been observed that the rate of soil losses in some parts of the country have increased from 1.4 tons/ha/year in 1960 to 224 tons/ha/year in 1980 (MTNRE, 1994). With the increased population pressure, the fallow periods, which were commonly used, have become shorter for the soils to recover, perpetuating the "soil mining" of nutrients. The replenishment of nutrients is low because of inadequate application of manure and inorganic fertilizers. This has led to a further decline in soil fertility, which is manifested in lower crop yields.

Therefore, CA can help improve, conserve, and use natural resources in a more efficient way through integrated management of available soil, water, and biological resources, in combination with external inputs (FAO, 2005). This, in turn, can help improve the productivity of agricultural land and water. The impacts of CA have been marked positive in agricultural, environmental, economic and social terms (Garcia-Torres *et al.,* 2003; Bishop-Sambrook *et al.,* 2004).

While millions of hectares of farmland are already under zero tillage in Latin America, conservation tillage in Africa, which is one of the practices of CA, was restricted mainly to larger estates. There are, however, enough examples demonstrating that conservation tillage can be practiced successfully by smallholder farmers, too, as it has been done in northern and northeastern parts of Tanzania (Babati, Same, and Lushoto districts) and central and eastern parts (Chamwino, Morogoro, Kilosa, and Mvomero districts). This paper reviews the CA practices in various case study sites in the country, which have also shown positive impacts of land and water management as a strategy toward water-smart agriculture.

Approach followed

The CA practices in Tanzania generally started with the sensitization of district authorities and farmers to create awareness on the CA initiative. Inception workshops were also conducted for all participating district authorities, technicians, manufacturers, researchers, and other stakeholders.

A total of 30 participatory farmer groups each consisting of 25 individuals, 10 in each district, were organized on the basis of common interests and similar constraints and were encouraged to work together. Each participating farmer was asked to set aside an area equivalent to 0.4 ha as a management training plot. The area was divided into two equal parts. One part was to be used for CA practices, where the farmer use inputs provided by the project. These included high-yielding varieties of maize crop as recommended by the District Agriculture Office for that particular area, and basal and topdressing fertilizer as a soil fertility improvement measure prior to the establishment of cover crops and cover crop seeds.

Farmers were trained on the use of better tools such as hand jab planters and direct seeders to reduce labor requirements for various agricultural operations. Training of farmers was conducted by trained village extension officers. Under their guidance, farmers also kept records of timing of activities, the costs involved, and outputs to facilitate the analysis of cost/benefit derived from the adoption or adaptation of CA practices. In this way, the farmers were able to see the differences between their practices and the proposed CA interventions.

Various methods were used to impart CA knowledge to farmers. Examples are farmers' field schools (FFS), exchange visits, farmers' field discussions, open day exhibitions, farmer-to-farmer contacts, and use of para-professionals/contact farmers just to mention a few. The Ministry of Agriculture training institutes and agricultural research institutes have played a big role in showcasing the importance of CA and many other agricultural techniques that made a difference through training farmers.

Key results

Conservation agriculture has created a huge positive impact in improving soil properties and structures, soil fertility, and soil and water conservation. It has also reduced soil erosion, increased infiltration of rain and surface water, enhanced retention of soil moisture, and shown resilience to the effects of drought. Regularly flowing streams have increased crop yields at lower production costs, mainly due to reduced labor inputs. This time-saving practice often allows diversification into other agricultural production or rural income-generating activities.

The impact of CA on livelihood is significant as it has brought positive changes on all areas where it has been practiced. The improved production of agricultural produce in various parts of the country is evidence of positive impact on the communities concerned. This is also reflected in the amount of harvest from the CA plots for the main crop (maize) and cover crop seed production. In Mvomero District, for example, maize harvests for all groups from the CA plots were 4870 kg/ha, compared with 3216 kg/ha realized from the farmer practice plots. In villages where the rains were better, the harvest from the CA plots was also higher.

The CA practices in all the selected districts and villages in Tanzania have been remarkably successful in those areas. Success stories include reduced erosion and improved soil structure; improved infiltration and moisture efficiency; improved soil health and nutrient retention; lower soil temperatures and better establishment; increased planting opportunities and flexibility; lower machinery, labor, and maintenance costs; and more reliable yields. All these increased the interests of the local manufacturers to produce direct seeding equipment and sell them to the farmers. They also increased the willingness of district/local government authorities to introduce CA as an important approach to reverse land degradation. This requires a change in mindset on the part of the farmers, who have used conventional tillage as the correct approach in crop production for many years. Also, links have been strengthened with local research institutions on suitable cover crops and proper crop rotation recommendations for adoption by the farmers.

Challenges and limitations of conservation agriculture

No single farming system or technique is perfect for all applications, and conservation farming is no exception. Conservation farming involves more planning, management, and a commitment to sustainability. Trade-offs are necessary and extra costs may be incurred in the initial years.

Conservation farming will not always result in higher yields, especially in seasons where rainfall is ample and well-distributed. The effectiveness of some herbicides is reduced by mulch on the surface as high rates of organic matter 'tie up' many chemicals. Fertilizers such as nitrates and herbicides may leach more readily through the soil due to higher infiltration rates under conservation tillage; however, runoff losses will be reduced. These aspects are being addressed through improvements in fertilizer and herbicide formulation, application technology, and better management practices.

Conservation farming systems are dynamic and call for innovation and continual improvement. Grazing, weed, insect, and fertilizer management are required for successful conservation farming, and it takes time and experience to develop these skills. A good understanding of the interaction between plants, animals, the soil, and the environment is necessary. Conservation farming systems are intended to be flexible and responsive and to work within the constraints of the environment.

Some of the challenges that have not been resolved yet include the lack of adequate funding to reach more farmers, shortage of locally available direct seeding implements, inadequate awareness-creation campaigns among all stakeholders, and poor integration of crop and livestock farming systems whereby several conflicts between pastoralists and farmers have been experienced.

Conclusions

Conservation agriculture consists of easily and readily available practices that can be used in every part of the world. It is a scalable, effective, cheap, and manageable practice that can be transferred from one place to another.

It has helped improve land and water productivity, thereby changing the livelihood of the smallholder farmers in various areas in Tanzania as it

- increases farm production and/or stabilizes it,
- has no adverse environmental effects,
- prevents erosion and improves soil fertility,
- is easy for farmers to adopt, and
- makes it easy to provide institutional support and outreach and technology transfer from one area to another.

More efforts are needed to ensure that the concept of CA and, hence, water-smart agriculture, is taken up by the government and adopted by the majority of smallholder farmers in Tanzania. This will help increase income at the household level and thereby improve livelihood.

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Evaluating Permanent Planting Basins to Optimize Plant Populations of Maize and Beans

Permanent planting basins (PPBs), as used in conservation farming, is a minimum tillage method. It is easily practiced by small-scale farmers. "You do not need special equipment to start conservation farming; all you need is a hoe and a piece of string" (IIRR and ACTN, 2005). It enhances the capture and storage of rainwater and allows precise nutrient application of limited nutrient resources. The method is widely used in southern Africa (Zambia and Zimbabwe) to reduce the risk of crop failure due to erratic rainfall. PPB, in combination with improved seed and crop residues, creates a mulch cover that reduces evaporation losses and has consistently increased average yields (Twomlow *et al.,* 2006).

This technology contributes to efficient and effective use of available water resources, which is important in promoting water-smart agriculture. This crop management method was introduced to Uganda from southern Africa and there was a need to understand how the technology responds to the different agroecological zones. This was intended to build practical evidence on how farmers in Uganda could apply the technology for optimum yield. The National Agricultural Research Organization, with financial support from Sustainable Intensification of Maize-Legume Cropping System for Food Security in Eastern and Southern Africa (SIMLESA) and Cooperative League of the United States of America (CLUSA), undertook a study aimed at establishing the optimum plant populations for both maize and beans in the agroecological (AEZ) zones of Lake Victoria crescent and northeastern savannah grassland.

Methodology

The studies were done at the National Agricultural Research Laboratories (NARL)–Kawanda in the Lake Victoria crescent AEZ and the Ngetta Zonal Agricultural Research and Development Institute (NgeZARDI) (see map). Kawanda receives an average annual rainfall of 1,200 mm while Lira gets 1,305.3 mm. The experimental design was a randomized complete block with three replications for Longe5 maize variety and NABE 15 bean variety. The treatments were three, four, and five plants per PPB for maize and six, eight, and 10 plants per PPB for beans.

The three and six plants/basin for maize and beans, respectively, were the control treatments.

Before field preparations, baseline soil analysis was done to establish the soil status fertility and fertilizer requirement. Fields were slashed; weeds were allowed to sprout and they were sprayed with glyphosate at a rate of 7.5 l/ha. Basins 35 cm long × 15 cm wide × 15 cm deep, with a spacing of 90 cm between rows and 75 cm within rows from center to center of the PPB were marked out using strings and dug before the onset of rains. Available crop residues were used as mulch. Organic manure at a rate of 1 mug PPB was applied. In addition, fertilizer diamonium phosphate (DAP), measured in a leveled soda bottle cap, was applied at the rate of two caps per pit. The pits were covered with topsoil before the seeds were planted. When the maize were knee-high, a mineral water bottle-top of nitrogen was applied per basin. The trials were done in two cropping seasons in 2013. Data were collected from 24 plots and analyzed using ANOVA to determine optimum yield based on the plant population per PPB. The outcomes of the study were disseminated and experiments are being tried by eight farmer groups in Nakasongola and Lira districts.

Map of Uganda showing location of study sites

Results

- There was a 27% increase in grain yield by using four plants per basin compared with three plants per basin currently practiced for the Lake Victoria crescent AEZ at NARL in season 2013A.
- For the northeastern savannah AEZ at NgeZARDI, there was no significant difference in grain yield between three, four, and five plants per basin for both seasons (2013A and 2013B).
- Notwithstanding the differences in plant population per basin, bean grain yield at both NARL-Kawanda and NgeZARDI was much lower than the potential yield of 2.5 tons/ha. Also, there was no significant difference between six, eight, and 10 plants per basin for both agroecologies.

Recommendations

- The maize plant population of maize the plant population of 59,259 plants/ha (four plants per PPB) was the optimum number in areas with relatively high soil moisture such as the Lake Victoria crescent AEZ.
- A plant population of 44,444 plants/ha (three plants per PPB) was the optimum number for the northeastern savannah grassland where there is low soil moisture.
- There was no significant difference in the bean plant population per basin. In light of this result, it was recommended that spacing of PPB be reduced from 90 x 75 cm to 60 x 60 cm to increase the optimum plant population, making it closer to the conventional practice of sowing 200,000 plants/ha. The implication is that, in each basin, a farmer can plant six seeds.

In line with the principle of crop rotation in conservation agriculture, the study further recommended the optimum plant population for maize as follows: three plants per basin at 60 x 60 cm of basin spacing or 83,333 plants/ha for Lake Victoria crescent AEZ and two plants per basin at 60 x 60 cm of basin spacing or 55,555 plants/ha for the northeastern savannah grassland agroecology.

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Addressing Learning and Complexity

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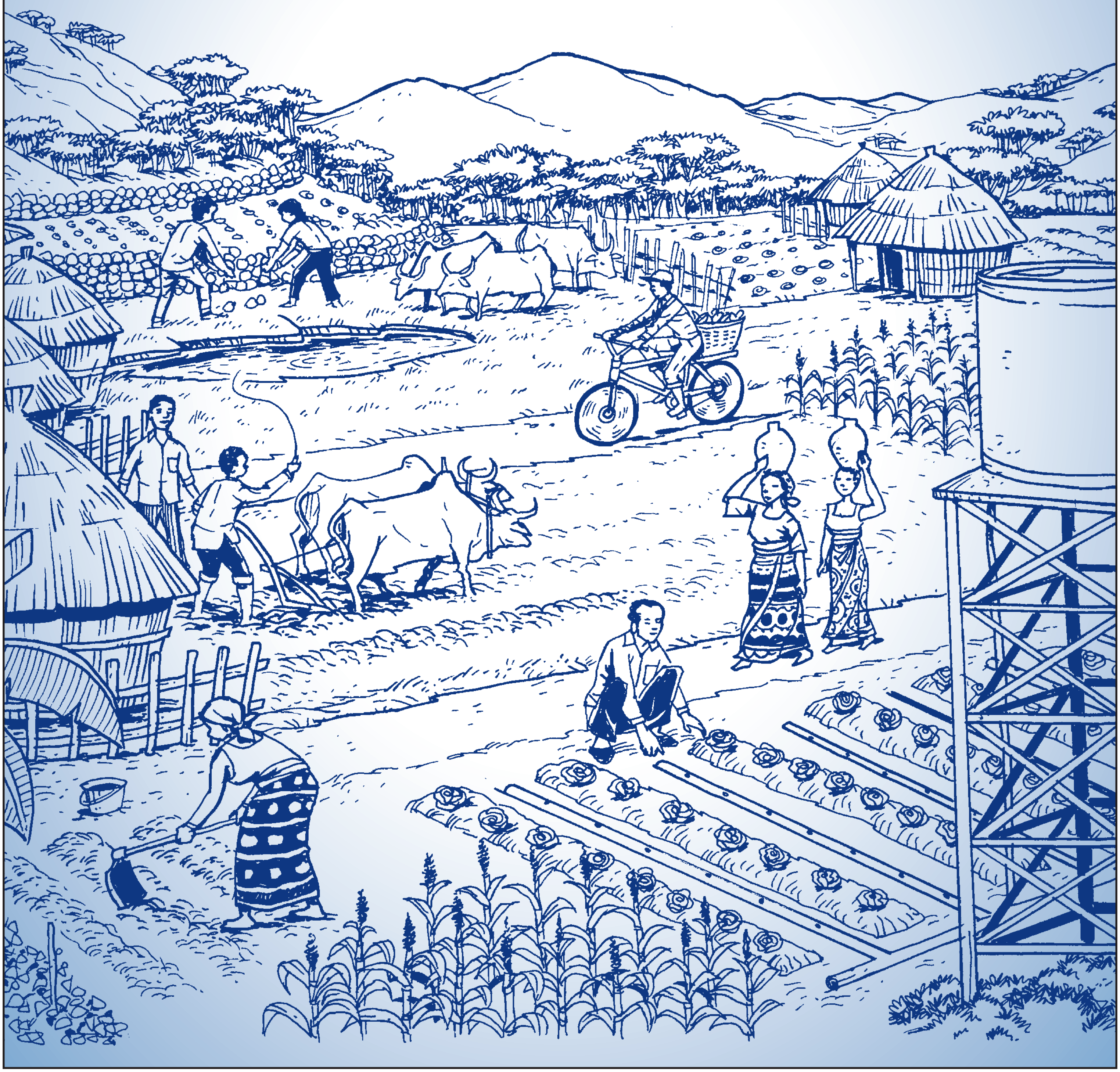

Gender Aspects of Small-scale Private Irrigation in sub-Saharan Africa

Irrigation is becoming an important trigger for agricultural growth in sub-Saharan Africa, with both women and men adopting small-scale private irrigation in ever larger numbers. This trend in farmer-led agricultural growth promises to enhance women's productivity and well-being, but only if research can clarify the relevant dimensions needed for effective interventions.

The opportunity

Researchers and program managers have done some assessments on gender in public irrigation schemes, where they have identified gender inequities in irrigated land allocation and membership in water user associations (Meinzen-Dick and Zwarteveen 1998; Van Koppen 2002; Peterman et al. 2010). However, support (and data) for small-scale private irrigation is still piecemeal, with many assumptions and stereotypes prevailing.

One such assumption is that men take the lead in technology adoption for improved productivity to better provide for their families. Yet women and men continue to have their own plots, crops, and incomes. Enhancing agricultural productivity requires, among other things, a better understanding of gendered production relations. Women could well be the leaders in private small-scale irrigation adoption, with women's labor generating incomes that women control.

The research

Researchers examined three gender-disaggregated variables using quantitative farm household surveys carried out under the Agricultural Water Management (AWM) Solutions Project in Ghana and Zambia: household headship; labor provision; and the use of small plots as intra-household production subunits (Table 1).

Table 1. Sample selection criteria and procedures

Country and region	Focus within regions	Sampling procedure and sample
Ghana Ashanthi Greater Accra Volta	• Focus on lift irrigation with some studies on other technologies	• Hut-to-hut census among 12,620 households in five regions • Hut-to-hut household survey among 494 households from 44 communities in 17 districts
Zambia Mpika Monze Sinazongwe	• Focus on all smallholder technologies with attention to the main technology per household • Selection of districts with highest prevalence of river diversions, motor pumps, conservation agriculture, and public irrigation scheme	• Hut-to-hut census among 1,935 households • Household survey among 240 representative households, randomly selected from census

In both countries, site selection focused on regions where AWM technology adoption rates were known to be high. In Ghana, the focus was on lift irrigation, but other combinations of technologies were also investigated. In Zambia, several technologies were represented: buckets, river diversions, motor pumps, conservation agriculture, wetlands and a public irrigation scheme.

In Ghana, 10% of the households were female-headed. Between 31% and 47% of these were de facto female headed households, that is, where the male heads of households are working elsewhere. De facto female-headed households tend to become more common with economic development, but have been largely ignored as a category.

Main findings

Technology adoption, by type of household

In Ghana, both male-headed households (MHHs) and female-headed households (FHHs) in all regions actively took up private lift irrigation and half or more moved into mechanization. There were small gender differences and exceptions.

The adoption patterns by type of household in Zambia were quite similar to Ghana. FHHs did adopt technologies but slightly less often than MHHs. FHHs adopted less labor intensive river diversions and motor pumps at half the rate of MHHs; cultivated wetlands twice as often as MHHs; used buckets more often than MHHs; and were more inclined to provide labor for agriculture.

Gendered labor provision for irrigation

Both men and women provided labor for irrigation. In neither country did we find cultural taboos, monopolization of mechanized technologies, or men categorically taking over irrigation for high-value cropping from women. Building capacity in irrigation skills among either women or men is socially acceptable. Control over the income from intrahousehold production sub-units (plots) further supports this view (Table 2). Almost all FHH-owning plots controlled money from sales (93%). When wives owned plots, they controlled the money in 69% of the cases.

Potential impact

The data imply that private small-scale irrigation adoption in sub-Saharan Africa is not necessarily a process driven mainly by male household heads in which women rapidly lose any independent farm

Table 2. Gendered decision-making about income from sale of farmer produce by owner of irrigated plot in Zambia

Owner of irrigated plot	N	Decision-making about income from sales of produce (%)		
		Female head or wife	Husband	Others
Female household head	N=14	93	–	7
Wife in MHH	N=13	69	15	15
Husband in MHH	N=90	24	57	19

The data also show that in MHH, the wife's decisions about the use of produce from her own plot and the husband's plot are relatively stronger on irrigated plots versus rain-fed plots.

productivity. The link between women's land rights and technology adoption warrants further attention. Gender equity in land rights may well contribute to more technology adoption among women.

Men tend to have better access to public support (e.g. extension services) and to private agricultural equipment and input stores, fuel stations, electricity companies, transport, and markets. Facilitating women's access to these assets would accelerate irrigation technology adoption even further. Targeting women for group ownership of motor pumps appeared to be an elective stepping stone to technology adoption as demonstrated in a World Wide Fund for Nature/SADC-Danida project in 2007.

The data suggest that a pattern of growth is emerging in which productivity and gender equality mutually reinforce each other. Agricultural support agencies will better achieve their goals by addressing structural disadvantages for women such as access to high-performing irrigation equipment, land, technical training and forward (e.g., output markets) and backward (e.g., inputs) linkages. This approach fully aligns with the aims of policies towards gender equality.

Using a bucket for irrigation in Keta, Ghana

Farmworkers using a hose connected to a powered pump for irrigation, Keta, Ghana

Source

Gender aspects of Small-scale private irrigation in sub-Saharan Africa by AgWATER Solutions. Agricultural Water Management Learning and Discussion Brief. September 2012. awm-solutions.iwmi.org

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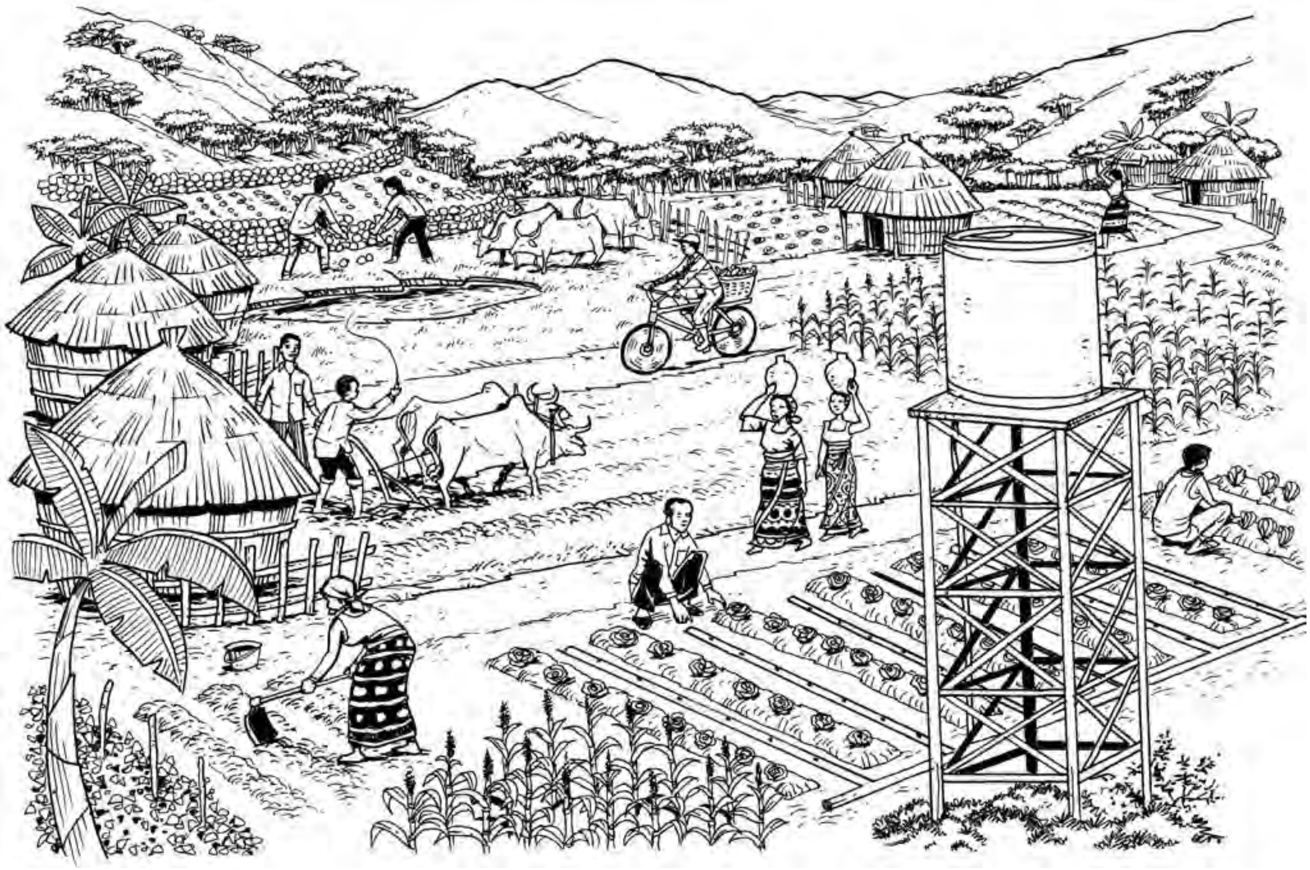
Putting Gender on the Map:
Methods for Mapping Gendered Farm Management Systems in sub-Saharan Africa



Gender differences matter in farming systems throughout sub-Saharan Africa, with ownership and management of farms and natural resources by men and women being defined by culturally specific gender roles. The different roles men and women occupy in various farming systems—whether it be planting, weeding, harvesting, postharvest processing, marketing, or food preparation for household consumption—vary depending on context and culture. Likewise the rights of men and women to access, manage, and own key resources—including land, water, livestock, and other key agricultural inputs—will also vary accordingly. While men and women farmers may play differing roles, both make important contributions to agriculture throughout sub-Saharan Africa. Estimates from the FAO (2011) based on internationally comparable data show that the female share of agricultural labor is almost 50 percent in sub-Saharan Africa, albeit with wide variations within and among countries. Despite this high contribution, in many instances the roles women play in farming and production are not formally recognized, and there is a persistent misconception among policymakers and farmers themselves that “women are not farmers” in spite of the myriad roles women play in agricultural activities (World Bank and IFPRI 2010).

There is increasing recognition that it is important to better understand the complex interactions between gender and agriculture within African farming systems if efforts to increase production and productivity are to be successful. However, there remains a significant dearth of data on the gendered nature of farm management systems in Africa. While there is a growing number of excellent in-depth studies on gender in agriculture, this information is not available for larger geographic areas. As maps and analyses based on geographic information systems (GIS) become an important tool for agricultural development planning. The lack of spatially referenced information on gender is particularly notable. As a result, planners developing agricultural or water management interventions, for example, do not know whether the interventions need to be targeted to joint household production systems or to men's and women's plots separately. Without information on gendered farm management systems, interventions are not able to target the appropriate decisionmakers and thus may lead to perverse outcomes by marginalizing or undermining women's production (see, for example, Schroeder 1993; van Koppen 2000, van Koppen 2002).

To a certain extent, this lack of data may be indicative of past tendencies within the agricultural research community to overlook the gender dimensions of agriculture. On the other hand, this lack of data may speak to the logistical difficulties of accessing this type of context-specific agricultural production information in the first place, and then of building up a spatially referenced picture of gender roles in agriculture. In particular, the great variability of gender roles, even within a single community, has limited the ability to generalize to larger areas. Overcoming these constraints requires three steps: (1) developing a better understanding of gender relations in agricultural production, (2) finding ways of aggregating observations to portray the dominant patterns in each area, and (3) geo-referencing the observations. This process is analogous to developing a soil map for Africa: There is clear variability in soils even within a field, let alone across a community or region. But soil maps are based on accepted soil typologies, ways of aggregating these soil types over larger areas, and georeferencing of the observations.

Gender and agriculture in sub-Saharan Africa

The rationale for gender mapping

African women are important in agriculture, and agriculture is important to African women. Women play significant roles in planting, weeding, postharvest processing, food preparation, and so forth (Schultz, 2001; Meinzen-Dick *et al.,* 2010). Despite the many roles African women play in agricultural production, however, they remain disadvantaged in numerous respects. To understand why agricultural productivity is often lower for women than for men, we need a broader understanding of the obstacles women face. For example, Udry (1996) found that productivity per unit of land on female-managed plots in Burkina Faso was 30 percent lower than on male-managed plots within the same household because labor and fertilizer were more intensively applied on men's plots. Extensive evidence documents pervasive gender inequalities in access to key agricultural inputs, including these:

- *Land:* Studies from throughout Africa demonstrate that women are disadvantaged in both statutory and customary land tenure systems (Lastarria-Cornhiel, 1997; Kevane, 2004). Even when legislation aimed at strengthening women's property rights is enacted, women often lack the legal know-how or enforcement mechanisms to ensure these rights are maintained.

- *Human capital:* In addition to well-documented gender disparities in education in many countries, studies from throughout Africa have found that women routinely have less access to agricultural extension than their male counterparts (Gilbert *et al.* 2002, Sakala, and Benson, 2002; World Bank and Republic of Malawi 2007; World Bank and IFPRI, 2010). Women are also disadvantaged with respect to labor because they have less access to labor-saving technology and to the hired labor needed for lucrative labor-intensive cultivation.

- *Technological resources:* Women are disadvantaged with respect to access to important technological resources, such as fertilizer, improved seed, irrigation, pesticides, and mechanical power. In a recent review of differential gender access to nonland inputs throughout the developing world, Peterman, Behrman, and Quisumbing (2009) reviewed 24 empirical studies and found that when input indicators were provided, 79 percent found that men had higher mean access and 21 percent found that women had higher mean access to the given technology.

In addition, many nontangible assets, such as social capital and decisionmaking power, are more difficult for women to access (Peterman *et al.* 2009, Behrman, and Quisumbing, 2009). These gaps in assets and inputs are a hindrance to agricultural productivity and poverty reduction. A wide-ranging body of empirical work suggests that increasing resources controlled by women could promote increased agricultural productivity (Saito *et al.* 1995; Udry *et al.* 1995; Quisumbing 1996). Udry et al. (1995) estimated that reducing inequalities in human capital, physical capital, and current inputs between men and women farmers in sub-Saharan Africa could potentially increase agricultural productivity by 10 to 20 percent.

Gender differences matter not only for food production but also for food use. From the broader perspective of food systems, women are income earners and guardians of household food security. Women play a crucial role in the distribution of the food and nonfood household resources that determine the food security of the household. In a variety of contexts around the world, increasing the resources that women control has been shown to improve the nutritional, health, and educational outcomes of their children (Thomas 1990; Schultz 1990; Lundberg *et al.* 1997; Hallman 2000; Quisumbing and Maluccio 2003; Skoufias 2005; Fafchamps *et al.* 2009).

Historically, the field of economics has been dominated by a unitary model of the household, in which the household was seen as a single unit that works together to pool common resources toward a common end. However, considerable evidence now exists to show that households do not act in a unitary manner when making decisions or allocating resources (Alderman et al. 1995; Haddad *et al.* 1997, Hoddinott, and Alderman 1997). This means that men and women within households do not always have the same preferences, nor do they always pool their resources. This reality has important implications for productivity. It is clear that men and women play different roles within particular systems of agricultural production and occupy different socioeconomic positions as a result of these different roles (Carr, 2008).

Several empirical studies have found that redistributing inputs between men and women in the household has the potential for increasing productivity (Saito *et al.* 1994; Mekonnen, and Spurling 1994; Udry et al. 1995). Not only are there gender disparities in control over agricultural inputs, but a growing body of empirical evidence suggests that increasing women's control over resources has positive effects on a number of important development outcomes, including food security, child nutrition, and education (Hallman, 2000; Quisumbing and Maluccio 2003; Skoufias, 2005).

Many of the reported gender analyses of agricultural production compare productivity of female-headed households (generally defined as having no adult male) with that of male-headed households, in which there is at least one adult male but usually also at least one woman. While such analyses are relevant for gender issues, especially when de facto female-headed households are included, they still use the unitary model of the household and hence miss the gender relations in male-headed households. For example, Holden *et al.* (2001), Shiferaw, and Pender (2001) reported that female-headed households in Ethiopia used land much less productively than did their male-headed counterparts, but this tells us nothing about the productivity of women within male-headed households. Are they, as is often assumed, only helpers on the farms of husbands, fathers, sons, or other male relatives, or are they joint decisionmakers, or do they have separate plots from those of the men? All of these patterns are found, especially in Africa. The key question is where.

Given all that we know about how men and women play differential roles in agricultural production and use resources differently, there is a need for context-specific, gender-disaggregated data on agricultural production. Gender mapping allows researchers to identify patterns in the gendered organization of farm management systems in a particular area, thereby allowing researchers and practitioners alike to better understand how to target water management and other agricultural interventions to women and men farmers.

Conceptualizing gender mapping

The underlying conceptualization of the farm household in gender mapping is the bargaining (or collective) model of the household (Safilios-Rothschild, 1988b; Quisumbing, 1996). While the unitary model of the household tends to focus on the (typically male) household head, often bypassing the roles of women in the farm management system, in the bargaining model a farm household consists of various subunits, each of which is typically managed by one adult household member. This model acknowledges that a person different from the household head can make decisions about a production subunit and that holding a land title is not required to manage a plot. Furthermore, this model allows for recognition that within the farming system, people engage in many tasks at multiple farming subunit levels and that agricultural production activities are not static but constantly changing in response to economic and social opportunities for the individuals, whose incentives may diverge from those of the household or the head of household.

Gender mapping is also a move away from studies that associate particular crops with men or women, problematically treating the category of women as singular, and by implication suggesting that the experience of, for example, all women in a particular country or agroecological zone is the same (Carr, 2008). Overgeneralizations of this nature are often too simplistic and potentially misleading when it comes to both context and scale of analysis. For example, Doss's (2002) examination of nationally representative household survey data from Ghana found that few crops could be defined as men's crops, and none was obviously a women's crop. This and other evidence suggests that in some settings, boundaries between male and female crops may be less rigid than they initially appear (Quisumbing et al., 2001). Though individual crops are not gendered, in some production systems there are nonetheless distinct gender patterns in crop choice (Wooten, 2003). However, Dolan (2001) showed that these patterns can quickly change as economic and social opportunities arise. In addition, the literature survey below reiterates the broad differences and similarities across countries, regions, and households.

In order to take these variations into account and examine larger trends, we propose to map the gendered management of farming based on who has greater managerial control of the aggregate system of the investments, production subunits, labor allocation, and profits within a specific region (Safilios-Rothschild, 1988b; van Koppen, 2002). This methodology allows for comparisons between different sizes and types of farm management systems. Although there are natural variations between households and farm management systems, such gender mapping illuminates trends from the community level to the subnational level, revealing how broad social and cultural variables impact a specific population. In addition, it allows for comparisons between aggregated farm management systems irrespective of their scale. In other words, small, female-managed groundnut plots and large, male-managed wheat fields are both examined.

Finally, gender mapping would generally take into account all types of production subunits that compose a farming system, including crops, livestock, and fisheries, which can highlight women's various contributions.

Gendered farm management systems can be defined by four types of management structures:

- *Male-managed farming system:* Agricultural production is completely or mostly controlled by the male head of household. Within this system, women either cultivate no land on their own, mainly providing labor for all agricultural activities, or cultivate only a small garden for household subsistence.
- *Female-managed farming system:* Agricultural production is completely or mostly controlled by women in either a female- or male-headed household. Women are the main decisionmakers about production and the use of outputs from the farming enterprise. In almost all cases, these households are either de jure female headed, in which women are widowed, divorced, or single, or are de facto female headed, in which women run the household and farm because their husbands are engaged in nonfarm labor or have migrated away from the household (Safilios-Rothschild 1988b).
- *Separately managed farming systems:* Both men and women control production subunits and are farm decisionmakers in their own domains. In this model, men maintain a specific plot or type of crop, livestock, or fishery while women are responsible for maintaining another subunit. Although they may provide labor or contribute inputs, such as fertilizer, to each other's subunits, men and women each have separate decisionmaking authority and control of outputs. While some researchers (such as Carr 2008) have tried to identify trends for the types of crops and livestock that men and women tend to control, Doss (2002) showed that most crops are maintained by both genders.
- *Jointly managed farming system:* Men and women share labor and decisionmaking over the farming enterprise and control the outputs. They have joint landholding and accounts. These management types can be identified at household, community, or higher levels of aggregation. Even at the level of the individual household, there may be some difficulty in

identifying the degree to which production in a household with at least one adult man and one adult woman is joint, separate, or male managed. At the community or higher levels of aggregation, it becomes necessary to identify the dominant pattern for display on a map. Because female-managed farming systems are almost always restricted to households with no man in agriculture (de jure or de facto female-headed households), it would be rare to find female-managed farming systems as the dominant pattern at the community or higher level. But when there is a mix of farm management systems in a community, district, or state, it becomes more challenging to identify the dominant form.

As an alternative to identifying areas in terms of a single dominant farm management system, it is possible to reflect a mix of systems by shading maps to indicate gradations between different systems. However, such shading is most easily done when there is a continuum, as between percentage of female and male-managed enterprises. In this case it is difficult to identify whether the middle ground is composed of a mix of male- and female-managed enterprises or a mix of joint and separately managed farming systems.

It is thus imperative that researchers and practitioners identify the unit of analysis used on the map: Is the type of farm management system determined at the level of production subunit, household, or area? In order to create the map, it is important to aggregate to area level, identifying the general patterns in a community or region. Furthermore, while there may be a dominant pattern, other types of farm management systems usually are present in the same area. It is thus desirable (though difficult) to identify the level of error and state what proportion of the area is represented by the specific type.

It is also important to distinguish between normative patterns and those that apply in practice. For example, during the workshops to identify gendered farm management systems in Zambia and Ghana, respondents tended to select jointly managed, especially when the relationship dynamics were unclear or complex. However, further probing revealed that only one adult member of the household made decisions about a specific production subunit. On the other hand, where patriarchal norms are strong, respondents may identify male-managed farming systems even where women have significant independent production. When carrying out a survey or workshop, it is important to note the respondents' gender, nationality, and experience, which could potentially have a significant impact on shaping their perspectives on gender dynamics.

While it is critical to identify broad patterns in gender roles of women in agriculture, it is equally important to recognize that these patterns can change. Shifts in economic and sociopolitical conditions can significantly alter the dynamic between men and women in various ways. As markets develop, women can find new opportunities for income generation, but they can also be pushed out of the market by men (Dolan, 2001). Migration by men for economic opportunities is also prevalent in sub-Saharan Africa and can have mixed impacts on women's decisionmaking power and workloads in agriculture (David, 1995).

Source

Putting Gender on the Map
Methods for Mapping Gendered Farm Management Systems in Sub-Saharan Africa by Ruth Meinzen-Dick (r.meinzen-dick@cgiar.org), Barbara van Koppen, Julia Behrman, Zhenya Karelina, Vincent Akamandisa, Lesley Hope, Ben Wielgosz. January 2012.

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Using Gender Mapping and Analysis to Boost Benefits from Agricultural Water Management Projects and Investments

Agricultural water management (AWM) investments that enhance both women's and men's productivity are likely to yield the greatest gains in agricultural growth and poverty reduction, as well as narrow the 'gender gap'. Achieving this requires an understanding of the different roles women and men play in agricultural production systems.

In some systems, women and men have separate farming enterprises, each making decisions for their own fields, gardens, or livestock. In others, agricultural production is a joint enterprise between men and women, with both having some say in decisions. And in still others, men dominate and women take part as unpaid labor or not at all. Knowing who makes the decisions and how labor is organized allows for better targeting of technology dissemination strategies and more effective AWM solutions. It also reveals where there are opportunities to unlock women's productive potential.

Currently, too little information is available on the gendered organization of farming. The AgWater Solutions Project is helping to fill this gap by mapping the estimated prevalence and scale of the various gendered farming systems in the six project countries and elsewhere in sub-Saharan

Why considering women's role is critical for crafting AWM solutions

- Women perform much of the agricultural work in sub-Saharan Africa. And, in many areas, a significant proportion of farm decisionmakers are women.
- Women often lack the resources that men have, but, when they are given equal access to resources and control over outputs, women farmers are as productive as their male counterparts.
- New technologies may increase women's workload, yet, women often do not have a say in adoption.
- AWM interventions that increase women's incomes are likely to have greater benefits for family welfare than those that target only men, since women tend to spend a higher proportion of their incomes on food, school fees, and health care for their children.
- AWM technologies can impact domestic water availability—positively or negatively—and thus reduce or increase the burden of carrying water, which is most often shouldered by women.

Africa. The project is also developing a portfolio of technological intervention approaches suited to the different systems and tools and recommendations for investors, implementers, and researchers to help them incorporate gender considerations into AWM technology investment and dissemination strategies.

Gender mapping to guide solutions

Because gender relations and issues vary widely, there can be no blanket strategy for gender-sensitive introduction of AWM technologies. Yet, there are patterns that allow project designers and technology investors to develop context-specific strategies that can be implemented at scale. The AgWater Solutions methodology looks at who makes the decisions and has control over the resources and outputs of intrahousehold production subunits and classifies subunits as female-managed, male-managed, or jointly managed. These subunits may include enterprises such as field cropping, homestead gardening, livestock keeping, and forestry.

Using production subunits rather than households or farms as the unit of analysis respects the diversified livelihood strategies pursued by most smallholders and reveals otherwise hidden opportunities to improve women's productivity and incomes. For example, in a given area, although men may dominate field cropping and cattle herding, women may have control over homestead gardens and chickens.

Based on the prevalence of female-, male- and jointly managed subunits, the aggregate agricultural production system of a specific area can be classified according to the dominant pattern as female, male, mixed, or joint (see table).

Unlocking women's productive potential

The analysis of the gendered organization of farming not only raises gender awareness but also enables the design of appropriate intervention strategies. The AgWater Solutions project will analyze and document best-practice strategies for the different farming systems. Great opportunities to improve women's productive potential and incomes lie in targeting female and joint farming systems.

In female farming systems: Interventions will only succeed if they primarily target women and ensure that women's own access to rainfed or irrigated land, technologies, and forward and backward linkages (e.g., to input and output markets) is improved.

In mixed farming systems: Technology adoption processes need to target both women and men as farmers in their own right. Technologies need to suit farm size, crops, and site of both male and female-managed subunits. Ideally, in such systems, men and women farmers will have secure land rights and equal access to information, credit facilities, and marketing linkages.

In joint farming systems: The challenge is to shape the process of technology adoption in such a way that women and men become co-owners of the new technologies and equally share in the burdens and benefits.

In male farming systems: Carefully designed interventions can encourage a shift toward more productive and wealth-creating jointly managed farming. Here, the introduction of measures such as women's inclusion in services and implementation

Various patterns of production enterprises.

Type of farming system	Definition	Implications for interventions
Female	The majority of farm decision-makers are women.	Solutions will only work if they target women.
Male	The majority of farm decision-makers are men.	Solutions should consider the impact on workloads and decisionmaking power of female unpaid family laborers and reach out to the minority of women who are farm decision-makers (de facto and de jure female-headed households and entrepreneurial women).
Mixed	Both women and men control production subunits and are farm decisionmakers in their own domains.	Solutions should target both men and women and ensure that both are represented in project institutions.
Joint	Most subunits are jointly managed by women and men, who both have a say in decisions.	Solutions should consider the division of tasks, benefit both men and women, and ensure equitable benefits and representation in project institutions.

strategies, joint land titling and men's sensitization can gradually result in genuinely joint enterprises that benefit both women and men. The formation of women-only groups and organizations and the use of activities in which women are relatively strong, such as micro-credit, as entry points can support a shift to jointly managed production.

In all farming systems: Opportunities of multiple water uses, in particular for domestic water provision to homesteads should be tapped. Strengthening women's land rights gives women greater decisionmaking power over resources and outputs.

Project outputs

- Intrahousehold analysis of AWM intervention adoption/disadoption, constraints, and impacts.
- Evidence-based menu of AWM solutions and targeting strategies to suit different gendered farming systems.
- Map for Africa of estimated prevalence and scale of female, mixed, joint and male farming systems (for better design and targeting of solutions).
- Generic tools and methodologies for assessing the gendered organization of farming and potential impacts of AWM solutions.

Key points for investors and implementers

When introducing AWM technologies or developing solutions, taking into account the gendered nature of the farming systems and targeting both men and women can

- improve the chances of uptake;
- result in solutions that meet needs and priorities of men and women, which are sometimes quite different;
- ensure that all household members, including women and children, benefit;
- expand the nature of the benefits, for example, by not only increasing income but also improving health through improved domestic water supply, enhanced nutrition or more money spent on health care; and
- result in higher gains in household income and productivity overall, since it fulfills the productive potential of women as well as men.

Source

Men + Women + Water = Greater Poverty Fighting Benefits by AgWater Solutions. Improved livelihoods for smallholder farmers. Project Gender Focus. Project Overview Brief Series. www.awm-solutions.imwi.org

Participatory Screening and Evaluation of Agricultural and Natural Resource Management Technologies

While there are a number of well-documented methods for screening and evaluating agricultural and natural resource technologies, there is not an approach tailored to the specific challenges of agricultural water management (AWM). Such an approach could greatly increase the percentage of AWM initiatives that succeed, while enhancing benefits and reducing associated negative externalities.

To fill this gap, the AgWater Solutions Project is developing and testing an approach known as Participatory Rapid Opportunities and Constraints Analysis (PROCA). PROCA provides a systematic analysis of different types of innovations (technology, policy, community empowerment) in order to identify solutions for improving agricultural water management and ultimately smallholder livelihoods.

Donors, ministries, investors, and NGOs can use PROCA to

- design and refine AWM investments or projects, and
- monitor and evaluate ongoing projects to improve implementation and assess the impacts of completed projects.

Putting PROCA into action

PROCA has three basic steps (see table). The steps are not necessarily linear and not all may be needed to identify appropriate innovations. They depend on whether the innovations under consideration are software (e.g., policy changes) or hardware (e.g., small-scale irrigation technologies) and how well-tested they are. In addition, the steps can be adjusted to suit ex ante or post evaluation.

Situation analysis and initial screening

This step starts with making an inventory of existing initiatives, ideas, and projects: Who is doing what? What approaches work and where? What are the factors that influence success or failure? The idea is to cast the net wide and look not only at technologies but also policy and management innovations.

Next, the resulting long list of possible AWM solutions must be screened using four key criteria (see Table) to identify those that deserve a closer look. In the AgWater Solutions Project, an important element in this process is the national consultation meeting where stakeholders make a first selection of promising solutions for their country. This national scoring and priority-setting exercise not only facilitates rapid identification of the most appropriate AWM solutions but also improves linkages among stakeholders and builds a spirit of collaboration.

Analyzing opportunities and constraints

Step 2 is to analyze opportunities and constraints for the promising solutions identified in Step 1, while looking for ways to enhance the former and ease the latter. PROCA focuses on seven clusters of constraints that must be addressed for a technology or a policy/management innovation to succeed. Some of these constraints will be internal to the community and can often be resolved locally; others will be the result of external forces and will require action at higher levels (for example, changes in national policy). This analysis will result in an even shorter list of possible solutions and a better understanding of the circumstances under which they can be successful.

Analysis of outscaling impacts

Although it is important to consider outscaling impacts from the beginning of the process, a more in-depth impact assessment is required before promoting the spread of an innovation. Step 3 is to evaluate the likely positive and negative impacts and externalities of outscaling the promising AWM solutions identified in Step 2, looking at the potential to positively or negatively affect water resources, the wider economy, and the environment.

The three interactive steps of PROCA.

Step	Activity	Methods	Key evaluation criteria
Step 1: Situational analysis and initial screening	Identification and prioritization of possible AWM solutions	Literature reviews, secondary data collection and analyses, brainstorming, surveys, workshops, gender mapping, priority setting using scoring and ranking techniques	Impact potential, gender-equity, scale potential, implementation pathway (ex-ante)
Step 2: In-depth case studies	Further evaluation of AWM solutions that passed step 1	Field research, modeling	Access, economics, social and institutional dynamics, backward linkages, forward linkages, resource sustainability, externalities
Step 3: Analysis of outscaling impacts	Analysis of sustainability and externalities at larger scales	Hydro-economic modeling, partial equilibrium analysis (e.g., cost–benefit analysis, economic surplus analysis), GIS/RS applications	Sustainability, externalities

Key questions for evaluating opportunities and constraints

1. Technology access: How accessible is the innovation at the household level and, in particular, to women?
2. Technology economics: How affordable is the innovation to adopt and maintain? What are the costs (in terms of money and labor) and benefits (in terms of income and food and livelihood security) and how are these distributed among different members of the household and the community?
3. Techno-institutional, social, and policy dynamics: What institutional structures are necessary to support uptake and optimal performance of the innovation? To what extent are these present, functioning, and accessible to men and women?
4. Backward linkages: How strong (or weak) are the input linkages necessary to adopt and benefit from the innovation?

Advantages of PROCA

It's participatory – PROCA involves a variety of people at different stages and levels: farmers, policymakers, donors, researchers, and key informants. Thus, it takes advantage of local knowledge and ensures that solutions that are tailored to the context and the needs of end users.

It's rapid – PROCA relies on participation of stakeholders to identify tentative solutions and then screen and prioritize the most promising ones for more in-depth analysis. This phased approach saves time and resources and demonstrates results up front, which helps keep stakeholders engaged.

It's multidisciplinary – To provide a more complete picture, the conceptual and theoretical basis of PROCA draws from the fields of hydrology, water resource management, sociology/social-anthropology, economics, management science, and irrigation engineering.

It's scalable – PROCA can be used at a variety of scales—farm, community, or watershed—and can be used to assess the potential for further outscaling.

It's adaptable – PROCA gives the user the freedom to use a variety of tools and methods as long as they provide robust answers to the evaluation criteria defined in the protocol. The table provides an overview of some compatible tools and methods. By outlining a common but adaptable approach, PROCA facilitates comparison of AWM interventions across types, sectors, and countries.

Project outputs

- A **proven methodology** to assess AWM interventions.
- A **portfolio of promising interventions** by country, selection criteria, and circumstances under which they succeed or fail. These results will be synthesized in a series of intervention briefs.

The four hurdles: Criteria for identifying promising solutions

Possible solutions are evaluated and compared according to four key criteria. These criteria can be thought of as hurdles that the possible solution must pass in order to qualify for the next step. The four criteria are

- **Contribution to smallholders' livelihoods.** It increases smallholder income, food security and household water availability and decreases drudgery, income fluctuation and risk.
- **Gender and equity considerations.** It benefits women as well as men, does not place an undue burden on women or children, and does not increase income disparity in a community.
- **Out-scalability.** It has the potential to benefit a relatively large number of people over a wide geographic area.
- **Ease of implementation.** It has an implementation and dissemination pathway that is sustainable and cost-effective and an identifiable champion to carry it out.

Source

Opportunities – Constraints = Successful Uptake of Innovations by AgWater Solutions. Project Overview Brief Series. www.awm-solutions.imwi.org

Using the Learning and Practice Alliance Model to Promote Water-Smart Agricultural Technologies in Otuke District

The Learning and Practice Alliance (LPA) is an approach used by the Global Water Initiative East Africa (GWI EA) to facilitate learning, information dissemination to promote water-smart technology adoption, and influence policy at local and national levels. LPA has been described as multistakeholder engagement (Lundy *et al.,* 2005), a platform, (Yasabu, 2008), and a multisectoral, multistakeholder framework that uses stakeholder-led research to inform interventions (Kennedy *et al.,* 2014). It has been used to deliver the GWI EA strategic outcomes, contributing to the goal of "smallholder farmers achieving greater food security through more sustainable access to and productive use of water." The outcomes of the program are greater political attention to water for smallholder production achieved through changes in policies and plans and their effective implementation; increased investment in smarter, affordable, and innovative solutions to provide water for smallholder production, especially for women farmers; and greater say for women smallholders in institutions that regulate and control access to water for agriculture.

Problem statement

Agriculture extension is the key to the transformation of Uganda's agriculture sector. The sector supports 86% of rural livelihood (MAAIF, 2014). Different extension approaches have been adopted over time (Bashaasha, 2008): Train and Visit (T&V), which is a unified extension system adopted in the late 1980s, was implemented through the public service delivery system with funding from the state. More recent models are aligned to public service reforms; flexible, pluralistic, with focus on efficiency, relevance, and appropriateness, recognition of the role of private sector and increased participation of farmers in decisionmaking, thus addressing issues of cost effectiveness of extension services (Bashaasha, 2008).

In spite of these positive attributes, Nahdy (2014) observes that weak linkages among the actors are responsible for the stagnant growth in agricultural productivity. The Otuke baseline (2013) established that farming households, on average, realized only 15–20% of target yield in a season and only 10% practiced soil and water conservation practices. Yet, the area is fairly dry, receiving between 700 and 1,300 mm of rainfall annually.

Such findings are partly attributed to limited access to and use of technologies due to poor linkages among actors (Naluwairo, 2011). The high farmer to extension worker ratio was estimated at 1:1,500 (Rwakakamba *et al.*, 2008), accounting for only 10% of farmers being served (Rwamigisa, 2014) despite the presence of many actors in the sector. Adopting the LPA approach by all stakeholders along the water-smart agriculture value chain is an opportunity to find solutions that increase farmers' resilience and capacity to cope with weather variability. LPA partly responds to a call by participants in the 2006 African Advisory Services Symposium (AASS) and the recommendation by Naluwairo (2011) to the Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF) to foster cooperation, linkages, interactions, and feedback mechanisms between and among players in the agricultural sector.

Implementation methods and tools

The LPA is an opportunity to implement the 2006 AASS participants' recommendation to adopt an extension system that supports interconnectedness and enhances feedback (Nahdy *et al.*, 2006). The LPA employs farmer-led action research with an in-built mechanism that involves all actors and provides feedback during the process.

Steps in establishing an LPA

1. *LPA formation/setup phase*

Stakeholders are identified and brought together to build a common understanding and a shared purpose for their existence.

a. *Stakeholder identification and consensus building.* A thorough institutional and stakeholder mapping at the national and district levels is conducted. This helps to place the LPA in the wider context. The most relevant actors are brought on board right from the start. The institutional and stakeholder mapping (2013) identified the most relevant actors as smallholder

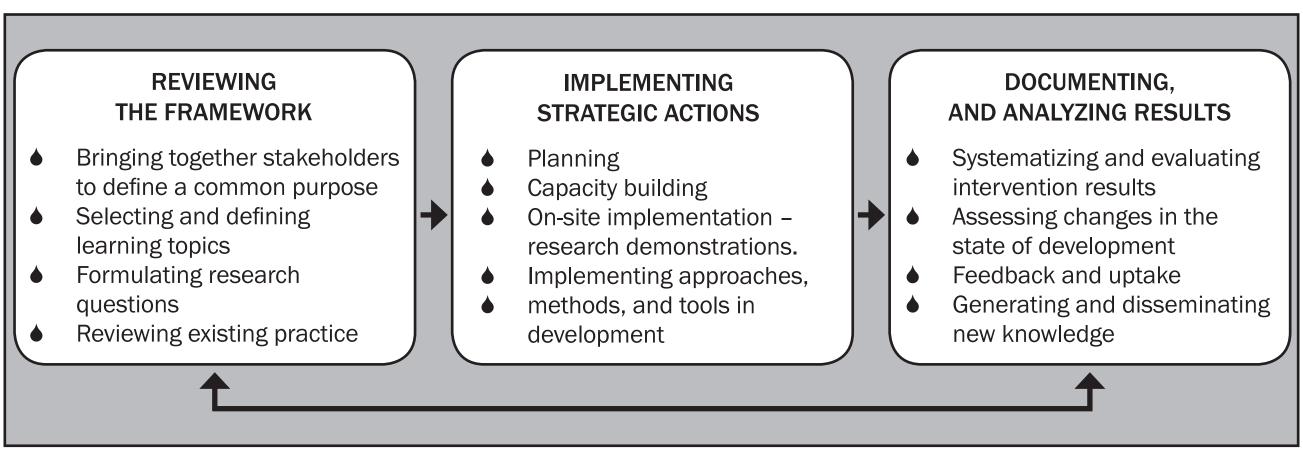

Fig. 1. *Double loop learning cycle in a learning alliance (Adopted from ILAC Brief).*

farmer forums, local government technical departments (e.g., community development, production and marketing, agriculture, water and environment), politicians at subcounty and district levels, research institutions like the Zonal Agriculture Research Institute (ZARDI), teaching universities, nongovernment organizations (NGO), media, and private sector. The diverse level of expertise of LPA stakeholders requires building a common understanding. This takes the form of training, providing information, and exposing members to different contexts of the LPA. The key issues covered include the what, how, when, who, and why of LPA. These experiences were used by the participants to establish their own LPA in Otuke District.

b. *Establishment of management structure, committees, and roles, and responsibilities.* Clarity of purpose, scope, and governance are central to the success of the LPA. Members are supported to constitute a task force that drafts the terms of reference for LPA to approve. Roles are articulated, a governance structure is agreed upon, and office bearers are nominated. The Otuke LPA formed a steering committee to provide an oversight function to the LPA. The action research teams undertook research activities on agreed topics and GWI EA served as the LPA secretariat.

2. *Planning and reviewing the existing approach*

a. *Review of existing practice.* The LPA is supported to review existing technologies, approaches, and practices. They identify what is working and the challenges of adoption. Using different participatory appraisal tools such as question-and-answer, brainstorming, or focus group discussions, they analyze and prioritize issues generated and agree on how to tackle them.

b. *Selection and definition of research topics and questions.* The issues earlier generated are further discussed and refined with the farmers' input. Together with farmers, they rank them in the order of importance, agree on three priority issues, and form topics for action research. The steering committee refines the topics and drafts the research questions.

c. *Formation of research teams.* Based on the topics and using the self-select principle, members were asked to choose a research topic of their interest, knowledge, technical competence, and with a potential to contribute to their institutional mandates. Each research team comprises five to nine members. This ensures that the formed research teams remain committed throughout the research cycle. Each team has two researchers from a teaching university and an agricultural research institute, a technical person from local government, farmers, a politician, a media person, an NGO representative, and where available, a woman.

3. *Implementing strategic actions*

a. *Design and adaptation of methods and tools.* The research teams identify chairpersons and secretaries to guide the execution of the action research. The secretaries are the custodians of minutes and documents generated during the research cycle. The steering committee supports the research team to refine the research questions and develop objectives of the action research. The research team designs the methodology and data collection tools. They work with the farmers to develop criteria for selecting farmers to host the technologies. The criteria in Otuke include ownership of at least 2 ha of land; willingness to learn and train others; readiness to host, maintain, and develop technology demonstration sites; and commitment or support from a spouse. All tools were reviewed and approved by the steering committee on behalf of the LPA.

b. *Capacity building and action research activities.* Both research team and champion farmers undergo a series of training to harmonize understanding and expectations. At the farmer level, the focus of the training is setting up and managing the demonstration plots. For the research teams, the training focus is support of champion farmers, data collection, and analysis skills and the team agrees on the role of each member in the research process. This increases the sense of ownership and commitment and members feel valued. Capacity building is a continuous process in the action research cycle and strengthens learning within the LPA.

4. *Documenting results and learning*

a. *Assessment of changes in the state of development.* The research teams pretest data collection tools for reliability and they review farmer's records during routine monitoring. This ensures compliance with agreed on standards for managing demonstration plots. After each monitoring exercise, teams convene to review experiences and agree on how to deal with challenges; three to five meetings are recommended in the entire research cycle.

b. *Analysis of results. Individual research teams review the collected data:* They process, sort, analyze and interpret data. This is consolidated into a research report which is enriched with qualitative data in the form of farmers' experiences with different water-smart technologies. The draft report is shared with the steering committee and the secretariat for further input and refinement.

c. *Experience sharing and learning meetings.* The chairperson of the LPA, with support of the steering committee and the secretariat, convenes the LPA meetings. Research teams are invited to provide updates on research and present the research reports at the district level. Meetings for targeting the champion farmers who hosted technology demonstration sites are also convened to share experiences. These platforms encourage peer learning among the champion farmers. In these meetings, common challenges are identified and solutions agreed upon by all the champion farmers. These meetings are also used to corroborate the results.

GWI EA has already achieved a degree of success through the LPA framework. Noteworthy accomplishments to-date include the strengthened relationship between local government and champion farmers and new interactions among diverse LPA members. (Independent evaluation, August 2014 – Emory student interns)

Monitoring and evaluation

The LPA has a built-in and well-structured monitoring and evaluation system that allows feedback, dialogue, and hence internal reflection. It also allows continuous review of progress and identifies lessons and challenges during the research cycle, which supports joint problem solving.

In order to track behavior change, outcome mapping is used to gauge progress. Outcome journals are kept by the GWI EA teams on selected boundary partners that are critical to assessing behavior with regard to adoption of the water-smart agriculture technologies in households and the community districts that form the LPA.

Lastly, an external review was conducted by a team of Masters' research students to assess the LPA achievements. Their findings confirmed that LPA's systematic feedback mechanism builds a strong sense of ownership. This instills commitment both from farmers and decisionmakers, thus increasing the potential of stakeholders to adopt water-smart agricultural technologies.

Key achievements

- District ownership of the process: The district agricultural officer chairs the LPA and relevant district departments are active members. The District Production Department allocated and prefer UGX 4 million on a drip irrigation system on a demonstration site in Olilim sub-county.
- Increased adoption of water-smart practices and techniques that were not in Otuke before: Initially, the project started with 24 champion farmers, 16 of whom were women; by the end of the first cycle, the number of adopters had increased to 27 youth, 20 of whom were men and 7 were women.

New farming techniques such as ridges, minimum tillage, and cover crops have been adopted by farmers. The farming members of the LPA have demonstrated willingness to procure their own agro input and are expanding the land under improved agricultural practices in anticipation of higher yields.

Members of the LPA come possessed with diverse technical and practical experiences. Once research topics have been agreed upon, members choose to participate in an action research study where they feel comfortable to provide technical knowledge, or where the organizations they represent have an interest because of mandate or where the individual has personal interest. This helps keep the research teams committed throughout the entire cycle.

Results

The immediate outcome has been the increase in knowledge and skills in the production of vegetables. Champion farmers earned extra income from growing and selling tomatoes. Farmers earned between UGX 330,000 and UGX 1 million from plots ranging in size from 200 to 600 square meters. This compares very favorably to the previous experience when farmers with very low incomes grew several crops on larger pieces of land (see box). This motivated farmers to procure inputs for the second cycle and attracted the youth to participate in agriculture where all 27 are below 35 years of age.

To date, a number of techniques and practices of soil and water conservation such as surface runoff, groundwater management, and conservation agriculture have been successfully piloted with the initial 24 farmers who were taken on as champion farmers. More noteworthy, 27 adopters are also practicing the soil and water conservation techniques learned from the champion farmers.

Conditions for long-term cooperation and coordination within the sector have been created through joint learning between farmers, researchers, extension workers, and policymakers and farmers informing the learning agenda as observed by Jillian Kenny in her blog (http://www.gwieastafrica.org/lpa-the-glue-that-binds-smallholders-and-district-officials-in-otuke/).

Local-level action research activities are now linked to the national level process through the research oversight committee with the Uganda parliamentarians' forum on food security further galvanizing the learning.

Key challenges

The LPA is a new concept that involves working with many stakeholders to generate action research results in a short period of time. Therefore, a flexible approach that emphasized building members' knowledge and concurrently working on the LPA establishment was adopted. Participation in the LPA is voluntary, and balancing the demands from their mainstream work would have been difficult in the critical research stages. Pegging the membership of research teams to individuals' interests and institutional mandate maintains commitment.

> Santa Opio Acen, a champion farmer in Orum subcounty says, "Last season (December 2013), from 3 acres of land, we harvested 3 basins of beans, 4 bags of unhulled rice, and 200 kg of millet. We only earned UGX 175,000 from the sale of 2 bags of rice. The plot size for Santa Acen was 400m^2 from which she earned the family earned a gross income of UGX 359,700."

The LPA activities were tied to the cropping cycle, which was delayed by late onset of rains. This meant that LPA field research activities were also delayed. However, the time was used to plan, design the research, develop data collection tools, mobilize communities, develop criteria, and select champion farmers as well as support training and establish, manage, and monitor the demonstration plots.

Conclusion

The LPA is an effective tool when complemented with action research driven by farmers whose behavior and practices are being influenced. With only 18 months of implementation, the LPA approach has demonstrated great potential to influence adoption using experiential learning through observation and reflection, which are embedded in the entire process. This supports action and accountability at different levels.

The LPA has demonstrated that promotion of water-smart agriculture technologies should be promoted together with marketable crop enterprises. This has been the incentive that attracted the youth to take up technologies because it was economically feasible as crop loss was minimized and there was ready market for the produce. It is important to select water-smart technologies together with crops and assess the viability of the entire value chain to minimize risks.

Adopting a structured process with jointly agreed milestones and timeframe ensures that all stakeholders are engaged. This harmonizes expectations and supports members to hold one another responsible. It is also imperative that financial resources are mobilized before introducing the LPA. Over time, external funding should decrease as efforts to integrate the LPA into the existing government structure is ensured from the start as a sustainability measure.

The government and other actors are encouraged to adopt the LPA approach as a mechanism to enhance coordination, synergy, learning, and feedback and ensure increased adoption of the water-smart agricultural technologies because of their effectiveness.

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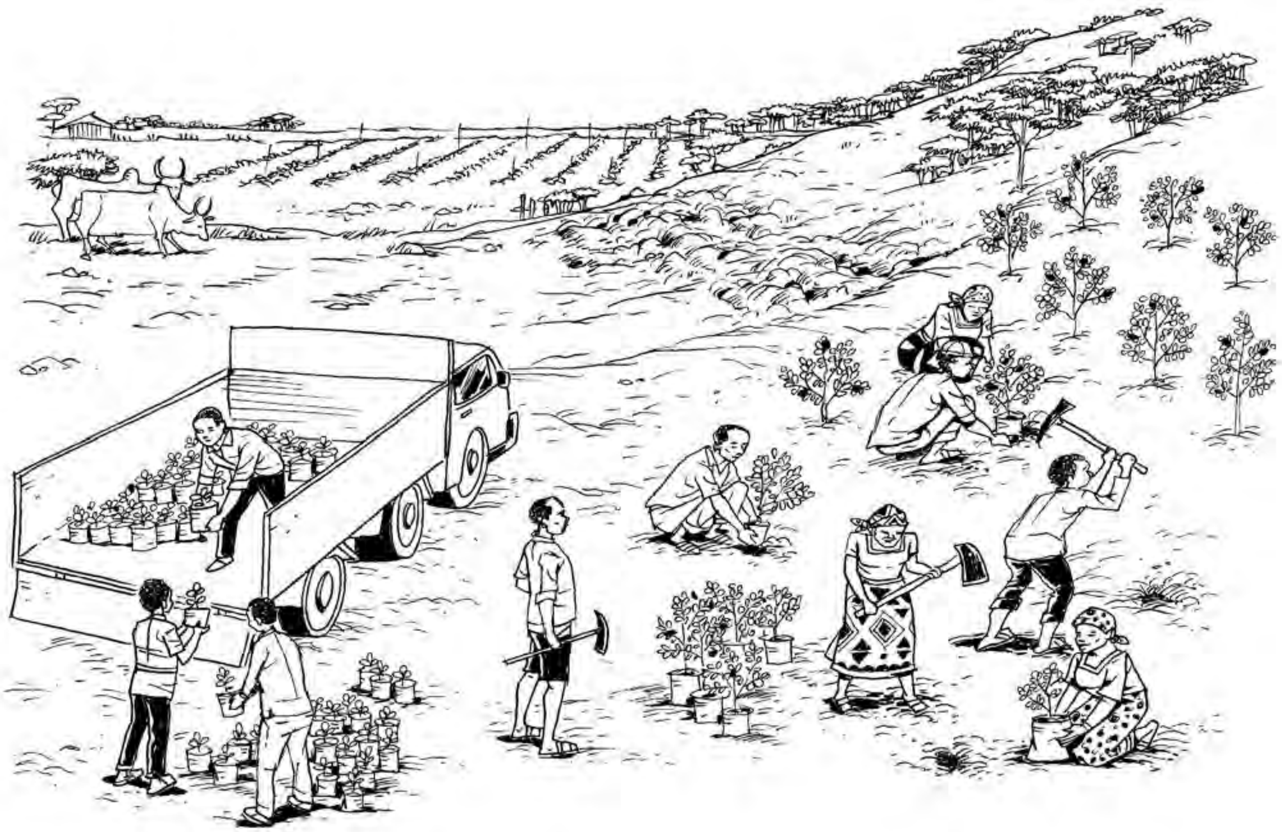
Role of Collective Action and Policy Options in Fostering Participation in Natural Resource Management



With globalization and liberalization, combined with democratization and the information revolution, the roles of governments and socioeconomic actors have changed significantly. From a direct role in delivery, governments are now beginning to act as facilitators. At the same time, communities are demonstrating far greater interest in public affairs and committing themselves to contribute more actively to the socioeconomic development of their countries. Furthermore, globalization, marketization, agglomeration, and corporatization of the economic sector are reducing policy space for the government, which diminishes the state's ability to manage information, respond to contingencies, and reach out to the poor in a manner that is mutually beneficial, transparent, and accountable (UNESCO, 2007). In such changing circumstances, governments, and NGOs, among other practitioners, should aim to transform themselves from using paternalistic approaches to using engaging partnerships with local institutions.

The past decade has seen the benefits of transferring control over natural resources from central governments to local bodies. Community-based management and the empowering of local communities hinge on concepts such as co-management, using local/indigenous knowledge, recognizing local institutions, and establishing a common property regime (Ostrom, 1990; Berkes, 1989). Local users often have intimate knowledge of the resource and because their livelihoods depend on it, they have the greatest incentive to maintain the resource base. It is now widely believed that people will only defend common properties if they feel they have a stake in them (Ostrom and Wertime, 2000). Therefore, giving certain benefits or empowering local users to be appropriators encourages communities into using a common resource in a sustainable manner.

The success of community organizations in the management of natural resources depends largely on collective action so that where local institutions are self-organized, the chances of success are higher. Social capital creates the capacity for collective action, which allows for better bargaining power, especially over rights governing natural resources that may be considered 'common property.' In Eastern Africa, as in many other parts of Africa, collective action is recognized and encouraged for development among rural populations (Place *et al.,* 2004).

Social capital, which is categorized into structural and cognitive components, is often associated with the ability of groups to act collectively. For instance, structural social capital includes composition and practices of formal and informal local institutions that are instrumental in community development (Sultana and Thompson, 2003). It is built through transparent decisionmaking processes, accountable leadership, and practices of collective action and mutual responsibility. Through structural social capital, groups or communities take collective action through established roles and social networks that are supplemented by rules, procedures, and precedents. On the other hand, cognitive social capital embraces values, beliefs, attitudes, and social norms that influence people and communities toward collective action (Sultana and Thompson, 2003). The values include cooperation, trust, solidarity, and reciprocity shared among members of a community, which create conditions under which communities can work together for a common good.

Natural resource management (NRM) is an approach that integrates research of different types of natural resources into stakeholder-driven processes of adaptive management and innovation. Local institutions should, through collective action, use NRM to improve livelihoods, ensure agroecosystem resilience, agricultural productivity, and availability of environmental services. NRM should help solve complex real world problems affecting natural resources.

There is a need for a holistic approach that facilitates decisionmaking at the landscape level as a substitute for isolated efforts. To achieve this goal, the spirit of collective action endemic in many societies in eastern Africa needs to be drawn upon in development and conservation activities. At the local level, partnerships among research, development, and conservation agencies can play a crucial role in ensuring more inclusive decisionmaking at all levels and to link livelihood goals with conservation objectives. This approach necessitates collaboration with local government structures at various administrative levels (Tanui *et al.,* 2007).

Policies and institutions have often caused important and sometimes unintentional impacts on land degradation and on how natural resources are used. Institutional development is particularly important in the case where common property and open-access resources prevail. Policies on natural resources should ensure that there is close interaction with farmers to increase the understanding of the natural resource dynamics, as local resource users have a wealth of accumulated transmitted knowledge across generations about natural resource status, typology, degradation, sensitivity, resilience, and value for livelihoods.

Development and conservation interventions continue to be carried out with an uncritical view to equity and possible negative repercussions on certain social groups and to environmental sustainability, while local institutions (rules and structures) remain largely invisible to outside actors. Development actors tend to ignore local institutions and their role in livelihoods, preferring instead to set up new structures—representing both a lost opportunity as well as marginalizing local institutions that work. Research and development organizations focus on individual over collective decisionmaking, often leading to solutions that bring benefits to some groups at the expense of other groups either because others do not access benefits or because actions taken by some individuals have a negative impact on others. For the full potential of collective action to be realized in development and NRMI reforms in institutional practice and local policies are needed (German *et al.,* 2008).

Community-based management and empowering local communities are based on co-management, using local/indigenous knowledge, recognizing local institutions, and the establishment of common property regime. Local users often have intimate knowledge of the resource and, because their livelihoods depend on it, they have the greatest incentive to maintain the resource base. However, community-based NRM can only succeed through building social capital, enhancing collective action, and empowering communities to be involved in policymaking and decisionmaking. Therefore, the objective of this study was to illustrate the importance of local collective action institution, and their contribution to NRM and setting policy options to foster their participation.

Some of the specific objectives were to examine the role and capacity of local collective action institutions in NRM, to illustrate the changing nature of local collective-action institutions in NRM, and to suggest some policy options that can foster collective action in NRM. Some of the research questions the paper seeks to answer are as follows:

1. What roles can the local institutions play in NRM?
2. How did collective action institutions evolve over time?
3. What policy options can foster collective action of local institutions in the management of natural resources?

Methodology

This paper highlights different modes of collective action that were randomly found in the countries under study by the African Highland Initiative (AHI). It illustrates how collective action in different scenarios has managed to solve problems facing the various communities. It is worthwhile to note that these methodologies were not predesigned but rather a learning experience and integration of various activities accomplished through collective action. These are lessons and experiences from the AHI projects aimed at improving livelihoods of grassroots communities. A descriptive meta-analysis on the growth, roles, activities of local institutions, and impacts in the countries was compiled in the form of tables.

Data were collected from the Gununo Watershed and surrounding villages in southern Ethiopia, which used an approach grounded on collective action and indigenous knowledge to control porcupines that were destroying crops from farms to engage in, soil and water conservation, and to enhance improved seed dissemination through local bylaws. In Kenya, data were collected from groups in the eastern and southern parts of Mt. Kenya forests and their changes over time to illustrate the role of collective-action institutions in managing forest resources, improving agricultural productivity, and generating income. In Uganda, data were collected from the Tuikat Watershed in Kapchorwa District to demonstrate the development of groups in addressing marginalization and inequality issues, soil and water conservation, local innovation and use of traditional indigenous knowledge. In Tanzania, data were collected from the northern Highlands of Tanzania in Moshi Rural (Kilimanjaro region) and Arumeru districts (Arusha region) to determine different roles of groups in NRM.

Study area

The Gununo Watershed is one of the sites of research where AHI, in collaboration with Areka Agricultural Research Centre in Ethiopia, is conducted. Located in Wolayita zone of southern Ethiopia, its population pressure is high. The area of the watershed is 544 ha and residents come from more than 622 households. Land scarcity and poor crop performance are big problems in the watershed. The area is located at an altitude between 1950 and 2100 m above sea level with an annual rainfall of 1350 mm. The area has low fertility, which adversely affects agricultural productivity. Through collective action and the development of by laws with the help of AHI, farmers were able to develop a system of improved seed dissemination, porcupine control, and soil and water conservation.

The Mount Kenya region groups from Embu and Meru South in Kenya were studied. The Mount Kenya ecosystem is categorized into four broad zones based on vegetation, altitude, land use, and management. It is composed of a forest reserve that covers an area larger than 200,000 ha, spanning Embu (18,398 ha), Kirinyaga (29,215.30 ha), Meru (53,560.60 ha), Nyeri (60,402 ha) and Tharaka Nithi (39,300 ha). The forest is one of the largest, most ecologically significant, and commercially important natural forest areas in Kenya and is considered among the highest priority forests for national conservation (Wass, 1995). It exerts a profound influence on the livelihoods of the communities living within this region. The forest presents a rich biological diversity that contains diverse vegetation that includes endemic afro-alpine plant species as well as the commercially valuable *Juniperous procera, Ocotea, Olea, Podocarpus,* and *Vitex* timber species (Emerton, 1999).

Mount Kenya forest forms a major water catchment area from which two of the country's five river basins arise, the Tana and Ewaso Nyiro, which together supply water to more than a quarter of Kenya's human population and more than half its land area (Wass, 1995), including the five main hydroelectric power sources that, in the aggregate, provide nearly three quarters of national electricity requirements. Forest degradation and excision has been taking place in the forest's long history and, as a result, there has been scarcity of forest products leading to a ban in entry and harvesting of products, from the forest. Communities, especially those in Upper Imenti, decided to form groups to curb the alarmingly high rate of deforestation while at the same time conducting income-generating activities.

The unreliable rainfall and the consequent insufficient water for agriculture were a problem in some areas in Mt. Kenya and the farmers expressed the need to have technologies for water harvesting and also crop varieties that are drought-tolerant. This was especially so in the drier areas of Laikipia District and Meru. These, coupled with the forest degradation, motivated the catalyzed formation of several groups to address the various problems facing the communities.

Kapchorwa District is situated on the slopes of Mt. Elgon in eastern Uganda. The district stretches from an altitude of 600 m above sea level (in the lowlands) up to 3000 m above sea level in the highlands. The Kapchorwa District Landcare Chapter (KADLACC) has played a major role as a district-level innovation platform. It works closely with local, district, national, and regional member stakeholders, including AHI, Mt. Elgon Ecosystems Regional Program (MERECEP), NAADS, Uganda Wildlife Authority (UWA), and UNDP. KADLACC is managed by a steering committee.

Data collection

Data were collected from collective action groups/villages in Kenya, Uganda, Tanzania, and Ethiopia. These groups/villages were picked from the various groups studied and monitored over varying periods of time, depending on the country, to determine their growth in terms of capacity and their adaptation to suit current trends of decentralization and participation of communities in NRM. These groups were selected due to their evolution and adaptation to these changing trends in terms of institutionalization and formation of bylaws. A total of 14 groups in Uganda, 12 in Kenya, 34 in Ethiopia, and 50 in Tanzania were selected from the different studies across the countries. The numbers differed due to differing scopes and objectives of the different studies in these countries.

Various participatory methods and tools had been used to collect information from the four countries. In the Kenyan and Ugandan sites, PRA methods, village meetings, and group discussions were carried out to facilitate interactions with community members, forest managers, and other key informants in the area and to get their perspectives on collective action. Historical trend analyses were conducted to capture the history of the groups and their evolution over time. Participatory action research was conducted in Ethiopia on how to enhance improved seed access and control of pests in the Gununo Watershed. In Tanzania, focus group discussions were held to get information and to better understand group activities.

One of the AHI Project sites (adapted from AGILE 2007).

Results and discussion

Roles of collective action-institutions

Results from the studies indicated that collective-action institutions were involved in various activities aimed at NRM and improvement of livelihoods (Table 1). They further indicated the groups' major roles in NRM, rehabilitation and enrichment, innovation and use of traditional indigenous knowledge, conflict resolution, networking, and, to some extent, ensuring equitable distribution of resources among the poor and the marginalized.

Collective-action institutions in eastern Africa (Kenya, Uganda, Tanzania, and Ethiopia) have been involved

Table 1. Roles of collective-action institutions in Eastern Africa.

Percent of groups/villages utilizing various modes in collective action*				
Mode of collective action	**Kenya**	**Uganda**	**Ethiopia**	**Tanzania**
Innovation/use of traditional indigenous knowledge	75	64	85	84
Management and conservation of natural resources	100	100	11	12
Rehabilitation and enrichment	67	36	11	6
Conflict resolution	42	14	85	82
Networking	92	100	100	18
Equitable distribution of resources to marginalized (e.g. women and the poor)	17	21	14	60

*The N value in Kenya-12, Uganda-14, Ethiopia-34 and Tanzania-50. Value in each cell is a percentage of the total number of groups per country

in various modes of collective action ranging from innovations and use of traditional indigenous knowledge to conflict resolution, management, and networking. Results indicated that most groups across countries had networking links with other partners (Table 2). This was crucial, especially in terms of information flow, introduction of new technologies, and ensuring access to inputs and financial facilities. Majority of the groups were also innovative in the use of indigenous knowledge in either management, conservation, or substituting technologies with indigenous ones, which were more popular and cost-effective. In Kenya, 75% used traditional knowledge, whereas Uganda, Ethiopia, and Tanzania recorded 64%, 85% and 84% usage, respectively. All groups studied in Kenya and Uganda had been involved in some form of NRM.

Majority of the groups were also involved in conflict resolution, which is a crucial aspect that must be addressed in collective action and management: 42% in Kenya, 14% in Uganda, 84% in Ethiopia, and 82% in Tanzania. Although not the majority, some groups also recognized the role of marginalized groups in society such as the poor, the landless, and women by addressing issues affecting them.

Evolution of local institutions

Results from Uganda indicated that all groups evolved into institutionalized collective-action entities registered at some level with bylaws to govern the functioning of the groups. This reflects their level of adaptability and capacity to handle emerging issues. Those that had not been registered at the time of their formation became registered and those that had been registered at the time of formation had either modified their structure or registered with higher authorities.

Results from Ethiopia showed that farmers managed to solve age-old problems through collective action. They were successful in disseminating improved seeds through use of bylaws, which they developed with the help of AHI. They also managed to control porcupines that greatly affected agricultural production. This indicates the capacity of collective action not only to improve livelihood but also to contribute to policymaking. This capacity is further demonstrated in the case of KADLACC in Uganda and MEFECAP in Kenya.

Table 2. Evolving collective-action institutions in Kapchorwa District, Uganda.

Name of collective-action institution	Old structure	Present structure
Trikat watershed	Had small watershed committees	Registered with KADLACC, Parish level; has village watershed committees.
Turban Organic Farmers Association	Not registered	Registered with KADLACC; has parish committees
Kapchorwa Bee Keepers and Agroforestry Association	Registered at district level	Registered with KADLACC
Keptotoy Integrated Farmers Association	Registered at district level Had management body	Registered at District level; registered with KADLACC, has executive committee
Kapchorwa Community Development Association	Registered at district level	Registered at national level; registered with KADLACC
Sabiny Community Development Association	Not registered	Registered with KADLACC
Bukwo Agroforestry Association	Registered at subcounty level	Registered with KADLACC
Chesower Integrated Farmers Association	Not registered	Registered with KADLACC and at sub county level
Gloria Mercy Women Group	Registered at district and sub county levels	Registered with KADLACC
Arokwo Growers Farmers Association	Not registered	Registered at subcounty level and with KADLACC
Kapchorwa Agro Veterinary Services	Registered at district level	Registered with KADLACC
KADLACC	Registered at district level	Planning to upgrade into an NGO

KADLACC is a platform under which 14 groups, NGOs, and local government bodies are involved in NRM. It contributes to policy making through supporting the development of bylaws on free grazing, boundary management, and co-management of natural resources. It builds the capacity of farmer groups and also links them to donors, thereby contributing to income generation. It trains them on bee keeping, soil and water conservation, agro-forestry, promotion of efficient wood-burning stoves, apple growing, and fish farming (Table 3).

MEFECAP (Kenya), on the other hand, has activities ranging from nursery establishment, tree planting events, forest protection and management, and rehabilitation and enrichment, among others. It is an umbrella body with 11 smaller groups involved in these activities. The association has been carrying out activities such as protecting the forest through patroling and reporting illegal activities, planting and maintaining plantations, protecting water catchment areas by planting appropriate tree species, uplifting the standards of living of members by starting income-generating projects, and educating its members on the importance of forests and environmental conservation.

Role of policy in fostering collective action

Collective action improvement is the aspect of NRM that can, too often, be neglected. Yet, improvements in human capital have been the source of most of the gains in productivity of agricultural land and labor in the past. Given that the land frontier has been reached in most

Table 3. Major KADLACC member organizations and activities undertaken.

			Budgetary contributions (US$)	
Organization	**Site**	**Activities**	**Community**	**AHI**
Bukwa Agro-forestry Farmers Association	Bukwa subcounty	• Planting of agroforestry (AF) trees and napier grass along contour bands; Rhodes grass *Calliandra* for fodder • Nursery establishment and management for agroforestry, fruit trees, and passion fruit seedlings. • Soil and water conservation	731.70	304.80
Tuban Organ Farmers Association	Tegeres subcounty	• Apple growing and management • Fish farming	1,463.40	487.80
Tuikat Watershed	Kwosir subcounty	• Fish farming • Apple growing and management	1,463.40	487.80
Kaseko Soil and Water Conservation	Benet subcounty	• Promotion of fuel-saving technologies • Demonstration on multipot stove installation		365.90
Kaptotoy Integrated Farmers Association	Binyiny subcounty	• Soil fertility and water management • Contour siting and construction • Agroforestry – planting of *Grevellia* tree seedlings along the contour bands	731.70	304.80
Kapchorwa Bee Keepers and Agroforestry Association	Kwosir and Tegeres subcounties	• Langstroth hives and KTB hives	914.60	365.90
Arokwo Growers Association	Tegeres subcounty	• Soil and water conservation • Napier grass along the contour plants for fodder and for stabilizing contour bands • Agroforestry	731.70	304.80

countries and that areas available for farming and forestry are likely to decline, policies to enhance rural human capital need to be given high priority.

Various studies indicate that effective collective action in watershed management improves natural resource conditions, reduces vulnerability to drought, and improves cash incomes for the poor via diversification into marketable products; marketing groups pay farmers higher prices than do brokers and middlemen. Performance improved where decisionmaking is participatory, members make regular contributions and provide starting capital; levels of collective action in watershed management increase where groups have prior history of cooperation, where they have conflict resolution mechanisms, and are closer to markets (Shiferaw *et al.,* 2006).

Proper policies are thus required to ensure poverty reductions. These will surely require integrated and effective implementation of a wide range of policy initiatives.

Conclusions and recommendations

Studies have shown that local institutions play major roles in the management of natural resources. The roles of the collective-action institutions have been changing over time from being directly controlled by governments to being a decentralized system where they are more involved in decisionmaking. They have further expanded their roles from lobbying to conflict management, raising funds, negotiating during most meetings, initiating rural development and forestry development activities, and, more importantly, developing systems that introduce equity principles and address the needs of the poor and disadvantaged members of the community. The institutions have also pioneered income-generating projects and dissemination of improved technologies, which have improved the livelihoods of grassroots communities. The initiatives have added value to collective action in a situation where communities would hardly realize any benefit from natural resources.

Some major of roles of collective institutions as a result of their evolution include capacity building as result of their vast traditional indigenous knowledge and benefit sharing, whereby availability of both tangible and intangible benefits to local institutions contributes to the cohesiveness of the members (Ongugo *et al.,* 2008; Stroud, 2003). Another important role where natural resources are concerned is the management role. Communities throughout the world are increasingly involved in the management of local natural resources and the environment. This trend toward participatory decisionmaking introduces challenges and opportunities for practitioners, donors, and analysts. Last is the conflict resolution role; conflicts are inevitable, especially in the use and management of natural resources in brittle ecosystems (Waithaka and Minde, 2007). Measures to reduce conflicts suffer in the wake of a lack of clear policy guidelines and weak institutional setups to enforce social order. Social capital is a potential least-cost means of addressing rural poverty, which can be sustained at reasonable costs in a community.

Local collective-action institutions have been evolving over time to adjust to emerging situations and to address various problems affecting them. As such, they have utilized their indigenous knowledge and sometimes able to synchronize with technical knowledge received from extension services. They have succeeded, to some extent, but due to various constraints (ranging from high poverty levels to lack of incentives to be involved in collective action), they have been unable to realize their full potential. This requires that policies be geared toward fostering their capacity building and improving social capital to ensure that they are involved in NRM.

While multiple strategies could be pursued to strengthen rural institutions and facilitate the development of collective-action institutions, the following focal interventions may address bottlenecks in collective natural resource management: apart from governments instituting legal and policy frameworks that recognize collective-action institutions, they should also strengthen rural institutions and farmer marketing groups. These would require public–sector resources and action plans to address the specific needs and constraints of similar organizations. Such support is justified, given the livelihood benefits to the rural poor and the growth linkages derived from improved commercialization of agriculture.

Source

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Do-No-Harm Approach: Lessons from Water Development across the Afar/Amhara Regional Border

The USAID-funded Water Sanitation and Hygiene Transformations for Enhanced Resilience project (WaTER)[1] aimed to increase access to water in the water-scarce Argoba Woreda in Afar regional state by digging deep boreholes. However, during identification studies, it became apparent that groundwater potential was poor in this region but abundant in the Amhara communities upstream of the Amhara regional state, across the border from Afar.

However, the situation was sensitive. Ethnic and religious conflicts, particularly between Christian agriculturalists in Amhara and Muslim agro-pastoralists in Afar, have a pattern of flaring up and was particularly acute at the time the project was being planned. It became clear that, in order to build a water source in the upstream Amhara community to provide water for the downstream Afar communities, a conflict-sensitive approach would be imperative. Staff from the WaTER project therefore

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[1] The USAID-funded WATER (Water Sanitation and Hygiene Transformations for Enhanced Resilience) project, led by the International Rescue Committee and implemented in partnership with CARE, aims to bring water and sanitation facilities, and hygiene behavioral change, to 146,000 pastoralists in Ethiopia's Somali, Afar, and Oromia Regions. Under the WATER project, key activities in the Argoba Woreda of the Afar regional state to date have included spring water development, replacement of diesel-powered water schemes to hydro-power systems, rehabilitation of one motorized borehole, construction of two blocks of sex-segregated school latrines, and community-wide mobilization around sanitation and hygiene promotion.

conducted extensive fieldwork to test a conflict-sensitive development approach called Do-No-Harm (DNH). This paper shares the approach and some of the findings on how to build a shared resource across community groups with a history of conflict.

The approach

The DNH principle has been widely used since the 1990s in developing countries of Africa and Asia (http://www.conflictsensitivity.org/node/103). It is a tool that was specifically designed to guide development and humanitarian assistance programs in conflict-ridden areas. DNH enables development practitioners to implement projects in a conflict-sensitive manner through methods of analysis regarding existing situations. Conflict sensitivity implies the ability of project implementers to understand the context in which they operate, the interaction between the context and an intervention, and the ability to act upon this understanding in order to avoid negative impacts and maximize positive impacts. DNH is used to enable community members to observe and analyze conflict-sensitivity situations in their own surroundings and participate in the creation of appropriate interventions.

The success of the DNH approach hinges on the full involvement and active participation of all key stakeholders—e.g., community members, regional government, leadership from rival community members to act as mediators, and continued monitoring by local community representatives who lead efforts to build a nonviolent and conflict-free society.

CARE started with a 5-day training to all project staff with the objective to strengthen understanding of key conflict-sensitive principles and to provide the team with the tools and approaches needed to support the application of conflict-sensitive principles. By the end of the training, participants gained the skills necessary to maximize the chances that the project would not escalate into a conflict, thereby maximizing the positive impacts of interventions. The training materials consisted of tools on DNH principles, conflict sensitivity, and timeline analysis.

The context

Community members from both ethnic groups, the Amhara ethnic group in the Amhara regional state and the Argoba ethnic group in the Afar regional state, move across the border primarily in search of forage and water for livestock during the dry periods and for the exchange of goods and services. The Afar agropastoralists in particular are historically particularly mobile.

Such movements, however, are periodically curtailed, restricting the socioeconomic interaction

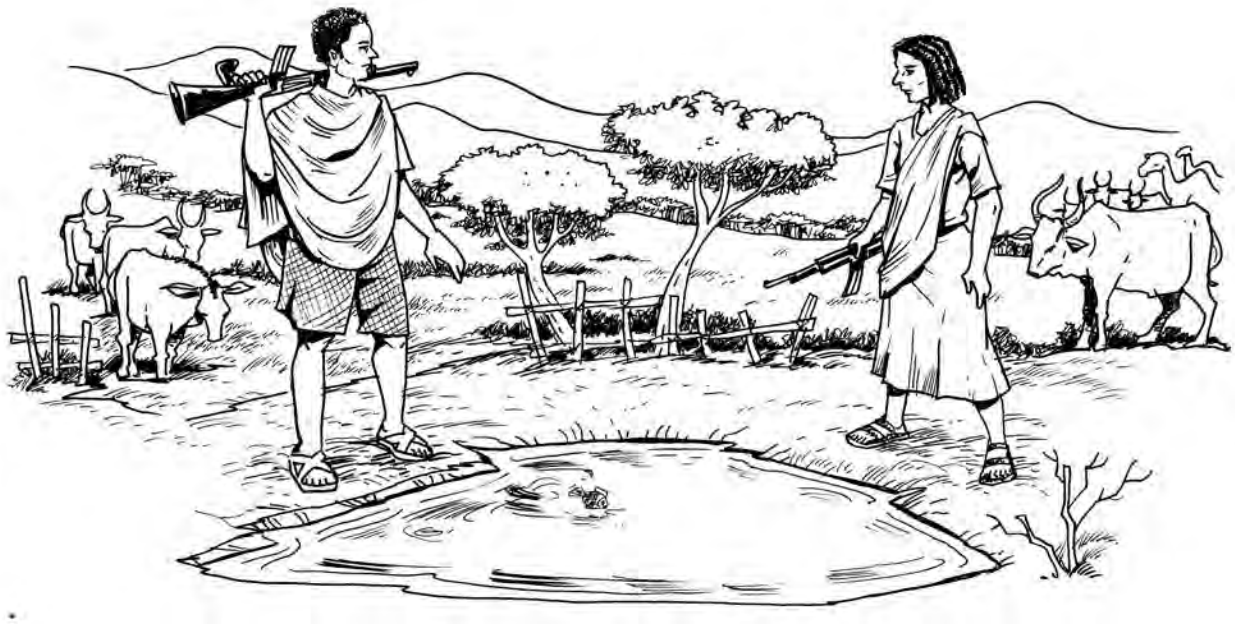
There are eight steps followed in the DNH approach. (see box).

The Do-No-Harm Framework

STEP 1	Train staff in the framework
STEP 2	Understand the context of the conflict
STEP 3	Analyze the dividers and sources of tension
STEP 4	Analyze connectors and local capacities for peace
STEP 5	Identify and unpack the development intervention—even the smallest details contribute to impact
STEP 6	Analyze the intervention's potential impact in the context of the conflict through resource transfers and implicit ethical messages
STEP 7	Generate programming options. If an element of the assistance program has a negative impact on dividers, feeding into the sources of tension or if an element of the program has a negative impact on connectors, weakening or undermining connectors, and local capacities for peace, then generate as many options as possible that can weaken dividers and strengthen connectors
STEP 8	Test options and redesign program

of both communities. Violent conflicts over land and water in the region are often the points that ignite conflict. These have had the following negative consequences: loss of human lives, loss of livestock through robbery, socioeconomic dislocation (abandonment of the common market), and increased social segregation, disrupting kinship (including marriage) and other cultural ties.

For the Afar, living in the arid lowlands, water shortages are a major problem, particularly during times of drought, but also when existing water and pasture sources are disrupted for other reasons. The potential of the project lay in providing water into the Afar lowlands, from a spring in the Amhara highlands, but in ways that would be acceptable to both parties.



Government and community discussions

Government officials from both the Ankober (Amhara) and Argoba (Afar) woredas held meetings facilitated by CARE Ethiopia to agree to start the process of finding a way to share water resources.

Community dialogues to identify and map major resources in the intervention area were then undertaken. The meetings were scheduled and conducted in both woredas, separately, to understand the drivers and cause of conflict and its resolution. Community members mapped basic natural resources as part of the identification of basic sources of livelihood and causes of conflict. Afterwards, elders, religious leaders from both faiths, women, men, youth community members of different social groups, and community representatives from both ethnic groups met together to discuss the overall cause of conflict.

The options were then narrowed down to a water spring in the Haramba kebele in the Ankober woreda of the Amhara regional state, which could supply water to the downstream community in Argoba woreda in the Afar regional state.

During the cross-community dialogue, the scope of work was mutually agreed by the upstream community (Amhara) and the downstream community (Afar). The Amhara community upstream demonstrated a willingness to share its resources with the Afar community downstream. The reasons for this included a greater understanding of the constraints faced by the Afar community, which led them into conflict with Amhara and an understanding that they could avoid future conflict by sharing increased harnessing of water resources together. In addition and critically important was the fact that the communities believed that improved socioeconomic relations could be restored, which were mutually beneficial to both communities, because of their different livelihood basis—i.e., trade between agriculturalists and agro-pastoralists.

Following all the discussions, representatives from both communities signed a peace agreement to restore peace and security and facilitate improved relationships in the future between the two communities.

Construction and management of gravity-fed water system

The water system was then constructed. It consisted of a spring that fed water into a 100 m^3 concrete tank, then along a 10-km pipeline, with 10 water points. Water was provided to three water points in two villages in Ankober prior to reaching the Argoba woreda in Afar where the remaining seven water points were constructed.

The decisions about where to place the pipes and each water point were jointly agreed, with the decisions involving both elders and government as power brokers but also women and girls in each community who traditionally are the ones who fetch water.

The hygiene and sanitation element of the work included community campaigns around improved hygiene, addressing taboos that have negative hygiene implications, distribution of behavioral change communication materials, and working toward open defecation-free kebeles.

A joint water supply, sanitation and hygiene Management Committee with members from both communities was then established to manage and maintain the scheme. There is an overall committee that directly manages committees under each water point. The committees have seven members out of which three to four members are women. Moreover, each water point has a caretaker who is responsible for minor maintenance and operation. CARE provided training for all committees and caretakers on good governance, addressing issues of participation, inclusion, accountability, and transparency. In addition, Ankober and Argoba woreda government officials signed a cooperation document to provide supervision and technical support to the maintenance of the water system and continue support with hygiene and sanitation.

Value of DNH approach in conflict resolution and peace building

To determine what impact the WaTER project had on peace building and conflict resolution as well as to look at what was happening in terms of water, hygiene, and sanitation, an assessment was conducted in the Argoba woreda at the Haramba water spring in March 2014, 6 months after the completion of the water system.

The study found that water was flowing and hygiene and sanitation had improved. Most interestingly, however, beyond these immediate benefits, the assessment also found that community members in the Ankober and Argoba woredas were able to reengage in market activities. They now go once again to the same market to barter goods and services. Agropastoral communities of Argoba sell livestock and Ankober communities of Amhara sell cereal crops. The joint committee responsible for maintaining and managing the water source and supporting ongoing hygiene and sanitation work continues to meet regularly and there have not been any incidents to undermine the water provision. Relationships between the communities are also improved.

Impact of the spring development

With the DNH approach, the WaTER project was able to improve hygiene and sanitation and increase access to safe water of about 10,350 people as a result of the construction of a water spring with 10 km of pipeline expansion between two states: the Amhara regional state and the Afar regional state.

Conclusion

Perhaps the main finding from the initiative is that it is possible to have a development intervention that has direct benefits for one community more than another, if a conflict-sensitive approach is undertaken. In this case, the Ankober community agreed to pipe water resources to the water-scarce Argoba community in order to restore peace in the area. The peace dividend then included restored socioeconomic relations between the two communities, which were mutually beneficial.

The DNH approach provides a method for collaborative planning, implementation, and monitoring of development activities, involving community members and government bodies. It is particularly useful in sensitive contexts to ensure that conflict is not exacerbated or ignited as a result of a development intervention. Given the potential for conflict when existing resources are altered and new ones made available, the DNH approach could usefully be mainstreamed as an approach within water resource development both for domestic and productive use, soil and water conservation interventions, and surface water-harvesting interventions to prevent conflict and promote peaceful sharing of resources.

The DNH approach is likely to help improve the sustainability of interventions because it invests time in establishing mutual trust, understanding, and joint ownership of resources between communities with a history of conflict. The involvement of local government across the two communities and their understanding of the importance of cooperation are also pivotal. Their official and formal oversight is also likely to ensure stronger long-term support.

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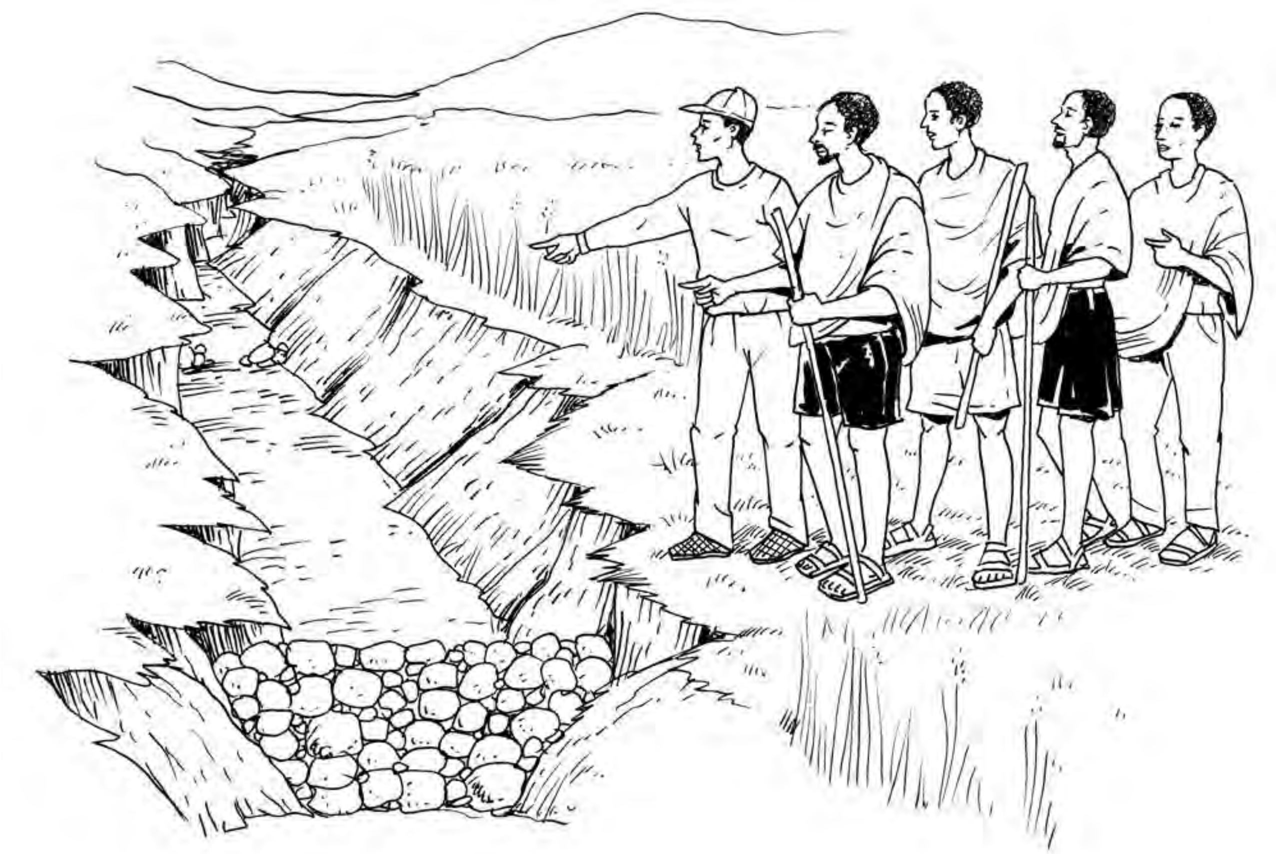
Application of a Farmer-expert Joint Learning Approach to Improve Soil Conservation: The Cases of Angereb and Enkulal Watersheds, Lake Tana Sub-basin



In the highlands of Ethiopia, where intensive agriculture is practiced, land resources are being depleted at an alarming rate. Balancing soil and water conservation (SWC) measures with the use of effective technologies and farm management practices against the current level of land degradation is a growing challenge to smallholder farmers, who are striving to meet immediate economic objectives, on the one hand, and sustainable environment, on the other. Past SWC programs focused more on land degradation and they used a top-down approach. Top-down programs tended to focus more on the symptoms of erosion through subsidized terracing rather than on the root causes of land resource degradation. There was less emphasis on integrating local knowledge of land users and planning together with farmers.

Soil conservation programs, thus, require a long-term, bottom-up, and interactive approach supporting farmers who generally have detailed knowledge of their farm. Land and water resource management demands an ongoing learning and negotiation process where high priority is given to questions of communication, sharing community and individual land user perspectives, and development of adaptive group strategies to solve problems (Pahl-Wostl 2002a; 2002b). According to Bandura (1977), social learning refers to individual learning based on observation of others and their social interactions within a group, for example, through imitation of role models. It assumes an iterative feedback between the learners and their environment, the learners changing the environment, and these changes affecting the learners.

Through such interactive exercises and iterative processes, the knowledge, which is difficult to articulate, can be made explicit. Therefore, in order to improve the efficiency of soil conservation, the present case approach aimed to articulate local soil erosion knowledge and assess the learning process and pattern of changes in attitude, skills, and knowledge of farmers by making use of local erosion indicators as learning objects. This paper provides information on the participatory learning processes through farmer-expert joint learning approaches (JLAs) and explores local knowledge of erosion and changes in soil conservation practices, taking case studies at Angereb and Enkulal watersheds in the Amhara Region.

Implementation processes and stages

Angereb (located in the Gondar Zuria District, north Gondar) and Enkulal (located in Dera District, south Gondar) watersheds were the case study areas. About 58 (from three small catchments) and 22 landowners were involved throughout the participatory learning process at Angereb and Enkulal watersheds, respectively. The following implementation stages were employed to explore and share farmers' knowledge about local soil erosion indicators and conservation practices: (1) organizing community awareness meetings; (2) conducting field visits and discussions to explore erosion indicators, causes, impacts, and their measurement; (3) identifying erosion problems and planning potential conservation measures and improvements; (4) implementing improved measures; and (5) monitoring and evaluating the performance of already implemented measures and outcomes of the learning process.

Initially, the JLA involved awareness and attitudinal change activities to motivate and increase the level of participation of farmer households during the process. This is a key step to build confidence and trust in the process and encourage individual farmers to be actively involved in the learning process. Another critical step was for well-experienced experts (who have good knowledge and communication skills) to orient, facilitate, and motivate the participants to actively participate in discussions, as well as record the changes in attitude, skills, knowledge, and practice in every process. The participating farmers themselves led the participatory process.

This approach applied frequent field visits and discussions and dialogues with farmers rather than use of empirical expert-based methods. Farmers formed groups based on the catchments and the location of their plots. Each of the groups held periodic field visits after every erosive rainstorm and held discussions in groups about the erosion processes observed in each of the participant-farmer's plot and their sources and impacts. This process gradually facilitated a collective understanding of land management practices and the associated problems and constraints with its solutions. This approach was practiced by means of consensus building through iterative procedures in order to reach a common understanding and explore local erosion indicators. Upon agreement, they described the local erosion indicators and means of verification at individual plot and landscape levels. Through continuous dialogues and discussions, the land users gained environmental knowledge that would help ensure ecosystem sustainability. Eventually, based on the knowledge of the erosion processes, farmers sat together and developed intervention plans to control the erosion processes. After implementing the controlling measures, they made regular field visits during erosive storms, collected information, and evaluated the efficiency and performance of conservation practices. In evaluating each improvement measure, participants made field observations and gathered quantitative evidence.

The outcomes of the learning process of the JLA were measured before and after each learning event. The outcomes of the JLA were measured by (i) exploring and explicitly describing more erosion indicators through the learning period, (ii) evaluating the extent of practicing improved soil conservation measures and innovations, and (iii) interviewing the learning group about their perceptions and attitudinal changes on soil erosion processes and soil conservation.

Local knowledge of erosion indicators

In the early stage of the JLA, qualitative and quantitative assessment of local erosion indicators showed that, while farmers were aware of highly visible gully erosion, landslide, flooding, damage of trees, and yield reduction, they were less aware of emerging and more frequent seasonal erosion indicators such as sheet erosion, rill erosion, ditch erosion, and tillage erosion. They hardly perceived the long-term and irreversible consequences of seasonal erosion processes, which often cause far more visible indicators like gullies. By contrast, farmers perceived those indicators that they can easily notice as being costly and beyond their capacity to reverse and control.

Later in the learning process during the first rainy season, farmers in the Angereb watershed were able to explore and come up with more erosion indicators such as rills with a depth of 15–20 cm, tree and stone mounds, exposure of plant roots, and gradual change of soil color. In the second rainy season, additional erosion indicators such as sheet and surface erosion, small rills with a depth of 5–15 cm, tillage erosion, and on-farm drainage ditches were perceived and explored. Subsequently, practicing in-depth joint learning exercises by observing the causes and effects of erosion indicators as well as the causes of the limitations of soil conservation practices were described. Similarly, in the case of Enkulal watershed, farmers identified damage to terraces, excessive traditional ditches per parcel, and excessive removal of crop residues as common local erosion indicators. Exploring a combination of different categories of indicators is, therefore, desirable to generate context-specific knowledge, both social and ecological. The different types of indicators can help to relate local knowledge to the scientific methods. The farmers learned which indicator works where, under what conditions, and why.

Change in practices

Once farmers have analyzed and understood the erosion indicator processes and problems, they implemented improved measures to address the observed problems. In the subsequent learning events, farmers gradually demonstrated changes in their practices as a result of the co-learning and knowledge sharing (Table 1).

Farm drainage ditches at Enkulal watershed

Farmers decided to reduce a significant number of ditches with lengths not more than 25 m and a gradient less than 6% each from every parcel. The participating farmers (in two groups) surveyed the number of ditches on their farms and monitored the erosion hazard of ditches. In the beginning of the learning process (in 2011), a total of 256 ditches were recorded in the agricultural fields of 22 participating farmers (a minimum of 3 and a maximum of 52 ditches per parcel). The participants noted that the average initial depth and top width of ditches was 19 cm and 38 cm, respectively. The gradient of ditches was, on average, 5-9%. After one rainy season in 2012, farmers were convinced to install bunds. As a result, the total number of ditches was reduced to about 74 ditches (an average of 2.4 ditches per parcel) (Fig. 1). Except on a few parcels, a significant number of farmers reduced ditch gradient to below 6%. None of the constructed ditches crossed the soil bunds. Measurement of sediment accumulation at the bottom of the ditches and the change in the dimension of ditches revealed that the sediment transport rate was between 0.5 cm^2 and 4.0 cm^2 per meter of the ditch. The transport

***Table 1**. Changes in practices and innovations by applying JLA at the Angereb watershed.*

Initial stage of the process (1st iterative stage)	After one rainy season (2nd iterative stage)	After two rainy seasons (3rd iterative stage)
Maintenance of terraces	Constructing new terraces	Runoff disposal trench on terraces
Constructing cutoff drains	Planting along terraces	Improving cross-section of terraces
Constructing farm ditches	Fallowing	Excavating pits in the field
Constructing check dams	-	-

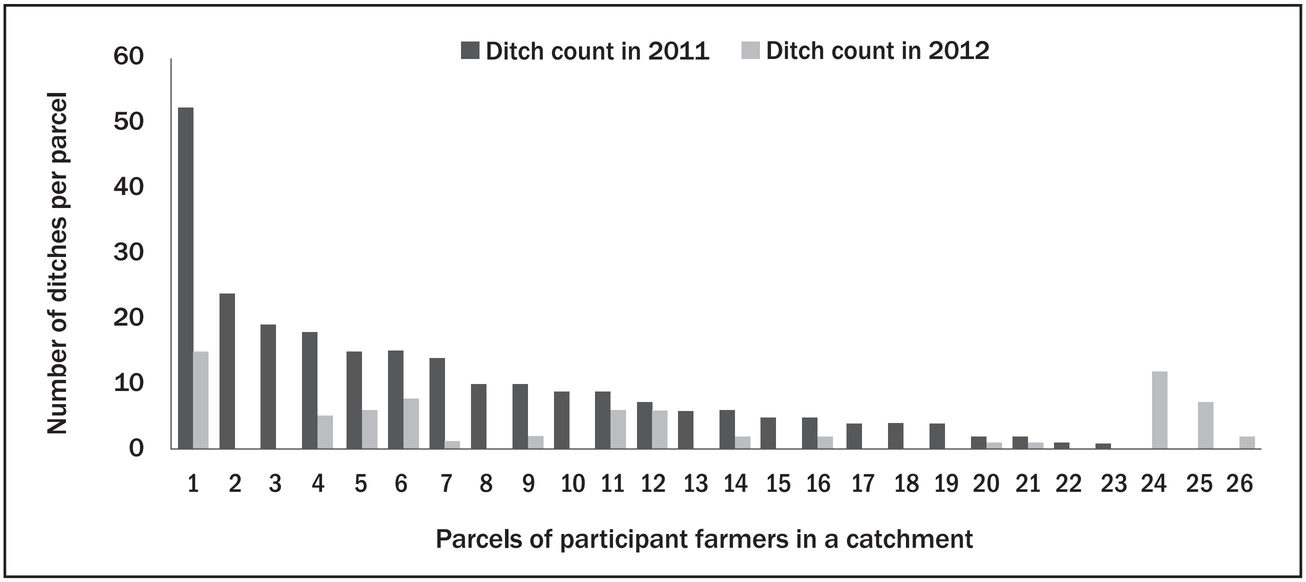


Fig. 1. Number of ditches per parcel in 2011 and after the learning process in 2012.

rate varied temporally and along the length. The respective rate of sediment transport at the top, middle, and bottom parts of the ditch was 0.19, 1.33, and 1.52 cm^2 per meter in July, and 0.93, 3.39, and 4.32 cm^2 per meter in August.

The average seasonal sediment transport rate was 1.27, 2.70, and 3.97 cm^2 per meter per ditch at the upper, middle, and lower sections of the ditch. This implies that the impact of the reduced number of ditches per parcel has resulted in a significant reduction of total sediment transport in a catchment. Reducing the total number of ditches in a catchment by 180 can prevent about 450 cm^2 of sediments from being eroded out of ditches.

Increased harvest height of wheat residue at Enkulal watershed

Another practice was to increase the height of crop residues left after harvest by 10 cm, 50–55 cm, 10–12 cm, 45–50 cm and 75 cm for teff; wheat and barley; millet and linseed, lupine, and niger seed, respectively. A small number of farmers harvested wheat by adding 10 cm more than the usual height. Wheat residue measurement indicated that an average height of 7–14.5 cm (equivalent to 8.5 g biomass) and 21–30 cm (equivalent to 16.6 g biomass) crop residue were recorded at the usual harvesting height and on improved height, respectively. This implies that an additional biomass of 8 g were left over the field, which, in turn, contributed to an increase in soil organic matter, gradually reducing the erodibility of the soil.

Terrace, cutoff drain, and check dam construction at Enkulal and Angereb watersheds

Farmers reached a consensus to construct new and maintain old terraces and cutoff drains in all farm plots and protect gullies together by constructing check dams. Farmers agreed to lay out structures in a toposequence in order to maintain the integration of structures and connectivity of runoff flows.

Farmers who have no bunds/terraces on their plots have been constructing terraces, cutoff drains, and check dams on cultivated lands and in gullies. At Enkulal, farmers mobilized a total of 1684 person-days (865 male and 819 female) for 34 working days. Based on the agreed specifications, a total of 6290 m (volume about 2500 m3) graded soil bunds, waterways 180 m long, more that 100 m of cutoff drains and some check dams were constructed.

At Angereb, a total of 6800 m terraces and cutoff drains and 140 check dams were constructed in the first year. In the second year, 14 new check dams were constructed while 156 old check dams were maintained. After installing the check dams, farmers regularly quantify the sediment retained by the check dams after a heavy rainstorm in order to increase the awareness of other farmers on soil erosion and nutrient loss from farm plots. For example, in Angereb, the farmers quantified 8 tons of total sediments retained in all check dams constructed during the first rainy season. Subsequently, they traced back and identified the farm plots from where the sediment was eroded and transported so that actions could be planned for the next period.

Participants' views

1. "Initially, I felt the learning process was what we already knew. Now, I realize we have learned new practices. I learned how much of our soil, drainage ditches wash away." *Fentie Mandie (male)*
2. "I learned that our tillage operation has damaged the terraces." *Dires Tebabal (male)*
3. "In the past, many were not interested in constructing terraces on their land. Now, we have learned the benefits. I learned how to divert runoff through ditches to an adjacent land. We managed to protect communal lands and pathways together. I was happy that both men and women have made equal contributions." *Birkie Zewdie (female)*
4. "The participatory process gave me an opportunity to learn from other farmers and now we can do things together." *Lakew Mesel (male)*
5. "The field visit and dialogue help individuals to take common responsibility. We understood that seeing is believing. I learned that increasing crop residue improves soil fertility." *Aragaw Muche*
6. "I learned that improved terrace construction is beneficial because our land is protected from erosion." *Manhal Ewnetu (female)*
7. "In the beginning I was reluctant to participate. But now, I've learned how to protect my land from damage and how to make decisions jointly with other farmers. I will protect terraces from animal damage and I feel responsible to protect our land." *Marie Yimam (female)*

Integrating trenches with terraces at Angereb watershed

Modified trenches were constructed to safely drain and partly retain runoff water and sediment from the terrace area. The modified trench improves efficiency of the terrace and provides multiple functions: (i) retaining excess runoff water, (ii) trapping sediment eroded from the terrace area, and iii) increasing infiltration and interflows. During the first season, one innovative farmer integrated trenches on terraces. Later, in the second year, nine other farmers implemented the innovation on a total of 557 terraces.

Improved cross-section of terraces at Angereb watershed

Damage to stone terraces due to unstable cross-sections is common. It is also difficult to maintain or improve stone terraces on steep slopes by adding more stones on top of them. Making improved cross-sections of the terraces was co-learned from an innovative farmer and practiced by other participant farmers in all of the cultivated lands. The height of structures on the top side is limited to the ground surface while the bottom riser is increased to retain as much sediment as possible. The improvement increases structural stability and is not susceptible to damage.

Change in perceptions

Twelve randomly selected participant farmers were interviewed by an independent interviewer to find out about their views on the farmer-expert JLA and their attitudinal changes on the soil erosion processes and soil conservation practices. The views of some of the participants are encouraging (see box).

Lessons learned

The farmer-expert JLA motivates farmers to explore local knowledge and adapt innovative ideas and practices. All farmers practiced certain types of soil conservation measures. The approach helped farmers to understand short-term erosion indicators and oriented them toward long-term erosion protection strategies. The JLA minimizes the sense of dependency and enhances the empowerment of farmers. In the long term, this participatory and interactive approach helps to reduce the workload and pressure of extension agents. It can be a potential tool for participatory soil conservation and useful in development research as local adoption and adaptation realities are considered toward developing sustainable technologies. It can also serve as a local platform and as an extension approach to transfer and support the adoption of sustainable soil conservation technology.

However, the approach requires well-trained experts (with skills, knowledge, and commitment) who will act as catalysts for continuous dialogue and exchange of knowledge. Facilitators need technical experience; skills of facilitation, negotiation, and conflict resolution; as well as a range of personal qualities, attitudes, and behaviors. It was observed that building a common understanding and more effective knowledge systems of sustainability takes time and patience. Scaling up this approach requires greater coordination, time, and commitment to build trust and ensure continuity.

Conclusion

If erosion processes and problems are to be understood and effective soil conservation technologies planned, economic, social, and environmental contexts that govern decisionmaking need to be considered. As context is so different from place to place and from time to time, understanding the specific local context can provide insights into the relevant issues. Therefore, in order to sustain appropriate soil conservation technology development, farmers must be involved in the process and acquire the capacity to respond to these local changing situations. The participatory learning process can be conceptualized as the interaction and integration of biophysical dimensions with the human dimensions. This determines the limits within which conservation technologies are physically possible, viable, and socially acceptable.

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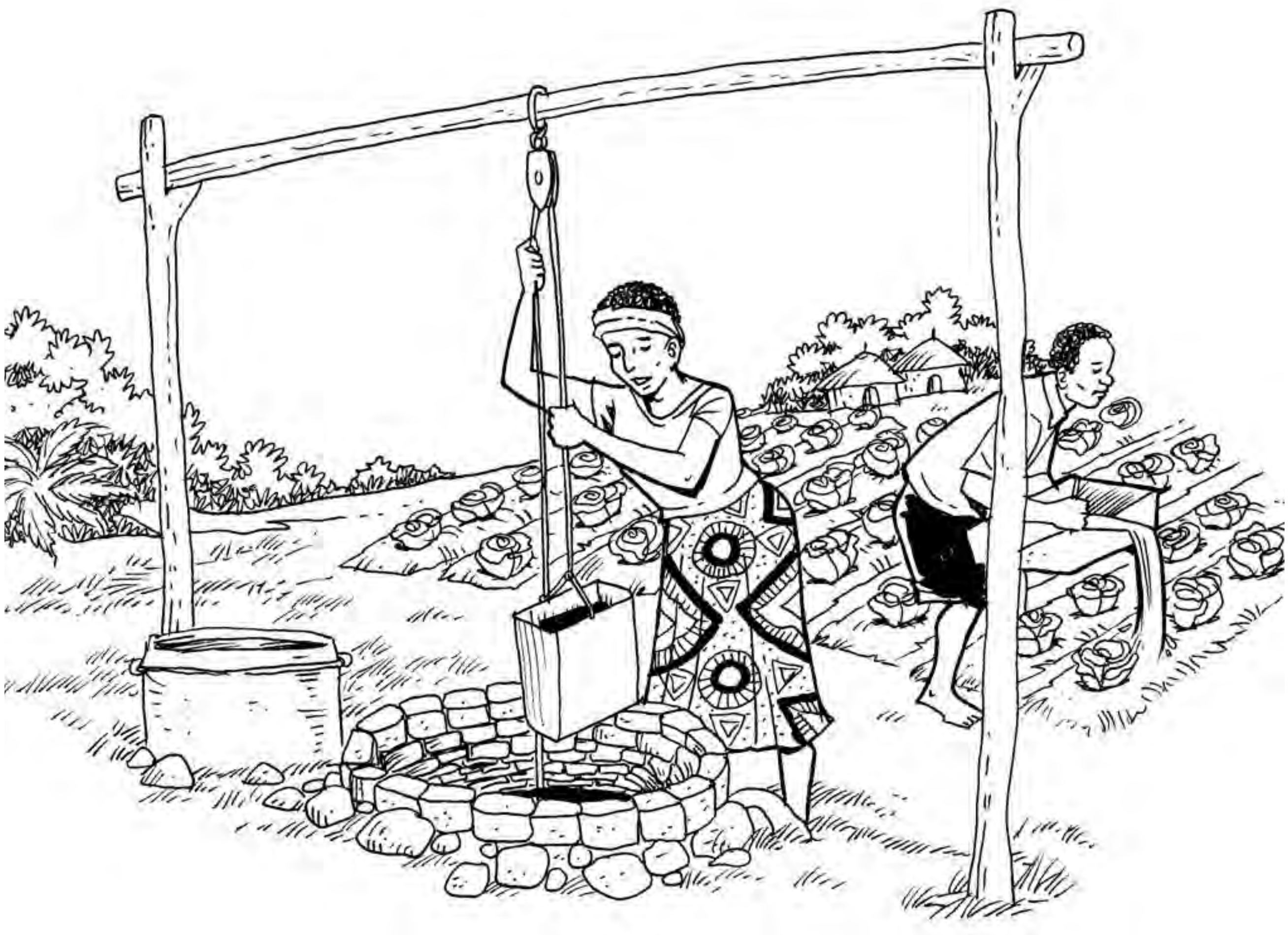
Addressing Water Access Problems in Dera District through the Learning and Practice Alliance Approach



The Leaning and Practice Alliance (LPA) is a learning approach whereby groups of stakeholders come together to innovate, share experiences, and scale up good practices using a common platform. The groups are usually composed of different stakeholders: implementers, policy and decisionmakers, researchers, and private sector actors operating at various levels, who would normally be working in isolation from one another but have joined hands through a joint platform to address common sector challenges. The premise of the LPA approach is that addressing complex sector problems in a sustainable manner requires involving all the stakeholders in the problem-solving process and focusing on development of local knowledge to support local solutions. It assumes that conventional research fails to make impact on policy and practice because of its academic, nonparticipatory nature and underlines the fact that sustaining innovations requires involving those responsible for scaling it up in the process from the initial stage (Moriarty *et al.,* 2005).

Experience in Ethiopia

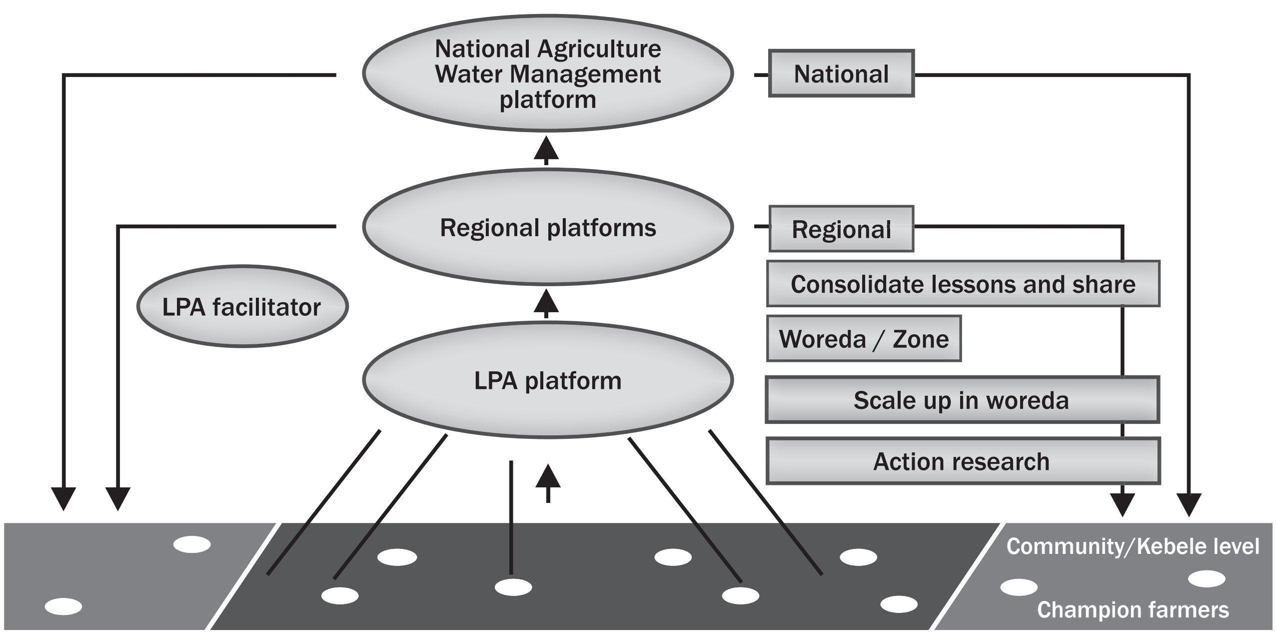
In Ethiopia, a recent experience in testing the LPA approach came from the RiPPLE project, an action research project on water and sanitation (http://www.odi.org/projects/466-research-inspired-policy-practice-learning-ethiopia-nile-region). Within the RiPPLE program, LPAs were set up in SNNPR, East Hararghe, and Benishangul regions. The work undertaken through the LPA has achieved important results at the local level as well as provided an evidence base that has informed sector policy discussions nationally, through a national platform set up in collaboration with the Ministry of Water.

As an example of the impact of the approach, RiPPLE undertook a study on water supply scheme functionality conducted through the LPA in Alaba woreda and identified much higher non-functionality rates than those reported by government (regionally reported as 25% or less, whereas the research found non-functionality of 62% for water points and 42% for water supply systems, based on an inventory of water supply schemes in Alaba woreda) (Israel and Habtamu, 2008). The findings were acknowledged by the government and led to an increased budget allocation to the water supply sector by the woreda government, as well as a revisit of the implementation strategy by Water Action, an NGO engaged in water supply provision in Alaba, whose schemes showed very low functionality rates in the study. The findings of very high levels of non-functionality and lower than reported water supply coverage contributed to the initiation of a regional WaSH inventory by the SNNPR Bureau of Water Resources to improve data on water supply service coverage (Butterworth, *et al.,* 2009).

Establishment of the LPA

Through the Global Water Initiative (GWI) East Africa program (http://www.gwieastafrica.org/), CARE aims to promote water–smart agriculture[1] addressing the challenges that smallholder farmers face because of variable rainfall and barriers to water capture, storage, and distribution for agricultural production. Given the complex nature of water management challenges for smallholder farmers, the program selected the LPA approach as a vehicle for action research. The approach aimed to provide a breadth of experience and depth of knowledge that can help achieve sustainable solutions for smallholder farmers, which are also embedded in and derived from the local social and institutional environment.

The establishment of the LPA platform in Dera District was preceded by stakeholder mapping to identify the key actors working in the agriculture water management sector. The LPA was established



[1] Water-smart agriculture is defined by CARE as investment in cost-effective and sustainable water management systems that optimize the use of rainfed and irrigated farming to generate food security and ensure resource sustainability.

in September 2013 at a launching meeting held in Debre Tabor. Representatives of government offices from woreda, zone, and region levels, research organizations, NGOs, and community-based associations attended the meeting. CARE's GWI-EA staff introduced the LPA concept to participants who discussed problems affecting smallholder farmers' access and use of water for agriculture and came up with a list of problems to be addressed in the first cycle of action research. The participants then identified action research members who would work on the first action research cycle. In addition, they set the criteria for the selection of intervention kebeles and champion farmers who would be demonstrating the technologies and agronomic practices identified through the research.

Ultimately, 63 champion farmers, more than half women, were selected from six kebeles in discussion with the woreda agriculture office. Action research groups, composed of research institutions and agriculture and water experts from government, were formed around issues of household irrigation technology and improved agronomic practices. These action research groups were led by the Agriculture College of Bahirdar University and the Amhara Regional Agriculture Research Institute, respectively.

Potential sites for different irrigation technologies were assessed by the action research group and challenges with existing household irrigation technologies and farmers' preference and technology choice were assessed. Based on the findings, trainings on how to develop hand-dug wells for irrigation, construct water-harvesting structures, and use different irrigation technologies such as motor pumps, pulleys, rope and washer pumps, wing pumps, and drip irrigation systems were given to champion farmers. The household irrigation components were provided on loan.

Demonstration plots were then set up by the champion farmers, and following an assessment of gaps in knowledge and skills on irrigation agronomy, training was provided for them on irrigation agronomy systems; water management techniques; seed multiplication and handling; and planting, harvesting, and marketing. High-value crops suitable to the agroclimate were identified and the champion farmers were given improved seeds.

Results of the intervention

Although it has only been a year since the intervention started, a number of achievements are evident in terms of changes of attitude, knowledge, and skills of the champion farmers and improvements in their livelihood. All the 63 champion farmers, using their set of skills and inputs, have started growing horticultural crops: potato, tomato, onion, and green pepper. Using improved seeds and agronomic practices, coupled with the irrigation techniques, farmers were able to harvest their produce with increased yields. The crops were sold at higher prices, increasing their overall incomes. Non-champion farmers living near the champion farmers have also been influenced and have started adopting the new techniques. For example, other farmers have started using the improved seed varieties of potato and tomato used by the champion farmers.

Making farmers' voices heard

Champion farmers report that their engagement in the public sphere has increased as the LPA gave them a platform through which they can voice their needs. They said that they have gained recognition both within and outside of their communities. Several stated that they are now viewed by the public as 'people who have knowledge,' 'people who support the community,' and 'people who can contribute to the local economy' (Biruh *et al*, 2014).

Female champion farmers in Dera were happy with their increased engagement. Initially, the female champion farmers were quieter and did not express their opinions and concerns as strongly as did the male champion farmers. LPA members have noticed that the women were beginning to feel more comfortable speaking up during meetings because of their exposure to training and interactions with different actors through the LPA. The visibility and success of female champion farmers had helped improve the perception of women within households and communities. One LPA member stated that, due to the LPA, "we now know that there are serious women farmers" (Biruh *et al.,* 2014).

Ownership of the LPA process

An assessment carried out on the LPA process indicates that LPA members feel that the LPA process has met or exceeded their expectations (Biruh *et al.,* 2014). Initially, members were skeptical about the feasibility of the approach, warning that facilitating this multistakeholder platform in practice would be challenging, and that program activities may not be implemented, unless clearly defined roles were assigned (GWI, 2013). However, one year on, they had changed their minds. The LPA members were also pleased that research was followed by action. One LPA member expressed his initial concern that, like many research projects, the LPA would be theoretical, but was glad that the research has led to tangible interventions. Others were surprised by the scope of the program and appreciated its wide-scale application from the household through the zonal level (Biruh *et al.,* 2014).

> Yeshume Chekole, a 20–year–old farmer from Korata Kebele, was selected as a champion farmer and underwent training on improved irrigation agronomic practices and received improved seed varieties. With her newly acquired knowledge and inputs, she planted potato, tomato, hot pepper, and maize on her 1.2–acre land. Additionally, she rented half an acre of land. The yield was high from the sale of vegetables and she was able to pay 3,000 birr (US$150) rent to the landlord. Together with her other savings, she was, for the first time in many years, able to buy three sheep and was able to improve and furnish her house (Agiro, 2014).

> Dassashe Bekoyegne, a 45–year–old single mother of six, became a champion farmer and received training on soil and water conservation methods, such as mulching and construction of ridges to help retain soil moisture and supplementary irrigation techniques. With her newly acquired skills, Dassashe prepared her land for cultivation, enriching the soil with compost manure. She planted rice, maize, potato, sugar beet, pepper, and tomato. From a 10 x 10 m^2 plot of land, she reaped 500 birr ($25) worth of tomato compared with 300 birr ($15) the year before. She also obtained 400 birr ($20) worth of pepper as opposed to last year's 200 birr ($10). Her onions did best and fetched her 2,200 birr ($111), more than double the previous year's harvest of 900 birr ($45).
>
> Cultivating vegetables and using irrigation techniques have enabled her to become more–food secure and to earn a better income. Her two youngest children, who dropped out of school previously, have also resumed schooling. (Agiro, 2014).

In addition, in Ethiopia, the government has given greater attention to issues linked to water–smart agriculture through various national programs targeted at improving agricultural water management. The similarities of these national program goals to those of CARE's GWI-EA initiative have captured the attention of government officials and motivated their participation within the LPA. Also, because government officials have participated directly in the LPA process, from defining selection criteria to participating in the action research, they have a feeling of ownership in the LPA and the research results. This is evidenced, for example, by the incorporation of technologies recommended from the assessment on household irrigation technologies by the woreda's agriculture growth program (AGP) in their annual plan for funding.

Capacity building

As members of the action research groups, government sector staff developed research questions and tools and engaged in data collection and discussion of results. The process helped the sector staff build their capacity to do research techniques, develop a deeper understanding of the challenges farmers face on the ground, and learn about new ideas and approaches through working closely with research institutions. Getahun Tiruneh, the Dera District agriculture officer and a member of the irrigation agronomy action research group, noted,

I'm the crop agronomist and I'm the focal person for the program. My participation in the action research group has led to an interaction with different experts like the staff of the Agriculture Research Institute. This has given me exposure to new ways of working and new technologies, such as varieties of improved seeds etc, which is useful for my work. The short-term training I received on how to identify high-value crops for irrigation suitable for the woreda was also very useful. It can help build the capacity of extension agents, who in turn can cascade the training to farmers.

Connecting local research with national platforms

Lessons from local action research of the LPA shall be disseminated to other platforms. For example, a national learning platform on agriculture water management is jointly being developed with the Ministry of Agriculture. The platform has evolved out of a small-scale irrigation task force within the ministry, following discussions, as the ministry realized the benefits of a more holistic and integrated approach to addressing agriculture water management. In addition, a source book that documents good practices and lessons from the East Africa Region is being jointly developed with the International Water Management Institute and the Water, Land and Ecosystem Program as another method of linking local level lessons with wider platforms. Finally, a national radio program is also used to open a dialogue between smallholder farmers and government decisionmakers by providing the farmers access to a wider national platform on which they can raise their concerns and share their experiences and lessons.

Challenges

One of the main challenges in LPA implementation was the huge effort required around coordination and scheduling of action research meetings. Participation of government staff, while high during LPA meetings, was low in the actual research undertaking due to workload and unanticipated meetings or campaigns organized by higher level government structures. Conversely, government officials expressed frustration with the research institutions for scheduling research meetings at times that were sometimes inconvenient for government officials, especially as the action research was conducted during one of the busiest times of the year for the agriculture offices.

Another challenge has been the turnover of participants, especially from government offices. For various scheduling and compensation reasons, government offices alternate on who is sent for LPA meetings and action research. The high turnover of local government participants resulted in a loss of institutional knowledge and orienting replacement members posed its own set of challenges.

Lessons learned

One of the main lessons is that while the LPA approach is very useful in ensuring ownership of research results by government, the extent of time the process takes to effectively coordinate research activities, monitor implementation, and document change should not be underestimated. The process works best when schedules for particular tasks have some flexibility. Tangible results from the implementation of the approach are very exciting because of the multiple benefits generated at the different levels, but the approach requires a significant level of engagement and time.

Conclusion

Although at its early stage of development, the LPA framework implemented by CARE through GWI in Dera has shown considerable achievements. The relationship between local government and champion farmers has strengthened noticeably, and new relationships have been established among LPA members who previously did not interact. The platform has helped link researchers with endusers of the research both on the ground in terms of individual farmers and at the government level in terms of policymakers, and it has ensured ownership of the research results by all. The process has shown that the LPA framework is a promising approach for bringing together stakeholders from different sectors and levels of society to increase awareness, investment, and collaboration.

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Socioeconomic Barriers to Adoption and Scaling-out of Water-Smart Agriculture in Tanzania

Between 1980 and 2000, Africa is estimated to have spent about US$4 billion on agricultural research (Gura and Gundula, 2000), which has generated a wealth of agricultural innovations. However, only a few improved agricultural technologies have been adopted on a wider scale. This is the result of poor adoption and scaling-out processes of agricultural innovations, including water-smart agricultural technologies (Morris *et al.,* 2005; Tumbo *et al.,* 2011).

Tanzanian agriculture remains predominantly rainfed, largely facing water scarcity particularly in the semiarid areas that cover around 60% of the country. In this regard, harnessing agricultural water resources is critical for upgrading rainfed agriculture.

The concept of water-smart agriculture (WaSA) relates to previous concepts that harness agricultural water mainly in rainfed agriculture–e.g., soil-water conservation (SWC), water system innovations

(WSI), conservation agriculture (CA), and climate-smart agriculture. Such concepts are adequately expounded in literature with the exception of the WSI[1], which was prompted by UNESCO-IHE and IWMI (2003).

As most potential agricultural technologies, the adoption and scaling-out[2] of water-smart technologies have been unsatisfactory in spite of successful field tests in many places (Tumbo et al., 2011; Kahimba et al., 2014). An overarching question is why the uptake of such technologies at the farm-level and spread of the same over most of the agro-landscapes remain limited. This paper is a modest attempt to answer this question by underpinning socioeconomic barriers limiting successful adoption and scaling-out of WaSA practices.

Objective

The objective of this paper is to consolidate critical socioeconomic barriers that hinder successful adoption and scaling-out of WaSA.

Methodology

The paper draws empirical insights primarily from two published literature. The first covers adoption and scaling-out of water-system innovations based on a study conducted in Same District (Tumbo *et al.,* 2011). The second covers adoption and scaling-out of CA in Arusha and Dodoma regions (Kahimba *et al.,* 2014). Moreover, some insights were drawn on request from FAO's yet unpublished adoption study under its project called Mitigation of Climate Change in Agriculture (MICCA) in the Uluguru Mountains in Morogoro Region, Tanzania. The empirical results from these studies are blended with expert experience to consolidate evidence-based knowledge on the barriers to successful adoption and scaling-out of WaSA. The three reference studies collected data through cross-sectional surveys using a household questionnaire coupled with focus group discussions to gain communitywide insights.

Results and discussion

The successful scaling-out of WaSA technologies depends on a range of socioeconomic factors that can be grouped into three categories—farmer-related, community-related, and institutional.

Farmer-related include those factors emanating from the internal conditions of the farmers and those within his control. These include education and skills, labor, household resource base, and intrahousehold gender relations.

The community-related envisaged factors involved social capital, culture, and norms and values of the community. These actually determine the diffusion of innovations at the community scale. The institutional factors are those related to governance, political participation, delivery of socioeconomic services, influences and roles of external change agents, input and output markets, and microfinance.

The three categories interact in a dynamic way through complex feedback mechanisms that determine outcomes at different decision scales—i.e., farmer, community, and government. Therefore, an attempt to draw a line of distinction is arbitrary but may be necessary to enable a systematic organization of ideas.

Farmer-and community-related factors

Land tenure insecurity

Water-smart agricultural practices are carried out on the land. Insecure land tenure could be a barrier to adoption and scaling-out of WaSA. Some investments in WaSA have lasting streams of benefits that a farmer wishes to enjoy over time. When the future of resource ownership and access rights is uncertain, the farmer will be unwilling to commit such investments. For example, benefits of double digging and terracing on the farm last beyond one season; a farmer renting land may be reluctant to undertake the practice in fear of the landlord taking back the plot next season. Any arrangement that will enable secured land tenure such as land use planning and good land governance by both institutions of state

[1] WSIs can be defined as all indigenous and novel technologies for improved agricultural water management, covering both crop and livestock production (UNESCO-IHE and IWMI, 2003)—such as deep tillage, mulching or crop covers, terraces, water storage reservoirs, water harvesting and drip irrigation (Tumbo et al., 2011).
[2] Scaling-out is the horizontal or geographical spread of innovation to more people or locations (Guendel et al., 2001).

and that of society is an incentive for successful adoption and scaling-out of WaSA.

Scarcity of land resource

Land is a vital resource to resource-poor smallholder farmers. However, the land resource is not plenty to many smallholders. Land is becoming increasingly scarce over time due to increasing population, coupled with poor productivity. In the face of scarcity, resource-poor farmers tend to be risk-averse—i.e, reluctant to commit their land on new technologies. A farmer with ample farmland may be ready to try a new technology on one part of the land and spare the remaining while learning the outcome of the new technology before scaling it up on a larger land. Despite the fact that land is a finite resource and some pockets of extreme land scarcity exist in the country, still majority of the farmers, especially in the dryland, have enough land. However, the most pressing situation is low productivity mainly due to agricultural water stress.

High investment and operational costs

A range of costs is associated with adoption of WaSA. These include costs on investment in on-farm structures such as terraces and recurrent costs on inputs such as improved seeds, management, and maintenance costs. Other important typologies of costs include opportunity and transaction costs. For example, the crop residue to be incorporated in the farm under conservation farming may have alternative uses as feed for livestock and as fuel (Giller *et al.,* 2009; Bishop-Sambrook *et al.,* 2004). Transaction costs involved in searching for information about the technology and time spent in meetings and collective action can be a hindrance to adoption and scaling-out of WaSA technologies. The cost barrier can be counteracted through functioning pro-poor micro-finance schemes that can extend credit to smallholder farmers to solve the liquidity constraint.

Labor constraint

Family labor is the major input in the implementation of WaSA technologies. A household that has inadequate labor force and has no means of hiring labor would find it difficult to adopt the practice and vice versa. Improving human health through better health services and nutrition will increase labor productivity. Introduction of labor-saving technologies such as draft animals and specialized implements to carry out WaSA practices are among incentives for adoption and scaling-out of WaSA technologies.

Lack of access to input and output markets

Access to input and output markets plays a big role in the uptake of agricultural technologies. However, majority of smallholder farmers have limited access to input markets (that deliver affordable inputs timely) and to profitable output markets. The efforts committed at adopting the technology in the field is rewarded through access to affordable input and profitable output markets. Improved market access that ensures higher returns to land and labor is therefore a critical factor for the adoption of WaSA practices.

Lack of access to credit

Majority of smallholder farmers are income-poor—hence highly constrained of both investment and operating capital. The rural micro-finance institutions are underdeveloped and majority cannot access credit. This may limit the uptake of water-smart practices that are relatively capital-intensive such as terraces. Initial costs can prohibit adoption of bench terraces in spite of their potential returns on investment compared with less costly practices such as grass strip farming. Tenge *et al.,* (2005) estimated investment costs per hectare of bench terraces and grass strip to be US$215 and US$84, respectively. However, respective rates of return per shilling invested were 19% and 6%, but adoption rates were 26% and 55%. Arguably, unless poor farmers have access to credit, adoption of bench terraces will be curtailed. Change agents and development practitioners who have been promoting costly and labor-intensive innovations such as terraces have tried to have different incentive packages. Most of them—such as FAO in its MICCA project in the Uluguru mountains, Traditional Irrigation Project (TIP) and Same Agriculture Improvement Project (SAIPRO) in the south-Pare mountains—have been encouraging collective action through farmer groups as a means of mobilizing labor. Some of the NGOs, particularly TIP and SAIPRO, have had conditional incentives such as food for work and urging farmers to have installed terraces first before they get supported in the rehabilitation of traditional water reservoirs (locally called *ndiva*).

Limited access to appropriate farm implements and tools

Implementation of some water-smart practices requires appropriate tools. Layout of terraces needs farmers to have tools such as pick axes, shovels, and levels. Double digging can be done with an improved hand hoe designed to penetrate easily in the soil. Ripping to enhance moisture infiltration by breaking the soil hardpan can be done easily with animal-driven rippers. Majority of smallholder farmers may be unable to access these productive farm tools. Incentives would be to enable farmers to have access to such tools. This can be achieved through organized technology hire schemes, training and supporting local manufacturers to fabricate affordable tools, and improve the micro-finance arrangements for micro-capital acquisitions. Kahimba *et al*. (2014) found that training on the use of draft animal power and affordability of oxen technology contributed to increased adoption of conservation tillage in Dodoma.

Limited social capital

Some social capital elements are important for scaling-out of agricultural technologies such as water-smart technologies. Such elements include farmer group networks, interactions with different people, and collective action (Tumbo *et al.,* 2011). For example, FAO's MICCA program has used the contact farmer-trainers as paraprofessionals in the transfer of climate-smart agricultural technologies in the Uluguru mountains. The sustainability of the farmer-trainer approach depends much on how the respective community will continue to trust and value the knowledge delivered through farmer-paraprofessionals.

Institutional factors

Limited presence of non-state change agents

Increased involvement of external change agents through programs and projects is critical for successful adoption and scaling out of WaSA. However, most of the programs are short-lived and change agents leave the target communities shortly. There are evidences that adoption of water-smart practices such as terraces requires intensive training and presence of change agents over a long time (Tumbo *et al.,* 2011; Kahimba *et al.,* 2014; FAO, 2014). The farmers also stressed that the locals usually tend to value the knowledge extended by external people (FAO, 2014). The successes seen in some areas such as terraces in the Lushoto highlands, south Pare mountains, and parts of Arusha are due to interventions by TIP and the Soil Conservation and Agroforestry Programme (SCAPA) in respective areas for more than a decade from the late 1980s. For example, most of the farmers attributed the adoption and diffusion of terraces in the Makanya catchment to NGOs that have had lasting interventions in the area. For example, Kahimba *et al.* (2014) reports that an NGO called Lay Volunteers International Association (LVIA) successfully promoted conservation tillage using ox-drawn rippers by conducting training and issuing a set of oxen and oxplow at a subsidized price to a farmer group.

Lack of effective knowledge and outreach strategies

Different change agents and the government extension use different approaches to transfer agricultural technologies—including those with and without demonstrative and interactive features. Demonstrative and interactive knowledge transfer and outreach strategies are effective for successful adoption and scaling-out of WaSA. Tumbo *et al*. (2011), Kahimba *et al*. (2014), and FAO (2014) found that field demonstrations, farmer field schools, self-help groups, study tours, and field visits were perceived by farmers to be the most effective methods of communicating knowledge on water system innovations, CA, and climate-smart agriculture. In contrast, non-interactive methods that do not provide means for physical witness and immediate feedback would be less effective.

Limited partnerships and alliances

The programs and projects promoting agricultural technologies in rural areas tend to work in isolation. Partnership between key stakeholders and institutions in the community is a prerequisite in successfully outscaling an innovation. Tumbo *et al*. (2011) reports that a strong partnership between TIP, SAIPRO, the district government, and the communities was the major reason for scaling-out of some technologies such as terraces and water harvesting in Same District. The external change agents should seek to forge a partnership with a spectrum of administrative, development practitioners (internal change agents), and community-level institutions at the innovation promotion sites.

Conclusions and recommendations

Harnessing agricultural water resources is the centerpiece of upgraded productivity of rainfed agriculture, particularly in the vast dryland areas. Therefore, addressing what limits the uptake and spread of WaSA is indeed an agricultural development topic.

The socioeconomic barriers to successful adoption and scaling-out of WaSA are not different from those that have shaped the adoption and diffusion patterns of agricultural technologies in Africa. However, such barriers vary on how to address them, depending on the contexts of the technology and the biophysical and socioeconomic settings.

The most policy-relevant barriers that limit successful adoption and scaling-out that have to be addressed include land tenure insecurity especially among women, limited access to input and output markets, and poor access to credit.

The paper recommends that the critical barriers be addressed in order to advance WaSA in the country. By addressing the barriers, WaSA practices could be widely adopted and scaled-out at the agro-landscape level.

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Policy and Institutional Framework: Implications in Support of Effective and Efficient Use of Water Resources in Tanzania

The core objective of water–smart agriculture (WaSA) combines the best available knowledge and experience on rainfed systems (green water) with the development of surface and groundwater irrigation (blue water) to achieve an optimal balance for farmers. Promotion of the WaSA concept focuses on effective and efficient use of water resources.

Water-smart agriculture as an organizing concept has evolved from a comparative semantic of climate-smart agriculture (CSA), which was pioneered by FAO (FAO, 2013). Virtually, WaSA encompasses conventional agricultural water management practices—predominantly in the rainfed and smallholder irrigation systems. Water-smart agricultural practices broadly include soil-water conservation, water harvesting, and development of underground water.

WaSA technologies are mainly meant to upgrade the productivity of rainfed agriculture. Policies and institutional frameworks that have implications on sustainable development of WaSA practices are worth assessing.

Objective

The overall objective of the paper is to highlight and create awareness among readers and planners on the existing policy and institutional frameworks for sustainable development of WaSA.

Methodology

The paper is based on a desk review of both published and gray literature and draws on expert micro-level case experiences on the adoption, implementation, and outcomes of water-smart agricultural practices. The central focus is on highlighting policies and institutional frameworks that have implications on sustainable development of WaSA.

Water-smart agricultural practices are addressed in three major blocks: soil and water conservation (SWC) practices including minimum tillage, deep tillage, mulching, terracing, ridging, and grass trips and stone bunds on the contours; water harvesting (WH) mainly for supplemental irrigation, which include runoff harvesting, and water harvesting with storage such as ponds, micro-dams, tanks and cisterns; and groundwater development (GWD) covering groundwater recharge and extraction practices.

The policy and institutional frameworks envisage sectoral and mainstream policies and enacted legislations, regulations, and organization. On the other hand, the policy framework entails a "continuum" of sector policies, strategies and plans, programs and projects. In this paper, the word "policy" will be referring to sector policies excluding strategies, programs, and projects. Policies for water–related sectors were reviewed. For climate change, the agriculture climate resilience plan was reviewed.

Water-smart agriculture explains how smallholder farmers can manage the little water resources they have to cope with the uncertainties associated with rainfed production systems. It builds farmers' resilience to deal with the growing uncertainty in rainfed production systems, combining rainfed farming with sustainable small-scale irrigation from surface and ground sources (IWMI, 2014).

Water-smart agriculture–a landscape of policies

The landscape of policy and institutional frameworks that affects WaSA in the context of agricultural water management in smallholder agriculture was illuminated in three rather distinct policy periods. The policy periods were arbitrarily defined to guide insights on the implications of policies and institutional frameworks on agricultural water management over time. The approach extends a framework used by Tumbo *et al.* (2007) in assessing the policy and institutional frameworks governing agricultural water management in Tanzania.

The study period of 1985–2014 was split into three distinct policy periods: 1985–1996, 1997–2005, and 2006 to date (Table 1). The period from 1985 to 1996 is characterized by major moment-defining political and policy events, which included gradual implementation of structural adjustment programs including the decreasing role of the state in the market due to economic liberalization and the first multiparty election. The period from 1997 to 2006 involved the formulation of key agriculture and water–related policies and legislations—the Agriculture and Livestock Policy of 1997, Land and Village Land Acts No. 4 and 5 of 1999, the Water Policy of 2002, and the Environmental Management Act of 2004. The period from 2006 to date is marked by the start of a second-term political tenure, which advanced with economic reforms that mainly involved privatization of public investments, including irrigated farms, the Irrigation Policy of 2009, and the Agriculture Policy of 2013. Following a growing discourse on climate change agenda, the National Climate Change Strategy of 2012 and the Agriculture Climate Resilience Plan of 2014 were developed. These policy frameworks including others have had implications on WaSA in the context of agricultural water management.

Aside from showing the policy trend, it is imperative to highlight the reviewed water-smart policies that are operational currently. These include the Land Policy (1995), Environmental Policy (1997), Water Policy (2002), Irrigation Policy (2009), Agriculture Policy (2013), and the Agriculture Climate Resilience Plan (2014).

Generally, Tanzania's policy direction is toward supporting irrigation as a strategy to transform agriculture (Box 1). This is a good move since the country has not exploited its full irrigation potential. However, attention to modern irrigation is likely to scoop much of the budgetary resources at the expense of other agricultural water management approaches that have historically received limited public investment, such as soil-water conservation and rainwater harvesting.

Box 1: *Selected ambitious agriculture development targets*

6%	**Annual growth target for the agriculture sector** Tanzania Agriculture and Food Security Investment Plan (TAFSIP), CAADP
10%	**Allocation to the agriculture sector from national budget** Kilimo Kwanza, Maputo Declaration, CAADP
100%	**Food security in terms of food self-sufficiency** Tanzania Vision 2025
7 million	**Area (ha) under irrigation** Kilimo Kwanza

Source: Agriculture Climate Resilience Plan (2014).

Key institutional frameworks

Legislative frameworks

Water laws

All the waters in Tanzania are vested in the United Republic. The main water legislation was the Water Utilization Act of 1974, which deals with allocation of water among the different users. The Act was amended in 1981, 1989, and 1999. The exclusive rights to use water belong to those who have water rights granted under the Water Utilization Act. Two recent legislations that govern water resources include the Water Resource Management Act No. 11 and the Water Supply and Sanitation Services Act No. 12, both of 2009. The Water Resource Management Act is comprehensive, covering most of the issues related with water resource management; it is thus more relevant to WaSA.

The Water Resource Management Act sets out systems for managing the growing demand for water

Table 1*. Evolution of policy and institutional frameworks over time.*

Policy	Key elements/features		
	1985 – 1996	1997 – 2005	2006 – to date
Agriculture Policy, 1983	• Dominance of public sector control in the economy • Overemphasis on irrigation (narrow definition of agricultural water) • Land conservation not designed for moisture conservation • Environmental sustainability not explicitly underscored	-	-
Agriculture and Livestock Policy, 1997	-	• Increased engagement of private sector • Irrigation still emphasized to upgrade and stabilize agriculture and animal production	-

Policy	Key elements/features		
	1985 – 1996	1997 – 2005	2006 – to date
Agriculture and Livestock Policy, 1997	-	• Integrative management of natural resources expressed (land, soil, water, and vegetation)	-
	• Environmental sustainability emphasized • Conflicts between farmers and pastoralists highlighted	-	-
National Agriculture Policy, 2013	-	-	• Specific issues on climate change underscored • Irrigation emphasized • Rainwater harvesting promoted • Water use efficiency emphasized • Integrated and sustainable utilization of agricultural land protected and promoted • Gender-equitable land tenure governance promoted
Water Policy, 1991	• Government considered as sole investor, implementer, and manager of water projects • On the issue of water for environment, 'the voiceless' sector, not accorded importance • Agricultural water management marginally addressed compared with domestic water supply	-	-
Water Policy, 2002	-	• Paradigm of integrated water resource management came into play • Economic and institutional instruments for water management expressed for increased water use efficiency, sustainability and equity (water permits, pricing, water user associations) • Water allocation system distinguished and water use permit separated from land title	-

Policy	Key elements/features		
	1985 – 1996	1997 – 2005	2006 – to date
-	-	• Water for environment emphasized • Rainwater harvesting for both crop and livestock production emphasized • Stipulated roles of the Basin Water Office (basin approach in water administration)	-
National Irrigation Policy, 2009	-	-	• Strong emphasis on irrigation development • Promoted rain water harvesting-based irrigation, e.g., runoff diversion • Upgrading of infrastructure in traditional irrigation • Emphasis on registered irrigator associations • Equitable access to irrigated land addressed
Environmental Policy, 1997	-	• Water use efficiency in irrigation, control of water logging and salinization considered • Protection of catchment areas, wetlands emphasized • Afforestation through tree planting strongly emphasized • Environmental protection and water pollution underscored • Land husbandry through soil erosion control and soil fertility improvement emphasized	-
Land Policy, 1995	• Customary land rights secured in law • Presidential power over land underscored (President can revoke any right of occupancy for the public interest) • Demarcation and protection of agricultural land • Women's access to land guaranteed by the law	-	-

Policy	Key elements/features		
	1985 – 1996	1997 – 2005	2006 – to date
-	• Customs and traditions over land access and rights hold if they are not contrary to the constitution and repugnant to principles of natural justice	-	-
Agriculture Climate Resilience Plan, 2014	-	-	• Rain water harvesting promoted • Increased water use efficiency • Catchment protection and conservation
-	-	-	• Improved soil, water and land management • Conservation farming

through integrated planning and management of surface and groundwater resources. The Act assigns local water user associations to foster water resource management on the ground by helping in the implementation of water policies and enforcement of related legislations. Through the IWRM framework, the water user association can help protect catchments and water sources.

Tanzania is a country with legal pluralism, meaning that the legal system is composed of statutory and customary laws. In many parts of rural Tanzania, statutory water legislations have existed parallel to customary laws for many years. These traditional systems are deeply rooted and often quite functional, particularly in areas of conflict resolution, water resource and catchment protection, and water allocation among different users (Sokile *et al.* 2005).

The unwritten and flexible nature of customary law implies the complexity of application. Contrary to land rights, customary water rights have never earned recognition under the law in their unwritten or informal status.

Application of statutory laws governing water management at the grassroots level has never been smooth under different circumstances. Subjecting local users to water rights and fees as per statutory law requirement is incomprehensible to local users. The local communities think that they are not supposed to seek user permit or pay fees for water, which is a God-given resource.

A number of examples show conflicts between traditional users and those with formal water rights as in the case of the Lower Moshi Irrigation Scheme where the project had a water right that was contested by traditional users upstream (Tumbo *et al*., 2007).

Land laws

This analysis focuses on land tenure and gender relations as they logically affect WaSA. Access to agricultural water is subject to access to land. Therefore, tenure arrangements that govern access to land are very relevant in sustaining WaSA. Also, a gender perspective of land access is critical in order to comprehend the position of women who are major actors in the smallholder farming sector.

Land tenure is defined as a bundle of rights that a person may possess with respect to a piece of land. Such rights prescribe what the person can or cannot do on the land, including means of access, disposal, and exclusion. Restrictions on these rights impinge on one's security of tenure on that piece of land, while unrestricted continuous use and disposal rights enhance them (Isinika and Mutabazi, 2010).

Since Tanzania has embarked on economic liberalization in the mid-1980s, there have been deliberate efforts to induce land reform so that the prevailing land tenure is consistent with the ongoing economic transformation.

Consequently, a number of steps have since been taken to guide the land reform process. First, in order to address the increasing number of land conflicts, a presidential commission of inquiry into land matters was established in 1991 to, among other things, review policies and laws, which were then in force and recommend for their improvement. The reform process continued, with a new land policy in 1995, based on which two new land laws were enacted in 1999. Land Act No. 4 of 1999 covers general land, while Land Act No. 5 of 1999 addresses land that falls within village boundaries. The latter is specifically intended to cover customary law. Under this law, security of customary tenure is assured by issuance of a customary land certificate, thereby giving equal status to both granted and deemed rights of occupancy. The land laws stipulate that all land is public land under the trusteeship of the president, and this public land is categorized into general land, village land, and reserved land (Land Act No. 4, section 4 of Fundamental Principles of National Land Policy, Village Land Act section 5). Some people argue, however, that such equality cannot exist since village land can be transferred into general land by order of the president (Isinika and Mutabazi, 2010).

Both the land policy and the land laws sought to improve the ownership rights of women. Authorization must be sought for any act of excavating, abstraction, drilling, draining, or distributance of water resources. By implication, where statutory law. However, the same policy and laws also recognize ownership and administration of land under customary law, which is the most dominant in rural areas. In 1992 it was estimated that about 82% of the land in Tanzania was administered under customary law (Tibaijuka and Kaijage, 1995). It is widely known that these laws do not work in favour of women; especially in as far as ownership and transfer rights are concerned. The Village Land Act No. 5 of 1999 protects access rights to land under both customary and statutory laws, not only by women but also other disadvantaged groups such as youths and people with disability. The Land Act No. 4 of 1999 safeguards gender rights land mortgaging arrangements as the lenders should not discriminate applicants on gender basis.

Despite that women can access land, lack of secured land ownership can limit adoption of water-smart agricultural technologies with long-term investment such as terracing. Empowering women economically remains to be another pathway through which women can own land acquired through exchange in the rural land markets.

Environmental management laws

The environmental management policy was made available in 1997 and the law to enforce it came seven years later. Meanwhile, enforcement of environmental management issues was done in a fragmented manner under diverse legislations. In 2004, the Environmental Management Act (EMA) came into play, to enforce environmental management in a more coherent manner. It is imperative to underpin the hotspot legal narratives legal in the EMA that imply on the EMA.

The authorities are responsible for the environmental matters are mandated to issue guidelines and prescribe measures for protection of water bodies – rivers and lakes. In most cases, the top-down environmental governance is problematic when the grassroots resource users are either not aware or possessed guidelines are not compatible with reality on the ground.

The EMA prescribes that a permit or prior Authorization must be sought for any act of excavating, abstraction, drilling, draining, or disturbance of water resources. By implication, where guidelines and prescribed measures do not comply with. Considering the circumstances of local water users, this law might deny water access by farmers, which will further undermine the adoption and development of WaSA technologies.

Every applicant for a water use permit issued under the relevant laws governing management of water resources, abstraction, and use of water shall be required to make a statement on the likely impact on the environment of the use of water requested. A mere smallholder farmer is not in a position to know the impact that he/she may cause as a result of his/her act of using water.

Basin water boards that mandated to issue water permits indicating the extent of compliance by water use permit holders—e.g., returning the water after its use to the body of water from which it was taken, ensuring that water that is returned to any specified source is not polluted. The practicality of such conditions, of returning flows which are free from pollution, is questionable mainly because the

Basin Water Office (BWO) lacks the capacity, mainly in terms of staff and budget, to monitor and analyze pollution levels among sparse users dominated by unregistered water users (Tumbo *et al.,* 2007).

Regulatory frameworks

Establishment and functions of the Basin Water Office

The BWO and its mandate envisage a critical regulatory framework for WaSA at the agro-landscape scale. Tanzania had already adopted a river basin management approach for water resource management in the 1980s. BWO is declared to be the body responsible for water administration. The mandate is to enforce and follow-up on existing legislation, regulations and operating rules governing water use and control of pollution; become the legal authority to collect the various water use fees; facilitate the establishment of lower level water management organizations, which will bring together users and stakeholders of the same source; and become centers for conflict resolution in water allocation, water use, and pollution (URT, 2002).

National Environmental Management Council

The National Environmental Management Council (NEMC) is the legal regulatory body for environmental management. The role of NEMC was made more explicit and inclusive in the Environmental Management Act of 2004. The Council was mandated to undertake enforcement, compliance, review, and monitoring of environmental impact assessment and, in that regard, facilitate public participation in environmental decisionmaking, exercise general supervision and coordination over all matters relating to the environment assigned to the Council under this Act or any other written law. NEMC works through the regional secretariat and the local government authorities, which ensure participation of local organs in one way or another. The village environmental management Committees of each village shall be responsible for the proper management of the environment (Tumbo *et al*., 2007). However, NEMC has been more evidently visible at the national level dealing with industrial pollution by large corporations. The presence of NEMC at the grassroots with smallholder land users is less vivid.

Organizational framework

Tanzania is divided into nine river basins that do not follow administrative boundaries such as regions and districts. The main levels of water administration and planning are national, basin, district, and community or user level.

At the national level, the ministry responsible for water oversees water resource governance. The central level is responsible for developing, disseminating, monitoring, and evaluating the National Water Policy of 2002. At the water basin level, the BWO oversees water administration at the basin scale, covering catchments and sub-catchment units in its area of jurisdiction.

At the district level, the district councils under the local government administer and govern water resource at catchment and subcatchment units. The district has a district irrigation development team that oversees irrigation issues, including rain water harvesting-based irrigation. Although not specifically formed for managing water, wards influence water management considerably.

The ward development committees frequently pass bylaws that impact on sanctions and penalties that seek to guide water allocation and quality. Ward councilors represent community members who elected them into power in the district council and mobilized communities toward the formation of water user associations (Tumbo *et al.,* 2007) or irrigators' organizations. The village is the lowest legal organization in Tanzania. Each village has 25 elected representatives to form the village council. The village council operates through three mandatory committees–the Finance, Economic and Planning Committee, the Social Services and Self-reliance Committee, and the Law and Order Committee. Water subcommittees fall under Social Services.

Conclusions

The policy landscape indicates that agricultural water has been for decades viewed under conventional irrigation. This narrow policy outlook on agricultural water management has denied meaningful attention in terms of public investment to other agricultural water management practices such as rain water harvesting and SWC that are of much relevance in the context of smallholder-based WaSA. Even the policy attention that such technologies gained in the mid–2000s seems to ebb with the renaissance of modern irrigation under grand government initiatives such as SAGCOT and BRN.

The concept of IWRM surfaces in the policy arena on agricultural water management. The operationalization of the concept is challenged by the lack of a clearer basis of water allocation. Overarching questions include the following: Should allocation be based on economic criteria such as returns per drop, and if so, how is water for the environment, of which the absolute amount is not widely known, valued? Should water be treated as a social or an economic good? If water is to be considered an economic good (and hence has to be paid for), how will the very poor access water for food, their basic survival right? These are policy challenges around pro-poor WaSA in the context of agricultural water management.

The water policy highlights some positive issues, including that of separating water rights from land titles during water allocation. This means that a formal right to water is not the subject of a land title. A landless farmer, who has acquired a piece of land through other arrangements such as through borrowing or renting, can still be granted water rights. The owner of a piece of land on which the common water resource is found or flows on cannot deny access to water of other neighboring land users.

The analysis of institutional frameworks has revealed that customary rights to water, though recognized in policies, are not articulated in statutory water laws. This is in contrast to land resources where customary tenure is articulated in the formal law. There is, however, a large group of small farmers without water rights but who claim to have a right-based custom—i.e., use of water by their families or tribes since time immemorial. The non-recognition of traditional or customary water users is at the root of many water use conflicts and jeopardizes the effective management of agricultural water resources.

The right to survive is a human right and access to food is the primary precondition for such survival rights. Therefore, access to agricultural water to produce basic food should be one's right. However, this is contrary to institutional frameworks that impose water permits (rights), which also envisage water fees. In addition to the costs paid, with the formation of WUAs and application procedures, the applicant bears significant transaction costs.

Recommendations

To upgrade productivity in smallholder rainfed agriculture promotion and investment in WaSA in a broad context are critical paying attention to highly orphaned rain water harvesting and SWC technologies.

Whereas food security is ranked high in policy priorities and access to agricultural water is critical in food security, especially for the poor, it is time now to consider 'free basic water for food' in our policies and institutional frameworks.

Customary rights to water, which are widespread in agricultural water management in the country, should be mainstreamed into formal water laws as in the case of land. This will increase access to water by smallholder farmers and reduce conflicts between holders of customary rights and formal rights.

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