Food and Agriculture Organization of the United Nations

Convention on Biological Diversity

MAINSTREAMING ECOSYSTEM SERVICES AND BIODIVERSITY INTO AGRICULTURAL PRODUCTION AND MANAGEMENT IN EAST AFRICA

TECHNICAL GUIDANCE DOCUMENT

BIODIVERSITY & ECOSYSTEM SERVICES IN AGRICULTURAL PRODUCTION SYSTEMS

MAINSTREAMING ECOSYSTEM SERVICES AND BIODIVERSITY INTO AGRICULTURAL PRODUCTION AND MANAGEMENT IN EAST AFRICA

Practical issues for consideration in National Biodiversity Strategies and Action Plans to minimize the use of agrochemicals

TECHNICAL GUIDANCE DOCUMENT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
and
SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY

ROME, 2016

ISBN 978-92-5-109215-6 (FAO)

Cover page picture:
© FAO/Giulio Napolitano

Back cover photos (left to right):
© M. Kasina; © M. Kasina; © FAO/Giulio Napolitano; © B. Gemmill-Herren

TABLE OF CONTENTS

Part III Policy measures for mainstreaming ecosystem services in agriculture

Boxes

Figures

Photos

Tables

ACKNOWLEDGEMENTS

This Technical Guidance Document was prepared in the context of the EU-funded project "Capacity-Building Related to Multilateral Environmental Agreements (MEAs) in ACP Countries – Phase 2". FAO implemented the first phase of the project focusing on the elimination of obsolete pesticide stockpiles and capacity development for improved pesticide management. This second phase continues some of the pesticide-related activities addressed in Phase 1, but includes activities related to additional MEAs, to address synergies between MEAs in the agriculture sector. The Convention on Biological Diversity, the implementation of relevant Aichi Biodiversity Targets and the preparation/implementation of National Biodiversity Strategy and Action Plans are a focus. In this context, this Technical Guidance Document was prepared for the East Africa region – with a focus on Kenya – for building institutional capacity for synergistic implementation of MEAs and to identify opportunities for managing biodiversity and ecosystem services as alternatives to chemical inputs.

This document was prepared in collaboration with experts on a range of topics related to ecosystem services management, at technical, institutional and policy levels. Its aim is to provide information on how ecosystem services and biodiversity can be mainstreamed into agriculture. The full list of contributors, to whom FAO and the CBD Secretariat are thankful, is available at the end of this publication.

We would like to thank Béatrice Grenier, Caterina Batello, Livia LoyDona, Maria Hernandez-Lagana, Nurit Roded, Renée van Dis and Soren Moller for their review and inputs on this technical guidance document.

ACRONYMS

ACP	African, Caribbean and Pacific Group of States
AEM	agri-environmental measure (CAP)
ASDS	Agriculture Sector Development Strategy (Kenya)
BCA	biological control agent
CA	conservation agriculture
CAADP	Comprehensive Africa Agriculture Development Programme
CAP	Common Agricultural Policy (EU)
CAWT	conservation agriculture with trees
CBD	Convention on Biological Diversity
COP	Conference of the Parties
EFA	ecological focus area (CAP)
EPWS	Equitable Payment for Watershed Services
EU	European Union
EWM	ecological weed management
GAEC	good agricultural and environmental condition (CAP)
GDP	gross domestic product
GIS	Geographic Information Systems
GIZ	Gesellschaft für Internationale Zusammenarbeit (German Technical Cooperation Agency)
GWC	Green Water Credit
ICRAF	World Agroforestry Centre
IFAD	International Fund for Agricultural Development
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IPM	integrated Pest Management
ISFM	integrated soil fertility management
ITK	indigenous technical knowledge
IWM	integrated weed management
IWRM	integrated water resources management
KenGen	Kenya Electricity Generating Company
KWAP	Kenya Woodfuel and Agroforestry Programme
LANAWRUA	Lake Naivasha Water Resource Users Association
LAPSSET	Lamu Port – South Sudan – Ethiopia Transport corridor
MEA	multilateral environmental agreement
MTP	Medium Term Plan (Kenya's Vision 2030)
NASCO	National Agroforestry Steering Committee (United Republic of Tanzania)
NBSAP	National Biodiversity Strategy and Action Plan
NEMA	conservation agriculture with trees
NERICA	New Rice for Africa
NGO	non-governmental organization
NWSC	Nairobi City Water and Sewerage Company
PCPB	Pest Control Products Board (Kenya)
PPB	Pharmacy and Poisons Board (Kenya)
SAICM	Strategic Approach to International Chemicals Management
SDC	Swiss Agency for Development and Cooperation
SIDA	Swedish International Development Agency
SIDS	Small Island Developing States
SMR	statutory management requirement (CAP)
SOC	soil organic carbon
SOM	soil organic matter
TEEB	The Economics of Ecosystems and Biodiversity
TN	total nitrogen
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
WHO	World Health Organization
WRMA	Water Resources Management Authority (Kenya)
WRUA	Water Resources Users Association (Kenya)
WWF	World Wide Fund for Nature

Part I

Context

© FAO/Giulio Napolitano

1 INTRODUCTION

Agriculture is central to human well-being and sustainable development. However, essentially every statement on the future of agriculture acknowledges that a transformation is needed in the way the sector is conducted. Agriculture has to achieve the dual and interrelated goals of food and environmental security while simultaneously increasing production to meet global food demands (Foley *et al.*, 2011; Godfray *et al.*, 2010; IAASTD, 2009; The Royal Society, 2009). Concerns over the sustainability of agriculture and the growing environmental footprint of farming systems have grown exponentially over the past 25 years. To many observers, agriculture looms as the major global threat to nature conservation and biodiversity; as noted in *Global Biodiversity Outlook 4* (CBD, 2014), the drivers associated with food systems and agriculture account for around 70 percent and 50 percent of the projected losses by 2050 of terrestrial and freshwater biodiversity, respectively. More recently, consensus has emerged that the fates of biodiversity and agriculture are intertwined.

Biodiversity and ecosystem services are at the heart of many solutions for sustainable increases in agricultural productivity that not only deliver better outcomes for food and nutrition security but also reduce externalities of production. The environment-agriculture discussion is shifting from a polarized debate of trade-offs to a discussion of mutually supporting agendas. It is encouraging that the agriculture sector itself has identified and promoted such approaches.

Conventional high-input agriculture, where yields have been increased largely by simplifying landscapes, adding more external inputs and increasing mechanization, is already struggling as a model for sustainability. But in many parts of the developing world, conventional high-input agriculture has not taken hold – and has little chance of doing so – owing to external resource input limitations. In many such regions, resource-poor farmers contend with issues of marginal high-risk environments and experience poor yields just where food security is most vulnerable. The agricultural research establishment has recently begun to focus increasingly on such areas and to recognize that highly site-specific resource management systems are needed to sustain productivity gains under these conditions (Altieri, 2002).

A strategy to achieve sustainable agricultural productivity increases will have to do more than simply modify existing techniques. A successful strategy will be the outcome of novel approaches in designing agro-ecological systems where management is sensitive to the local resource base and the existing environmental and socioeconomic conditions. Fundamental to such a strategy is the better management of soils and landscapes as ecosystems. Through ecologically sensitive management, the conservation or restoration of soils and landscapes will facilitate their ability to deliver ecosystem services that underpin sustainable productivity gains and improve on-farm profitability. Depending on local conditions and farming systems, external inputs, including agrochemicals, may in some cases still be required (at least in the short term), but where needed they are used sustainably and to enhance biological processes rather than to compensate for their loss.

Approaches that can address both the negative externalities of conventional production systems and the challenges of resource-poor farmers have a central common thread: They recognize that agriculture and food systems are biological and social systems. They can be designed to build on and harness the forces of biodiversity and ecosystem services that underpin sustainable agricultural production – soil fertility, natural pest control, pollination, water retention – so that these are optimized and encouraged. Farming systems can be regenerative, building on and adding to natural capital, rather than being increasingly dependent on external inputs that are becoming more scarce, that the system cannot absorb and that more often than not contribute to negative externalities.

Farming has traditionally not been a solitary operation; it has been carried out over millennia by communities of people. An ecosystem perspective recognizes that regenerative agriculture occurs on the level of the whole farming system, at the watershed and/or landscape or community level, with the traditional knowledge and experience of farmers and empowerment of communities as its base. As such, it also contributes to building and strengthening the social capital underlying agriculture.

Mainstreaming biodiversity and ecosystem services into agricultural production – and providing alternative options to unsustainable agricultural practices such as the overuse of external inputs (e.g. agrochemicals) – is a part of FAO's work to increase and improve provision of goods and services from agriculture, forestry and fisheries in a sustainable manner. FAO is collaborating with the United Nations Environment Programme (UNEP) and the Convention on Biological Diversity (CBD), through a European Union (EU) funded project in countries of the African, Caribbean and Pacific Group of States (ACP), to strengthen regional and national institutional capacity for the synergistic implementation of target multilateral environmental agreement (MEA) clusters (on chemicals/wastes and biodiversity).

In particular, with regard to biodiversity, FAO is working in East Africa and the Pacific with the following aims:

» to enhance institutional capacity by working with the CBD Secretariat to develop tools and guidance on integrating agriculture into National Biodiversity Strategy and Action Plans (NBSAPs) to address selected Aichi Biodiversity Targets that are integral to agriculture (e.g. Targets 7, 13 and 14) (Box 1), for dissemination at national levels, and to build synergies with measures to eliminate the use of toxic chemicals in agricultural production systems;

- to bring together National Biodiversity Focal Points, focal points for the biodiversity-related conventions, other agriculture-relevant focal points, relevant units within the national agriculture ministries and relevant non-governmental organizations (NGOs) to mainstream agriculture into NBSAPs to address Aichi Biodiversity Targets that are integral to agriculture (e.g. Targets 7, 13 and 14);
- to build capacity of national partners to identify linkages, enabling policies and instruments to promote synergies among agriculture/biodiversity-related instruments (e.g. the Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture, the International Treaty on Plant Genetic Resources for Food and Agriculture [ITPGRFA], CBD, chemicals instruments).

Although the project focuses on Aichi Biodiversity Targets 7, 13 and 14, following consultations with partners from participating countries in both Africa and the Pacific, it became evident that Target 9 would also be relevant as it relates to weeds, crop pests and livestock diseases. Target 8, which deals with pollution, is also relevant, as it includes pollution from excess nutrients.

Box 1. **Relevant Aichi Biodiversity Targets**

Each of the 20 Aichi Biodiversity Targets, in some way and to some extent, can be relevant to the agriculture sector. However, the following are particularly relevant:

- ***Target 7.*** By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.
- ***Target 8.*** By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.
- ***Target 9.*** By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.
- ***Target 13.*** By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socioeconomically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.
- ***Target 14.*** By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.

Defining ecosystems and ecosystem services

The CBD (2016a) defines an ecosystem as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit". The Millennium Ecosystem Assessment (MA, 2005a) highlighted that humankind benefits in diverse ways from ecosystems. Collectively, these benefits are known as ecosystem services. Daily (1997) provided an early and still useful way of describing ecosystem services: "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life".

Different typologies of ecosystem services have been proposed. The most common includes the following:

» **Regulating services** are defined as the benefits obtained from the regulation of ecosystem processes such as climate regulation, natural hazard regulation, water purification and waste management, pollination and pest control.

» **Supporting services** are those that support the delivery of other services, such as soil formation and supplying habitat for species, which enable ecosystems to continue to supply provisioning and regulating services.

» **Provisioning services** refer to the goods and physical products obtained from ecosystems such as food, freshwater, wood, fibre, genetic resources and medicines.

» **Cultural services** include non-material benefits that people obtain from ecosystems such as spiritual enrichment, intellectual development, recreation and aesthetic values.

This guidance document primarily considers the regulatory services and how they may be promoted and enhanced to support more sustainable production (provisioning services) and reduce externalities detrimental to biodiversity by reducing reliance on chemical inputs. But other services, such as the cultural values of agriculture and related indigenous knowledge systems, are important in supporting efforts towards an improved ecological foundation of agriculture.

About this guidance document

This guidance document has been produced to assist East African countries in finding synergies between two important realms of international agreements: chemicals management and conservation and sustainable use of biodiversity. It is designed for use by countries in revising any of their strategies or policies related to these two realms, but in particular in revising or implementing their NBSAPs, to help countries attain a number of relevant Aichi Biodiversity Targets. It indicates where important synergies can be harvested, but it is not meant to be prescriptive.

This version is a prototype for use in Kenya as the country revises its NBSAP in 2016, but will also be of relevance to other East African countries.

After this introduction, Part II addresses the use and management of ecosystem services and biodiversity with a view to minimize the use of agrochemicals in agricultural production in the East Africa region. Individual chapters explore the role of ecosystem services and biodiversity in relation to pest control, weed management, enhancing soil fertility, water conservation and pollination. Part II also explores the role of farmers' knowledge and innovation in managing ecosystem services, and the integration of crops, trees and livestock in agroforestry systems for a coherent approach to conservation and management.

Part III addresses policies to promote ecosystem services in agriculture. It begins with an overview of the international context. Country-level policies and legislation in Kenya are then presented. The final chapter presents a review of how ecosystem services have been addressed in NBSAPs and makes recommendations for how the considerations presented in this document can be incorporated in national policy. Lastly, the Annex addresses valuation of ecosystem services, presenting a protocol that can be used to provide evidence-based arguments for investing in ecosystem services, to policy and decision-makers.

Suggestions and recommendations for revision are welcome and should be communicated to David.Colozza@fao.org.

African context: challenges of sustainable agriculture and food security

The imperative to increase food production in the places in the world where populations are increasing most dramatically, and where food security remains highly vulnerable, has alarmed policymakers and food system experts. Many parts of Africa are central to these concerns.

Agriculture drives many national economies in Africa. However, in this region agriculture – and specifically food production – has been noted to perform poorly. The amount of food grown in Africa per person rose slowly in the 1960s, then fell from the mid-1970s and has only just recovered to the 1960 level in recent years (Pretty, Toulmin and Williams, 2011). For comparison, over the same period, per capita food production in Asia and Latin America increased by 102 and 63 percent, respectively. To be fair, this generalization does not apply to the whole region; some parts of Africa have actually shown aspects of growth in net agricultural production, with the greatest increases occurring in North and West Africa (Pretty, Toulmin and Williams, 2011). However, any efforts made towards agricultural growth are obscured by spiralling population growth. Similarly, issues such as disinvestment in agricultural research by African governments, conflicts and climate change have impacted negatively on agricultural growth and would remain the dent in the agriculture sector if not adequately addressed.

The quest for more sustainable cropping and farming systems that can meet food needs while conserving biodiversity can be framed in the context of the emerging paradigm of ecological intensification. Agriculture and biodiversity inevitably interact, and it is increasingly recognized that one can serve the other, i.e. it is possible to exploit synergies between them through ecological intensification. Ecological intensification relies on improved solutions stemming from the use of (mainly) local resources such as agrobiodiversity at the gene, species and habitat/ecosystem levels and improved knowledge of biological interactions occurring in an agro-ecosystem.

International context: linkages to the Convention on Biological Diversity

On 29 December 1993, the CBD entered into force. A key instrument for sustainable development, the Convention has three main objectives: the conservation of biological diversity, the sustainable use of the components of biological diversity and the fair and equitable sharing of the benefits arising from the use of genetic resources. The CBD addresses a number of overarching and thematic and cross-cutting areas touching on biodiversity that are important for food and agriculture. However, for the purpose of this guidance document, two are of particular relevance: the CBD Programme of Work on Agricultural Biodiversity, and the Strategic Plan for Biodiversity 2011-2020 and its Aichi Biodiversity Targets.

Programme of Work on Agricultural Biodiversity

The CBD established the Programme of Work on Agricultural Biodiversity in 1995 (Conference of Parties [COP] Decision III/11), and the fifth meeting of the COP in 2000 adopted Decision V/5 containing the Plan of Action of the Programme of Work on Agricultural Biodiversity and its four elements (assessment, adaptive management, capacity building and mainstreaming). The Programme of Work on Agricultural Biodiversity defines the scope of agricultural biodiversity: "Agricultural biodiversity is a broad term that includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agro-ecosystem: the variety and variability of animals, plants and microorganisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agro-ecosystem, its structure and processes..." (CBD COP Decision V/5). In particular, it recognizes "the special nature of agricultural biodiversity, its distinctive features, and problems needing distinctive solutions" and describes the dimensions of agricultural biodiversity as:

- genetic resources for food and agriculture;
- components of agricultural biodiversity that provide ecological services;
- abiotic factors, which have a determining effect on these aspects of agricultural biodiversity;
- socioeconomic and cultural dimensions, since agricultural biodiversity is largely shaped by human activities and management practices.

The Programme of Work on Agricultural Biodiversity also includes three international initiatives, on pollinators, soil biodiversity and food and nutrition.

Strategic Plan for Biodiversity 2011-2020, including the Aichi Biodiversity Targets

Global Biodiversity Outlook 3 (CBD, 2010) reported that the target agreed by the world's governments in 2002 - "to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth" - had not been met. Based on this and other considerations, in 2010 the Parties to CBD adopted the Strategic Plan for Biodiversity 2011-2020 and its Aichi Biodiversity Targets. This plan has been recognized as a common platform for action among the biodiversity-related multilateral agreements and the United Nations General Assembly.

The mission of the Strategic Plan (CBD COP Decision X/2) is to:

> *"take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication. To ensure this, pressures on biodiversity are reduced, ecosystems are restored, biological resources are sustainably used and benefits arising out of utilization of genetic resources are shared in a fair and equitable manner; adequate financial resources are provided, capacities are enhanced, biodiversity issues and values mainstreamed, appropriate policies are effectively implemented, and decision-making is based on sound science and the precautionary approach."*

Global Biodiversity Outlook 4 (CBD, 2014) included a midterm review of progress towards the achievement of the Strategic Plan for Biodiversity 2011-2020, based on quantified assessments of progress towards the Aichi Biodiversity Targets. It concluded that under a business-as-usual scenario, the projected losses of terrestrial and freshwater biodiversity by 2050 will be attributable to escalating pressures from food systems (including patterns of and trends in consumption) and agriculture. Achieving sustainability in food systems and agriculture will be a dominant pathway for halting the loss of biodiversity.

The Strategic Plan for Biodiversity 2011-2010 and its Aichi Biodiversity Targets explicitly consider ecosystem services. The rationale is that biological diversity underpins ecosystem functioning and the provision of ecosystem services, contributing to human well-being by supporting, for example, food security, human health, local livelihoods, economic development and poverty reduction. As a recognized overarching framework on biodiversity for all stakeholders, the Strategic Plan is not intended to be limited to environmental goals and institutions, but also to other sectors, including agriculture. Indeed, as shown in Box 1, most of the Aichi Biodiversity Targets are relevant to agriculture, and the agriculture sector has a key role in achieving the targets. However, few agricultural stakeholders are directly involved in the implementation of the CBD, although many might be undertaking some measures consistent in practice with the CBD. NBSAPs offer a major opportunity for mainstreaming biodiversity and ecosystem services into the agriculture sector.

National Biodiversity Strategies and Action Plans

NBSAPs are the principal instrument for implementing the CBD at the national level, as stated in Article 6(b) and supported by Article 10(a), which calls for integrating consideration of the conservation and sustainable use of biological resources into national decision-making. Under the Convention, countries have an obligation to develop an NBSAP and to ensure that this strategy is mainstreamed into the planning and activities of all sectors whose activities can have an impact (positive and negative) on biodiversity. More specifically, Article 6 calls for countries to:

» develop national strategies, plans or programmes for the conservation and sustainable use of biological diversity or adapt for this purpose existing strategies, plans or programmes which shall reflect, *inter alia*, the measures set out in the Convention relevant to the Contracting Party concerned;
» integrate, as far as possible and as appropriate, the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans, programmes and policies.

National Biodiversity Strategies are meant to reflect how a country intends to fulfil the objectives of the Convention in light of specific national circumstances, and the related Action Plans will constitute the sequence of steps to be taken to meet these goals. Currently, however, major challenges remain, and there is a need to enhance national capacity for implementation.

The main COP decisions that provide direct guidance for NBSAPs are Decisions IX/8 and X/2. Parties are encouraged to review these decisions for consolidated guidance on the NBSAP process, substance, components, support systems and monitoring and review systems. More specifically, in Decision X/2, COP 10 called on countries to:

» develop national and regional targets, using the Strategic Plan for Biodiversity 2011–2020 and its Aichi Biodiversity Targets as a flexible framework;
» review, revise and update NBSAPs in line with the Strategic Plan;
» integrate national targets into revised and updated NBSAPs, adopted as a policy instrument;
» use revised and updated NBSAPs as effective instruments for integrating biodiversity targets into national development and poverty reduction policies and strategies, national accounting, as appropriate, economic sectors and spatial planning processes, by government and the private sector at all levels;
» monitor and review NBSAP implementation in accordance with the Strategic Plan and national targets, making use of the set of indicators developed for the Strategic Plan as a flexible framework;
» support the updating of NBSAPs as effective instruments to promote the implementation of the Strategic Plan and mainstreaming of biodiversity at the national level, taking into account synergies among the biodiversity-related conventions in a manner consistent with their respective mandates.

To this effect, the CBD provides comprehensive information and guidance on NBSAPs (CBD, 2016b). Furthermore, other COP decisions provide direction on specific issues. For example, on agricultural biodiversity, Decision X/34, Paragraph 7 "Invites Parties to incorporate, as appropriate, relevant elements of the programme of work on agricultural biodiversity into their National Biodiversity Strategy and Action Plans as well as into their relevant sectoral and inter-sectoral policies and plans".

Parties (governments) are in various stages of revising their NBSAPs, and would prefer to devote scarce resources to implementation rather than to continual revision. This guidance document is therefore designed to inform appropriate revision of an NBSAP and/or to support implementation of an existing NBSAP in relevant policy areas, depending on the status of NBSAP revision in the country.

Part II

Using ecosystem services and biodiversity to minimize the use of agrochemicals in agricultural production in East Africa

© FAO/Giulio Napolitano

2

PEST AND DISEASE CONTROL

Muo Kasina

The ecosystem services of natural pest control comprise the activities of predators and parasites that act to control populations of potential pest and disease vectors. An estimated 99 percent of potential crop pests are controlled by natural enemies, including many birds, spiders, parasitic wasps and flies, ladybugs, fungi, viral diseases and numerous other types of organisms (Photo 1). These natural biological control agents save farmers billions of dollars annually by protecting crops and reducing the need for chemical control. Under enhanced management, they could sustain crop yields even more.

Why is this important? Pests and diseases cause economic injuries to crops and livestock, contributing directly to the low levels and stagnating growth of crop and animal productivity in many parts of Africa – which, combined with dramatically increasing population, results in food security remaining highly vulnerable. Stem-boring insects, for example, destroy 20 to 40 percent of Africa's maize harvest on average, and as much as 80 percent during heavy infestations (Gatsby Charitable Foundation, 2005).

Photo 1. **Ladybird beetles are natural enemies of many soft-bodied insects such as aphids, whiteflies and scale insects**

© M. Kasina

Despite costly and increasing inputs of pesticides (insecticides, fungicides), current figures for global crop losses still show that pests and diseases are reducing food availability and security considerably. For example, global crop losses due to pests are reported to be in the order of 26 to 29 percent for soybean, wheat and cotton, while losses for maize, rice and potatoes are in the order of 31, 37 and 40 percent, respectively. Despite a sevenfold increase in pesticide use over the last 40 years, and application rates higher than the historic application levels for DDT (dichlorodiphenyltrichloroethane), crop losses due to pests have not decreased significantly during the same period. It is estimated that insects consume enough food (pre- and post-harvest) to feed more than 1 billion people. By 2050 it is estimated that there will be an extra 3 billion people to feed. By this time it is likely that insect pests will have increased in numbers and types. Climate change is likely to cause unpredictable changes in pest distributions.

It is clear that the predominant solution to pest problems is not delivering the results needed; in fact many of the most serious and costly pest problems in the developing world are, ironically and unfortunately, the direct consequence of actions taken to improve crop production. In recent decades, dependence on chemical insecticides has led in many instances to a high frequency of insecticide resistance, now recorded in more than 500 insect species worldwide. The outcomes have been pest resurgence, acute and chronic health problems, environmental pollution and uneconomic crop production. These issues are particularly severe in developing countries, where pesticides are poorly regulated and farmers often lack appropriate training or information. For many of these farmers, pesticide use is becoming a seemingly obligatory, ever increasing, yet increasingly unreliable component of the cost of crop production.

Thus, pests and diseases remain the most challenging biotic constraints to productivity of crops and livestock. In East Africa, even small-scale farmers have moved towards greater and greater reliance on chemical pesticides. Once the preferred pest management strategy for commercial farms and commercially oriented small-scale farms, pesticides are now used across all farming systems in East Africa. A study in northern Tanzania in 2007 (Ngowi *et al.*, 2007) found that small-scale vegetable growers were highly reliant on pesticides (insecticides, fungicides and herbicides) in their production systems. The majority of these farmers applied pesticides more than five times in a season.

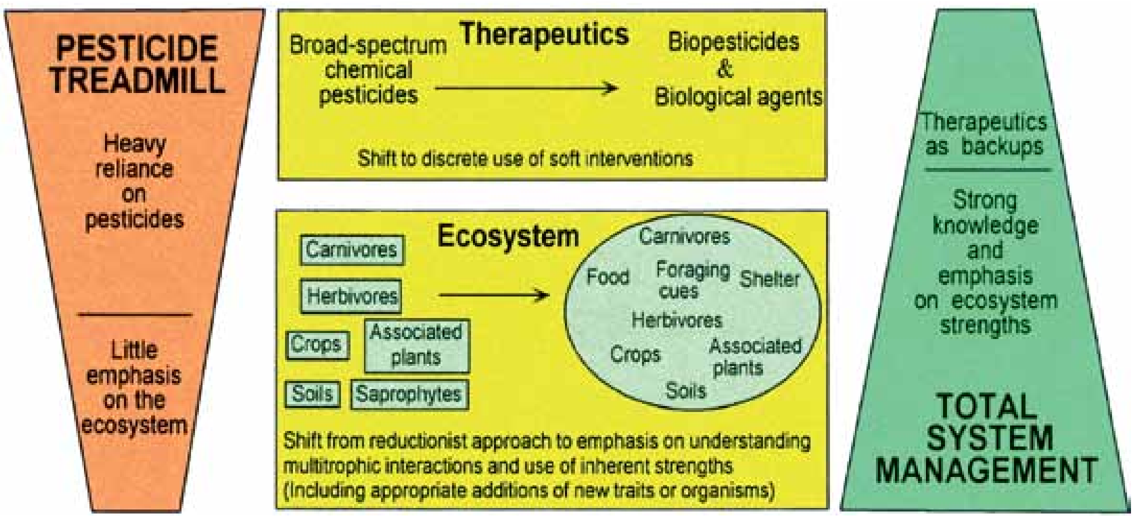
This dependence on pesticides can result in the following problems:

» development of resistance by pests as a result of frequent exposure to a given molecule for a prolonged period of time;
» emergence of new or previously minor pests when dominant pests of the agro-ecosystems are eliminated or reduced, requiring hitherto unneeded management solutions;
» increased cost of production as pesticides become less efficient;
» food safety concerns associated with unregulated and uncontrolled use of pesticides in crop production, with residue levels on the products posing risks to the health of intended consumers;
» rejection by export markets of produce with unacceptable residue levels, as these levels are strictly controlled in trade;
» environmental impact, including elimination of non-target organisms such as pollinators (with negative impact on yields of pollinator-dependent crops) and natural enemies (increasing the need for pesticides to control the pests).

Pest organisms (including insect pests, diseases and weeds) have been the focus of crop health research for many decades. Yet singular approaches to their control have often resulted in escalating costs and pest resurgences. While integrated pest management (IPM) is encouraged, IPM research in East Africa, as in many regions, has often been centred on a single-strategy solution or a small array of control measures such as more strategic use of pesticides, host-plant resistance or biological control, and rarely considers the interactions among them. Challenges in implementing IPM might be addressed by adopting a broader, more holistic ecosystem-based approach.

Natural pest control approaches seek to go beyond "therapeutic" measures to control pests. They involve restructuring and managing agricultural systems so that an array of biological interactions is in place which serves to prevent or reduce pest damage – disadvantaging pests, encouraging natural enemies and enhancing growth of healthy crops (Figure 1). This chapter describes how management of these complex biological interactions can result in positive outcomes for insect pest suppression in East Africa. The main focus is on the agro-ecological measures for managing pest organisms. The emphasis is on those strategies that are already widely applied in East Africa, with examples not only from the published literature but also from the author's experience working in the subregion.

Figure 1. **Illustration of a shift to a total system approach to pest management through a greater use of inherent strengths based on a good understanding of interactions within an ecosystem while using therapeutics as backups**



The upside-down pyramid to the left reflects the unstable conditions under heavy reliance on pesticides, and the upright pyramid to the right reflects sustainable qualities of a total system strategy.

Source: Lewis, 1997 (Copyright (1997) National Academy of Sciences, USA)

Ecosystem services of natural pest and disease control

Ecosystem services of natural pest and disease control are characterized in Table 1.

Table 1. **Ecosystem services of natural pest and disease control**

CLASSIFICATION	SERVICES AND RELATED ASPECTS
Regulating	Natural pest control (with collateral benefits for pollination services)
Supporting	Conservation of semi-natural habitats on-farm
Provisioning	Wild insects as food
Cultural	Traditional knowledge for pest control

Regulating services

Natural control, in relation to pest and disease management, can be defined simply as the reliance on nature to regulate pest and disease problems in both crop and livestock production systems. It includes the use of living (e.g. biocontrol agents) and non-living (e.g. plant extracts) products and services. Nature has a way of regulating populations of all living organisms. To use this service of nature, resource owners should carefully adopt land use and land management practices that are friendly to the agents that provide these services.

Natural pest control strategies include a number of systems such as biological control, IPM and breeding for host plant resistance. Biological control includes measures to enhance or introduce the natural enemies of insect pests, also known as biological control agents, including predators, parasitoids and pathogens. A key element in natural pest control is recognizing the value of such agents and working to ensure that they are an important part of the agro-ecosystem, largely through habitat management (Photo 2).

IPM has received considerable attention and has been defined and implemented in a large variety of forms. Essentially IPM espouses the concept that several different control methods should complement each other; these methods should be based on a solid knowledge of the agro-ecosystem and applied after weighing the economic, environmental and social consequences of any intervention. In its simplest form, it illustrates the principle that all crop systems should be monitored and that threshold levels of pest numbers should be established before any control is applied.

What is most important in agro-ecological approaches, however, is not the specific control measure, but rather the focus on designing and promoting ecological systems in which pests do not become problems. The focus must not be on applying particular controls in a therapeutic manner, which disrupts the current interactions; it must rather be on applying management that builds an ecosystem with inherent natural control functions.

To describe how such an approach should best work, it is important to consider whole-farm design. Typically, researchers have sought recommendations for a particular crop, for example

Photo 2. **Whiteflies (*Bemisia tabaci*) on beans – this pest is quite tolerant of pesticides but can be managed by use of natural enemies**

© M. Kasina

biological control of stem borers in maize. Yet on most farms, multiple crops may be grown together, and the pest management practices on one crop may directly or indirectly affect the other. Thus, a much stronger form of control is possible when the year-round soil, water, weeding and cropping practices are considered at farm and community level instead of simply targeting one pest and one crop. A good example is the push-pull system (Polajnar *et al.*, 2014) of maize production, which considers the value of placing different crops (including maize, forage grasses and forage legumes) in proximity to each other to "push" pests out of crops and "pull" natural enemies in.

It is also important to consider timing over the growing cycle. Pest problems often originate in the soil. Cover crops that enrich the soil may also serve as refugia for stabilizing natural enemy populations. If the cover is removed from land during fallow periods, natural enemies may be unable to build up sufficient numbers to be effective. Cover crops and the encouragement of areas of habitat on-farm may provide the timing advantage needed by biological control agents.

By looking at crops as ecosystems, it is possible to see the many interactions occurring between plants, pests and natural enemies. It has long been known that crops have traits that make them more or less attractive to pests, a feature that is exploited in host-plant breeding. But it is becoming more clearly understood that crops may actively respond to insects in specific, customized ways. For example, it is known that maize when attacked by pests may release volatile chemical cues that attract predators and parasites which in turn will attack the pests. These chemicals are not released in response to mechanical damage, only in response to herbivore pressure. The cues appear to help natural enemies to zero in on infested plants, thus contributing to their effectiveness. The capacity to respond in this way is well developed in landraces of maize and in wild grasses, while modern breeding has reduced the response in modern varieties. Some crops, such as tomatoes, may be able to produce compounds that interfere with the digestion and feeding behaviour of insects, while other crops, such as some varieties of cotton, contain extra floral nectaries that provide food to natural enemies. In learning to enhance and exploit such reactions, it is important not to try to single out individual compounds that might by synthesized; an ecosystem approach would study the plant's whole system of defence and encourage its expression by the plant – which is generally the most economical route as well.

Specific practices that can form an effective, whole-system approach to pest control are considered below.

Supporting services

A key part of agro-ecological approaches to natural pest control is habitat management, allowing some portions of a farm to have more natural vegetation where natural enemies may find refuge and build up populations sufficient for effective control. The practices involved are presented below under cultural practices. The Government of Kenya currently promotes a strategy of setting land aside, through a presidential directive aimed at increasing forest cover in the country to 10 percent of the total land mass. Landowners, particularly crop growers, have been advised to set aside at least 10 percent of their land for forest. In addition to assisting natural pest control, the adoption of this strategy is likely to support provision of other ecosystem services to farmed land.

The agriculture sector has a deep responsibility to prevent agricultural chemicals used on farms from getting carried away in runoff water and impacting biodiverse habitats. A stellar example of how this has been done comes from an intensive farming system around Lake Naivasha in Kenya (Box 2; see also Chapter 5 on water conservation).

Box 2. **Use of ecosystem services in managing agricultural chemical runoff into water bodies: riparian management in Lake Naivasha, Kenya**

Water bodies meandering through areas with highly intensive agriculture are likely to be polluted with pesticides and fertilizers, especially from farms with no wetland or runoff management system (particularly smallholder farming systems for which there are no policy interventions on managing surface runoff). In Kenya, the government has adopted regulations on the conservation and utilization of water which include environmental protection. These are implemented through the National Environment Management Authority (NEMA; see www.nema.go.ke). In addition, most commercial farms are implementing good agricultural practices to ensure sustainable access to external markets; the criteria for these good practices include riparian management. Chemical runoff has been significantly reduced as a result.

CONTINUES →

Lake Naivasha is one of the few freshwater lakes in the Great Rift Valley, with a watershed measuring about 3 400 km^2. The availability of water and nearness to Nairobi make the area attractive for horticulture farming. The lake and its catchment have the highest concentration of commercial, ornamental and vegetable growers in Kenya and are thus vulnerable to agricultural waste (mineral fertilizer, pesticides and other toxic materials) disposal. Most of the growers currently subscribe to the GlobalGAP standard on good agricultural practices, which entails waste management and protection of water. The Lake Naivasha farmers employ highly innovative ecological measures to improve water quality, such as constructed wetlands, which are water treatment systems that use natural processes involving wetland vegetation, soils and their associated microbial assemblages. NEMA monitors Lake Naivasha protection, and any grower found to be polluting the water of the lake is fined or barred from business.

These practices have ensured continued protection of the lake, and the fishing industry has become successful. Thus a combination of private-sector incentives and government regulation is restoring health to an agricultural/aquacultural landscape.

Provisioning services

Edible insects have always been a part of the human diet, to different degrees according to cultural norms. Interest is growing in the potential benefits of using insects more widely in food and animal feed, as a potentially powerful means of addressing issues of food security. Insect rearing for food and feed remains in its infancy, and key future challenges are still being identified. However, the possibility of rearing large numbers of insects that may have roles both in pest control and feed along a multitrophic food web is of potential interest.

Some animals, such as ducks introduced into rice paddies, may serve dual purposes of consuming weeds and insects while ultimately providing meat for farmers. Free-range chickens can also consume large numbers of insect pests.

Cultural services

Traditional approaches to pest and disease control are an important resource for farm communities, as they have evolved over considerable time through farmers' own research, are site and context specific and generally have low costs. Many farmers in East Africa manage pests through traditional strategies such as rotational cropping, early sowing, mixed cropping and intercropping, with ash, plant extracts, smoking and cow dung used to manage emerging pests in the system (Photo 3). Traditional knowledge and approaches are highly diverse and broad in application. They may be quite effective for some pest and disease problems.

Photo 3. **Mulching of cabbages: mulching conserves moisture and suffocates weeds, enabling plants to grow healthy and resistant to pest and disease infestations**

© M. Kasina

Natural pest control practices

Five types of practices that enhance natural pest control are detailed here: cultural practices, building plant health to withstand pest attacks, enhancing natural enemy populations, using insects' own chemical signals to alter their behaviour and IPM.

Cultural practices

Cultural practices are crop management practices that are not necessarily targeted at managing crop pests but make the crop environment more disadvantageous to the pests and more advantageous to natural enemies. The practices are equally important in enhancing crop growth and are known to enhance crop yields. They are often based on farmers' experience as well as on scientifically proven strategies promoted to ensure optimal crop performance. The following are some examples.

Early planting. This is a strategy for rainfed agro-ecosystems. Crops are sown before the onset of rains to ensure that they establish early and hence avoid water stress in periods of low rainfall compared with normal rains. Early planting can help crops better withstand pest pressures. In north Kitui County, Kenya, for example, farmers that planted early made their crops less vulnerable to armyworm (*Spodoptera exempta*) outbreak, while late-planting farmers bore all the effects of the pest outbreak (author's observation and experience growing in the area). Recent evidence in Kenya has shown that maize planted early in the season is escaping maize lethal necrosis disease (a recent disease problem causing total maize loss), in contrast with maize planted late (Daily Nation, 2014).

Synchronized planting. Farmers are encouraged to sow at the same period in a season. When crops are of a similar age over a wide area, farmers share the pest problems, and the pest impact in the area is reduced. For example, the impact of maize lethal necrosis disease in Bomet, Kenya, was contained through synchronized seasonal sowing and observation of closed seasons. Farmers were advised on which dates of the year to plant, and an established plan of monitoring by extension officers and farmers ensured compliance. Farmers were able to harvest a crop of maize after following these recommendations. When they reverted to individualized cropping, with no closed season, the disease set again, causing massive yield losses.

Another example is the avoidance of bird pest problems on pearl millet in north Kitui County, Kenya. From the 1960s to the early 1990s, almost all farmers in the county grew pearl millet, and planting was synchronized. As a result, the quelea bird pest had low impact, partly because of shared infestations. Another major contribution to pest management was scaring the birds using family labour. However, this practice has been drastically reduced because of declining household sizes and an increase in children's school attendance. As bird pest management has become less effective, fewer farmers are cultivating millet. Because fewer farmers are growing millet, synchronized planting is no longer effective, and the remaining millet farmers risk losing their entire crops to the quelea birds.

An array of cropping systems, such as mixed cropping, intercropping and strip cropping. Farmers often grow various crops at the same time to spread the risk of failure by any single crop. This strategy also reduces pest pressure, as pests have difficulties in finding their preferred hosts. Challenges in implementing these systems depend on the farmer's end goal, which affects the spatial arrangement of the polycropping system. For example, farmers growing crops for markets are more likely to implement monocropping in a single plot. Those growing for food use a more heterogeneous crop arrangement, including intercropping.

Push-pull strategy. The push-pull system is a companion cropping system in which plant volatiles are used to manage key pests, both to repel pests and to attract beneficial organisms. It has been used successfully in East Africa, particularly for maize pests and weeds (Cook, Khan and Pickett, 2006; Khan *et al.* 2008, 2014). The original push-pull system involved planting *Desmodium* spp. as an intercrop between maize and millet so that its smell will repel ("push") stem borer, a major maize pest. Napier grass is planted as a border crop to attract the stem borers away from the maize field ("pull"). *Desmodium* spp. can also fix nitrogen and increase mortality of *Striga* weeds. This system increases yields without the use of inorganic fertilizers and pesticides. Farmers not only obtain higher yields of maize but also gain two types of fodder, Napier grass and protein-rich *Desmodium* spp. To date about 90 000 smallholder maize farmers in East Africa have adopted this technique for stem borer and *Striga* control, increasing maize yields from about 1 to 3.5 tonnes per ha (Khan *et al.*, 2014). The push-pull strategy is based on locally available plants, not expensive external inputs, and fits well with traditional mixed cropping systems in Africa.

Box 3. Control of stem borer moth and *Striga* weed using the push-pull method: multiple threats, multiple benefits

The stem borer moth larva is a menace to maize in Kenya and causes up to 80 percent yield losses. The *Striga* weed, an equally huge menace, causes 30 to 100 percent yield losses in cereals, especially maize. This weed affects 24 percent of the maize cropping area in Kenya. The combined losses from these two nuisances are estimated at US$7 billion per year, huge losses indeed. The push-pull method has been tested in western Kenya and has been documented not only to reduce *Striga* weed (*Striga hermonthica* and *Striga asiatica*) infestations and stem borer (particularly *Chilo partellus*) incidences, but also to provide other benefits including improved soil fertility and increased crop (maize) and fodder yields. The push-pull technology involves intercropping maize with a stem borer moth repelling legume, *Desmodium uncinatum*, and then planting Napier grass (*Pennisetum purpureum*) around the intercrop which attracts and traps the stem borer moth.

Source: Khan *et al.*, 2008

Indigenous technical knowledge (ITK). Farmers' traditional knowledge about crop-pest relations is the basis for strategies in various categories of pest management, especially botanical pesticides and physical control. Just a few examples of the many ITK-based methods include:

» application of plant extracts (e.g. chilli, garlic or pyrethrum, extracted from chrysanthemum flowers) as a spray or dust formulation, developed according to diverse methods based on the target pest;

» smoking pests with the smoke of specific plants, a common method for managing pests in stored maize as well as aphids and other piercing and sucking insects of cowpea in northern Kitui County;

» application of ash from selected plants, usually as a spray or dust formulation, to control ants and termites, with the added benefit of improving soil nutrient content.

» use of domestic animals such as chickens to manage pest problems (Photo 4). These domestic animals also contribute to soil health through manuring.

Use of plant genetic diversity. Farmers inherently tend to plant multiple varieties. Growing different varieties of the same crop together consistently shows decreased spread of pest and disease damage. In Uganda, for example, it was observed that beans grown in a mixture of varieties supported fewer pests than those grown in a monoculture system (Mulumba *et al.*, 2012). Farmers in East Africa grow over 60 different varieties of beans, indicating that farmers already often apply this strategy. Further studies may be required to understand the best polycropping system combining various varieties of crops to secure farmer interest in terms of sufficiency of food and income.

Photo 4. **Chickens on farms can control many pests and hence avoid pesticide use**

© M. Kasina

Water conservation practices. Farmers in dryland areas create bunds, seepage areas and terraces, stabilized using natural vegetation, fallow or planting. These features increase on-farm biodiversity, for example by serving as nesting areas for many ground-nesting bees; they also harbour spiders, dragonflies, praying mantises and other natural enemies of pest species.

Physical and mechanical control methods. Physical control methods include creation of barriers so that pests have difficult access to the crop, thus lowering infestation. The most commonly used method is the greenhouse, which creates a favourable environment for crop growth while also excluding pests. A recent low-cost example for smallholder farmers in Africa is the use of low cover nets, usually placed about 10 cm from the plant canopy and supported by twigs.

Mechanical approaches, such as killing insects by squashing or squeezing them, are rarely used because many farmers believe they are tedious. However, these methods are highly effective and can drastically cut farm production costs associated with pest control. Most adult moths, for example, lay from 200 to 1 000 eggs in their lifetime. Squashing a caterpillar can thus prevent numerous individuals from infesting the crop. Caterpillars are the easiest to squash, since they are slow to move and are easily recognizable.

Building healthy ecosystems to grow plants that can fend off attacks

Healthy crops are the first line of defence against pests. Plants that are weak, often because of insufficient soil fertility, are unable to tolerate pest problems and are vulnerable to harsh weather conditions. To ensure that crops are vigorous and productive, farmers have to manage their supporting ecosystems so they can produce and deliver diverse services in a healthy manner. The building of healthy ecosystems depends on the following practices and institutional support measures.

- **Agronomic practices.** Practices that enhance crop growth by preventing or reducing weed competition and enhancing soil fertility include conservation agriculture (CA), minimum or zero tillage and organic fertilization. CA comprises a combination of three key practices done using locally suitable methods: direct seeding or planting to ensure minimum or no disturbance of soil; permanent soil cover; and crop rotation. FAO has been in the forefront of promoting CA in smallholder farming systems in East Africa; it has now been practiced there for more than two decades, and increasing numbers of farmers are adopting it each year. Where it has not been fully adopted, the reasons include aspects of landownership, knowledge levels, policy support and socioeconomic considerations. It is therefore necessary to tailor CA to suit local conditions.
- **Farmer training.** Investment in farmer training and extension, particularly through the format of Farmer Field Schools in East Africa, has a long history of multiple rewards. However, the support for farmer training is often project based and not sustained. Government recognition of the value of farmer training is critical, particularly for knowledge-intensive (rather than input-intensive) agro-ecological approaches.
- **Prevention of new pest entries.** Preventing new pests from entering agro-ecosystems can help to ensure healthy crops (Photo 5). Regulatory or quarantine measures can be effective to this end. East African countries have enhanced their phytosanitary regulations, particularly in the past ten years. They have been developing common regulations, seeking to standardize phytosanitary operations to smooth trade and protect the subregion's agriculture from new

Photo 5. **Thrips, now a serious emerging problem for kales and cabbages**

© M. Kasina

pest problems. In some instances, quarantine measures have been used in East Africa to halt the spread of a new pest in an area, to prevent further spread and to constrain the area of the pest. They are especially relevant for those entries that are noticed at an early stage and are confined to one area.

» **Integrated crop management policies.** Governments in East Africa are keen to ensure that farmers adopt effective crop growing technologies. Policies that support crop development, including those addressing soil health and water conservation, are promoted. However, policies that go beyond soil and water conservation to address the ecosystem services that underpin agro-ecology are not yet well articulated in the subregion, or even globally.

Enhancing or introducing natural enemies to manage pests

All living organisms have natural enemies, which check their populations through predation, disease or competition for resources. They occur naturally and co-evolve with each pest. Pests' natural enemies are classified as predators, parasitoids or disease-causing pathogens. Pest management with natural enemies, also referred to as biological control, has had great success against various pests in East Africa. Natural enemies have been used to manage pests in several ways.

» ***In situ* conservation of natural enemies.** Farmers in Kenya have been trained, by various entities, about the natural enemies that occur on their farms such as spiders, ladybird beetles (Coccinellidae) and wasps, so that while using various crop management practices they can take care of these useful organisms.

» **Classical biological control.** This approach entails importation and mass production of a given natural enemy for introduction in the country to control exotic pests, in particular. It has been successfully applied for various pests including cassava green mite, cassava mealybug, diamondback moth (a pest of cruciferae), stem borers (mainly on maize) and larger grain borer (on maize and dried cassava).

» **Augmentation of natural enemies in the agro-ecosystem.** Due to the disruption of the environment particularly due to the unwise use and abuse of pesticides, natural control has not been effective. To correct this, the natural enemies are reared and released to ensure the pest population is brought down. This approach is currently widely used in the horticulture sector in greenhouses for control of pests on both crops and flowers. Over the past decade the market for natural enemies has been growing in Kenya, leading to the development of an industry for the production and trade of biocontrol products, including parasitoids, predators, entomopathogenic fungi, nematodes and antagonists for soil-borne diseases. Notably, as with chemical control methods, evidence indicates that targeted pest species can evolve resistance, especially to entomopathogens. This shortcoming illustrates how important it is not to focus solely on a single tool, but to manage the agro-ecosystem to prevent pest outbreaks; biocontrol products might form part of the "therapeutic" approaches, applied sparingly.

Baiting insects with natural attractants

Insects use chemical signals (pheromones) to communicate with each other, within a species or across species. Through study of insect communication signals, scientists have identified molecules that alter insect behaviour. Sex signals are the most often used in pest management, mainly to attract males for the purpose of killing them. The rationale is that a reduced number of mating males results in fewer females getting fertilized, leading to an eventual reduction in fertile females and hence a reduced population over time. Males are attracted by the pheromone cue as they seek a mate (which under natural circumstances would be producing this signal), and the attractant is laced with a killing agent. The use of sex pheromones in East Africa has increased in the past two decades, and various products are available for different pests, for example tomato leafminer, *Tuta absoluta* (the newest pest in the subregion); diamondback moth, *Plutella xylostella*; African bollworm, *Helicoverpa armigera*; and fruit flies (Box 4).

Another form of attractant is protein bait. Most insects seek protein and energy for their growth and reproduction. For example, female fruit flies require protein to attain normal fertility and stimulate egg production. Therefore, protein bait can be used to attract them. The protein slurry can drown the attracted insects and is usually laced with a chemical, which kills them. In East Africa, protein baits have been used to date in the management of fruit flies.

Passive traps that contain a chemical or biological bait and/or a visual attractant to insects have also been widely employed in the control of tsetse flies.

While this approach does use toxic chemicals, they are limited to the bait and affect only the insects that are attracted to it. Pheromones specific to the pest species can be used. Baiting is also used very effectively in horticultural settings to control molluscs (slugs and snails).

Box 4. **Management of fruit flies in Kenya**

Fruit flies (Family Tepritidae) are major pests of various tree and non-tree crops, not only in East Africa but also globally. They are a major technical barrier to international trade. They are challenging to control because they infest fruit at maturity, when any pesticide use could result in non-allowable levels of pesticide residues, violating food safety standards.

In 2003, the mango fruit fly *Bactrocera invadens* was first reported in coastal Kenya (Lux *et al.*, 2003). The new pest became invasive, outcompeting most of the native and well-established fruit flies in Kenya. As a result of laboratory-based evidence showing that the pest can successfully complete its cycle through avocado fruits, by 2008 Kenya had lost its external market for avocado to South Africa, where the pest had been declared quarantined. Since 2003, the pest has spread in almost all African countries. It has now even invaded fruit orchards in South Africa.

CONTINUES →

In 2008, Kenya embarked on a programme to eliminate the pest in a delineated area, following international guidelines on trade. The strategy involves the use of a pheromone trap laced with an insecticide. Pheromone traps have a great advantage over conventional pesticides, as the pesticide is restricted to the trap and thus does not affect other organisms, such as beneficial insects; hence natural controls can operate alongside the pheromone traps. This pest control package has been registered by Kenya's Pest Control Products Board (PCPB) for *B. invadens* control. The activity is still ongoing, but evidence from target orchards clearly shows that it is possible to eliminate the pest (Kasina *et al.*, 2014). However, a wide-area approach where every farmer implements a set of practices, including the use of traps, will be required to ensure that the pest is eliminated.

Integrated pest management strategies

Integrated pest management (IPM), as described above, is not a technology as such but a raft of measures put in place to manage pests. Such measures should be chosen to be compatible in delivering an efficient and economically viable pest control solution. IPM is a knowledge-based pest management strategy that relies on scouting to make decisions on what options to use, after considering the pest threshold limits. In East Africa, IPM is widely promoted but has not been fully defined in terms of the level of applications of technologies in a crop cycle that can be considered IPM. This is particularly due to over reliance on synthetic pesticides. However, appreciating the need for IPM, farmers continue to improve and reduce their applications of pesticides (Box 5).

Box 5. **Adoption of good agricultural practices in pest and disease control in Kenya**

The past two decades have seen increased demand for products grown in systems that have adopted good agricultural practices. A global consumer-led standard, GlobalGAP (formerly EurepGAP), allows only those firms that meet the defined standard to access specific markets. The standard requires implementation of practices that promote sustainable farming, including environmental health and safeguarding of ecosystem services such as natural pest and disease control. This standard has played an immense role in adoption of IPM by many growers in Kenya and other East African countries. The system advocates for use of synthetic pesticides only as a last resort. Pesticide use is highly controlled, and only approved products are allowed. Farmers opt for intelligent pest control where

CONTINUES →

scouting takes centre stage, supported by insect trapping strategies (both sticky and pheromone) and inclusion of biological control agents, which are mass produced in Kenya and distributed in East Africa.

The horticulture sector in Kenya, which leads in export earnings for the country and has had tremendous growth in the past two decades, has transformed to meet the GlobalGAP standard in order to have access to its markets. The sector supports many small-scale farmers growing for export markets. Adoption of the standard reportedly costs small-scale farmers about 30 percent of their annual income, yet in the long run it should aid in sustaining their income. Indeed, once operations are aligned with the good agricultural practices, small-scale farmers have been reported to increase their income and market competitiveness (e.g. Henson, Masakure and Cranfield, 2011; Asfaw, 2008). Research has shown that smallholder farmers complying with the GAP standards use safer pest control products (based on WHO classification) than those who grow for the domestic market (Asfaw, 2008).

Challenges to adoption of agro-ecological pest control practices

Any technological and innovative farming intervention usually faces challenges and threats in the implementation phase. Agro-ecological practices require more understanding than less complex technologies involving a single solution to a problem. The following are some common challenges.

- Government policies enabling agro-ecological practices are generally lacking. Some food production policies in East Africa do not support the application of agro-ecological approaches and even promote practices that would seem to go against agro-ecological principles, resulting in severe negative impacts for farmers.
- Research methods for pest management are limited. The main results are always from agronomic trials; ecological approaches are not used to test various management plans. Because trials require a strict randomized design and identical factors such as soil characteristics, they are restricted to agricultural research stations and may neglect whole-system approaches and the use of diversity found on farms.
- Scientific information on biological interactions, such as pest life tables and threshold limits, is insufficient to support decision making for pest management (Photo 6).
- Proper identification of organisms – which is the foundation of pest management and the use of biological resources in pest management – faces major impediments, with a global decline in experts providing backstopping for specimens from East Africa and a limited number of taxonomists of the various pests in the subregion. It is practically impossible to develop any meaningful pest management programme for organisms that are not known. For example, before the confirmed identification of maize lethal necrosis disease in Kenya, earlier reports

Photo 6. **Bean fly, *Ophiomyia* spp., infesting common beans (*Phaseolus vulgaris*)**

© M. Kasina

Knowledge of life tables of such important pests can immensely contribute to their control and therefore ensure food security of farmers.

suggested that it was a fungal problem. This misidentification could have led the country to use fungicides to manage it, which would have been costly as well as ineffective. Considering the costs of wide-scale government emergency support to bring a disease to manageable levels, farmer costs of continuing with management practices, and environmental and human health effects of fungicides and pesticides, among others, the costs of poor taxonomic information could be devastating.

- Capacity is lacking in the regulatory environment for pesticides. Challenges include the growth in importation and the use of unregistered pesticides, which are causing public and environmental health issues in rural areas. However, Kenya has seen some progress in this area (Box 6).
- New pests and diseases are emerging as a result of climate change, environmental degradation, deliberate or accidental introductions and adaptation of existing pest species undergoing irruption (Martins *et al.*, 2014).
- Extension services are limited in capacity. Farmers may lack access to these services, and extension officers may lack up-to-date practical information. Little funding is available for farmer training. Provision of basic information, fact sheets, case studies and best practices is an important step for building more effective agro-ecological approaches.

Box 6. **Regulation of pest control products in Kenya**

Kenya has a regulatory mechanism to ensure that all pest control products for commercial use are registered by a legal body to ensure quality and prevent entry into the market of fake or counterfeit products. The Pest Control Products Board (PCPB) is mandated to register products targeting pests (e.g. mites, ticks, tsetse fly and fleas), while the Pharmacy and Poisons Board (PPB; see www.pharmacyboardkenya.org), is mandated to register veterinary drugs targeting diseases (e.g. east coast fever, Newcastle disease). In the year 2006-2007, PCPB recorded about 8 749 tonnes of pesticide imports into Kenya (for crops and livestock) and about 182 tonnes of exports within East Africa (showing the interlinkages in the subregion on issues of trade). However, in the same period there were reported cases of illegal pesticides which were not registered.

Tremendous growth in the information and communication sector in Kenya has enhanced reporting of unregistered products, hence reducing nonconformities. In addition, farmers are able to search for registered products on the websites of PCPB and PPB before making purchases. PCPB organizes training events for farmers and information providers, including pesticide handlers and those involved in trade.

Pesticides for ectoparasites are of some concern, since they may affect non-target organisms, including natural enemies in grazing fields. Studies on these products are lacking and are needed to support discussion on how to minimize their potential negative effects.

3
WEED MANAGEMENT

Gualbert Gbehounou and
Paolo Bàrberi

In the global quest for more sustainable cropping and farming systems, the emerging paradigm of ecological intensification exploits synergies between agriculture and biodiversity. Improved solutions stem from use of (mainly) local resources such as agrobiodiversity at the gene, species and habitat/ecosystem levels and improved knowledge of biological interactions in an agro-ecosystem. Within this framework, ecological weed management (EWM) is a set of practices using locally available resources (mainly at the gene or species level of agrobiodiversity) to attain long-term weed suppression without the use of synthetic herbicides. Although minimal and judicious use of synthetic herbicides may not necessarily jeopardize the overall efficacy of an EWM strategy, experience suggests that whenever herbicides are chosen as part of a weed management arsenal, overreliance on them and mismanagement are just around the corner. On the other hand, it is where herbicides are deliberately given up that EWM can deploy its full potential. This chapter focuses on weed management strategies and methods that do not imply the use of synthetic herbicides. Reference to them is included only where it is deemed helpful to provide an up-to-date picture on a given subject.

In East Africa, the most difficult weeds to control include weedy rice species, parasitic weeds of the genera *Cuscuta*, *Striga*, *Orobanche* and *Phelipanche*, and invasive plants such as *Parthenium hysterophorus* and *Prosopis juliflora*. Alien invasive plants in both terrestrial and aquatic ecosystems are a major threat to biodiversity and agricultural production in East Africa and need special attention for ecological weed management. For example, in 2014 infestation by *Salvinia molesta* was reported as a threat to biodiversity and livelihoods at Lake Kyoga in Uganda. This invasive fern is expected to spread to all of East Africa if appropriate measures are not taken for efficient management.

In East Africa, contamination of crop seeds by propagules of noxious weeds is of major concern. Recent surveys point to increasing use of herbicides (atrazine, bentazone, bromoxynil + MCPA [2-methyl-4-chlorophenoxyacetic acid], glyphosate, paraquat and 2,4-D [2,4-dichlorophenoxyacetic acid]) by farmers to overcome weed problems, exacerbated by labour scarcity in a context where manual and hoe weeding are the dominant practices. If ecological weed management is not promoted to counterbalance the increasing use of herbicides in East Africa, not only will environmental pollution increase, but herbicide resistance may become a major concern as is already the case in other parts of the world.

Ecosystem services of ecological weed management

The most evident impacts of weeds resemble "disservices" more than services: decreased crop production, increased production costs (including seed cleaning costs) and increased resource consumption (e.g. of water and nutrients) without contribution to production. However, it must also be recognized that in agro-ecosystems the weed community provides a number of biodiversity-related services which can be enhanced through ecological management.

Indeed "weed" is a relative term. In an EWM approach, it is important to distinguish between plant species that behave as weeds in a negative sense and those that can be beneficial, especially when their population does not significantly affect crop yield. This distinction can be done in any given agro-ecosystem context and in a participatory manner, i.e. with the active involvement of local farmers and other relevant stakeholders (Chacon and Gliessman, 1982).

This section presents a number of possible ecosystem services provided by ecological weed management (Table 2), before looking more closely at how weeds may be deliberately controlled through ecological processes.

Table 2. **Ecosystem services of ecological weed management**

CLASSIFICATION	SERVICES AND RELATED ASPECTS
Regulating	Reducing invasibility Natural weed seed predation Allelopathic effects of crops on weeds
Supporting	Providing habitat for biological pest control agents
Provisioning	Allowing greater growing space for crops Food and medicinal plants
Cultural	Heritage weeds

Regulating services

Reducing invasibility. Proper weed management has been shown to discourage weed invasions. Weed species diversity can be an important defence against invading species.

Maximizing crop species diversity in time and space (e.g. co-presence and rotation of different crops in the same field) is considered the most effective management tool for maintaining crop health and weed community diversity and for limiting weed invasions.

Sustaining ecological trophic interactions. It is known that some so-called weeds may support organisms belonging to higher or lower trophic levels, e.g. natural enemies of crop pests delivering a biological control service. The following are the most important agro-ecosystem services that weeds can provide:

- **Increased soil fertility.** In this regard one plant species emerges above all the others: *Chromolaena odorata*, which is not perceived as a weed at all in some areas. For example, in West Africa it is valued as a useful fallow plant that can considerably increase soil fertility, even in a short time period, and therefore boost crop productivity (Akinwumi *et al.*, 2013).
- **Biological regulation of pests, diseases, nematodes and other weeds.** Aqueous extracts of many weed species have been discovered to interfere negatively with the establishment of important crop diseases and parasitic nematodes, and some may also be used to control other weeds through allelopathic mechanisms (Mahmood *et al.*, 2014; Yahya *et al.*, 2014).

Natural weed seed predation. Seed losses due to predation may be an important mechanism in ecological weed management. Depending on tillage practices, weed seed predators may have a strong impact on the fate of weed seeds and their establishment; less disruptive tillage favours greater seed predation. Soil treatments that lead to higher plant diversity and density also tend to favour weed seed predation by arthropods. In a vineyard in California, United States of America, seed predation rates were from 20 to 40 percent in soil under a cover crop, twice that observed in a herbicide-treated soil (Sanguankeo and León, 2011).

Conceptually similar to weed seed predation by insects is the use of grazing animals to consume weeds. One of the most popular systems of this kind is the rice-duck system, which is relatively common in East Asia, especially under organic production (Photo 7). A study of the long-term effect of rice-duck farming on weed seed banks showed that after nine years total weed seed bank numbers and density in the field decreased by more than 90 percent (Li *et al.*, 2012).

Photo 7. **Grazing ducks in paddy rice provide an unusual yet excellent biological weed control system**

© Paolo Bàrberi

Allelopathic effects of crops on weeds. Crops may have inherent weed-suppressive properties through allelopathic traits; these can be enhanced through cultural practices. This feature has been particularly noted in rice, and the allelopathic traits are found even in high-yielding varieties (Kong *et al.*, 2008). Similarly, some cover crops may have allelopathic potential (Labrada, 2008).

Allowing greater growing space for crops to outcompete weeds. A study in India showed that allowing for a "missing row" of wheat, i.e. leaving one row unsown after several sown rows, favourably influenced weed suppression and the crop's ability to compete (Das and Yaduraju, 2011). Leaving 20 percent of rows unsown significantly reduced weed density and biomass and increased the competitiveness of wheat through increased leaf area, number of ear-bearing tillers, nitrogen uptake and crop yield (from 8.2 to 17.3 percent of gain in wheat competitiveness with the missing row system compared with conventional sowing).

Supporting services: providing habitat for natural pest control

The presence of a few weeds may benefit pest control, as shown in the case of reduced egg deposition and increased larval damage for the root maggot (*Delia* spp.) in canola fields with few weeds, and better control with more weeds (Harker, Clayton and O'Donovan, 2005). Diverse weed communities likely support a diverse herbivore community providing alternative prey therefore enhancing the effectiveness of the biological pest control service.

Provisioning services

Some weeds are useful for humans and animals, e.g. as a source of medicines, as feed for cattle, poultry or fish, as renewable biomass for on-farm use, or for bioremediation of polluted soils (Stintzing *et al.*, 2004; Willcox *et al.*, 2007).

Weeds that have long coexisted in farming ecosystems are often well appreciated for their medicinal attributes. Species-rich agricultural fields that harbour subthreshold weed communities may provide growing space for some plants that are important in traditional medicine. For example, different local populations in South Africa were found to harvest 34 different weed species to treat 21 diseases and sicknesses (Lewu and Afolayan, 2009).

Cultural services

Heritage weeds. Somewhat unexpectedly, weeds may have strong cultural values. For example, in the United Kingdom, it is recognized that numerous weeds have evolved over time in continuously cultivated landscapes. Many of them were introduced with grain crops by the first farmers, thousands of years ago; thus they have become an integral part of countryside landscapes. With dramatic changes in agriculture over recent decades, including the move to autumn-sown cereal crops, the decrease of overwintered stubble and increased use of fertilizers and broad-spectrum herbicides, some "heritage weeds" such as violet horned poppy and corn woodruff are now extinct or threatened with extinction (Kent Wildlife Trust, 2016). The fact that communities and NGOs have mobilized to protect these species is an indication of the cultural value of heritage weeds.

Practices of ecological weed management

Weed management methods can be grouped in three categories:

» **Preventive methods** are applied before a crop is grown. Their main effect is to reduce weed emergence during the crop growing cycle.
» **Cultural methods** are applied during the crop growing cycle. Their main effect is to increase the competitive ability of the crop against weeds.
» **Direct methods** are those applied during the crop growing cycle with the specific aim of eliminating emerged weeds. These methods include the use of synthetic or natural herbicides (chemical methods); the use of harrows, hoes or other tools (mechanical methods); flame weeding (thermal methods); other minor physical methods (e.g. use of electromagnetic waves or cold temperatures); the release of insects or pathogens for selective control (biological methods); and hand weeding.

EWM – a concept still in its infancy – can be defined as a combination of methods aimed to achieve long-term weed suppression through the use of ecological interactions between crop, weeds, soil and/or other taxa, fostered by appropriate agro-ecosystem management with the least possible use of direct weed control methods. In this sense EWM is similar to the original concept of integrated weed management (IWM), first adopted in 1982 as an extension of the aims and concepts of IPM. In IWM, weed management, like pest management, was considered as one important component of overall agro-ecosystem management. IWM was conceived as an approach integrating all possible means of control (agronomic, genetic, biological, physical and chemical), but with a main emphasis on prevention. However, over 25 years of practice it was usually (erroneously) considered an approach combining the use of synthetic herbicides with other non-chemical direct weed control methods (mainly mechanical).

EWM stresses the importance of avoiding both chemical and mechanical inputs, the latter being increasingly recognized as an environmental problem because of fuel consumption, soil degradation and production of greenhouse gases (even in systems with no synthetic herbicide use, such as organic farming). It can be applied to any cropping, farming or management system anywhere.

Among 521 papers reviewed for this chapter, only 7 percent explicitly used the term "ecological weed management" in their title or abstract, but most dealt with EWM approaches and methods. The refinement of the EWM concept and clarification of its role in the context of IWM could be instrumental to increase its adoption rate.

Photo 8. **The spectacular yet dramatic effect of invasive *Ipomoea* sp. on natural vegetation**

© P. Bàeberi

Examples of success stories in EWM include:

- the use of trap crops to stimulate suicidal seed germination in parasitic weeds (*Orobanche* spp., *Phelipanche* spp., *Striga* spp.);
- the continuous development and use of resistant or tolerant crop cultivars to minimize damage from parasitic weeds;
- the introduction of legume-based intercrops or fallows to improve weed management and soil fertility and to reduce considerably (sometimes to nil) the use of herbicides and fertilizers (Photo 8).

Methods and tools for Ecological Weed Management

Methods of ecological weed management (EWM) are based on three mechanisms: reducing weed emergence, improving crop competitiveness and reducing the size of the seed bank (Table 3). The following methods are all available for EWM in sub-Saharan Africa.

Reduction in weed seedling emergence. Seedling emergence can be reduced, for example, by covering the soil surface using either natural or artificial mulches. Mulches make the environment at the soil surface unsuitable for weed emergence by acting as a physical barrier, altering radiation or releasing allelopathic compounds (Davis, 2010).

Improved crop competitiveness. Solutions based on this mechanism include any management practice that shifts the temporal and/or spatial access to resources by crop and weeds in a direction favourable to the former and unfavourable to the latter. The following are some examples:

- **Altering the sowing or planting pattern.** Increasing the seeding rate of crops can make them more competitive against weeds by creating a denser crop canopy (O'Donovan *et al.*, 2013). However, there is an upper limit of canopy density (varying by crop) beyond which the competition among crop plants becomes too strong, making increased seeding rate of no further practical use (Williams and Boydston, 2013).
- **Transplanting.** Along the same lines, the use of transplanting instead of sowing can make the crop more competitive than weeds by shifting the temporal access to resources between the larger plants (the crop) and smaller ones (the weeds) (Bàrberi, 2002).
- **Proper management of fertilization and irrigation.** Specifically, localizing the application of fertilizers and water along the crop rows can alter competitive relationships between crops and weeds by facilitating capture of these resources by the nearest and strongest neighbour, which is usually the crop (Petersen, 2005). This can be seen as a way to shift the spatial access to resources between closer – and usually larger – plants (the crop) and more distant and smaller ones (the weeds).
- **Use of competitive genotypes.** Competitive relationships between crops and weeds can be altered by selecting cultivars that possess competitive traits within the available gene pool of a crop. In general, such traits include higher seed vigour, quicker emergence, greater height, greater tillering or branching tendency and a more developed root system (Andrew, Storkey and Sparkes, 2015). In addition, some crop cultivars can produce a relatively high amount of secondary metabolites with allelopathic potential, as it has been shown in wheat, sorghum and rice (Sangeetha and Baskar, 2015). Using cultivars with increased competitive ability against weeds is an important tool in EWM because it can reduce the need to apply direct weed control measures (including herbicides) during the crop growing cycle.
- **Application of polycultural systems.** Cropping and farming systems in which two or more plant species occur together in the same area (e.g. field) provide more productive and non-productive agro-ecosystem services than systems in which each species is grown alone. Polycultural systems are common in many tropical and subtropical areas of the world and yield clear potential for improved weed suppression anywhere (Picasso *et al.*, 2008). In annual systems, polycultures take the form of either intercrops (where all plant species, usually two, are cash crops) or living mulches (where a cash crop is grown side by side with a companion plant whose biomass is not taken out of the system because it is recycled to improve the system itself, including the performance of the cash crop) (Photo 9). In agricultural systems in sub-Saharan Africa it is not easy to distinguish between an intercrop and a living mulch because the companion plant may at times be used as fodder or for other on-farm purposes. Different types of polycultures include relay cropping (where a second species is interseeded within an already existing crop and concludes its life cycle after the crop has been harvested) and agroforestry systems (where annual and perennial plants – shrubs and/or trees – occur together). Mixed farming systems that include animals are properly called agrosilvipastoral systems.

Photo 9. **Shade-tolerant *Cajanus cajan* used as understorey living mulch in banana provides excellent weed suppression**

© Paolo Bàrberi

Reduced seed bank size. Most weeds on agricultural land reproduce and survive as seeds. Thus the soil weed seed bank represents the source of future weed infestations. The weed seed bank can be depleted by increasing seed losses and/or reducing seed inputs, in the following ways:

» **Attracting seed predators.** Weed seed predation, especially after seeds have been shed on soil, may be an important determinant of seed bank losses (Davis *et al.*, 2013). Insects and small rodents are the main contributors to weed seed predation. Thus manipulation of agricultural habitats to attract them (e.g. through no tillage, delayed stubble cultivation, introduction of uncultivated strips within fields or as field margins) is expected to decrease the weed seed bank (Landis *et al.*, 2005).

» **Promoting weed seed decay.** The mechanism of weed seed decay is so far poorly understood and consequently poorly exploited. It refers to the creation of soil conditions that are conducive to increased seed mortality, for example through fungal attack. Some interesting results have recently been noted; however, differences in weed species susceptibility to decay indicate a need to develop species- and cropping system-specific management solutions (Gómez, Liebman and Munkvold, 2014).

» **Increasing weed seed germination.** Methods for increasing seed germination include the false and stale seedbed techniques, i.e. early soil seedbed preparation to stimulate germination and emergence of weed seedlings that are subsequently destroyed before the actual crop seeding or crop emergence takes place (Cloutier *et al.*, 2007). In the false seedbed technique, weed seedlings are usually destroyed by harrowing or using similar mechanical tools, whereas in the stale seedbed technique chemical herbicides or thermal methods (flame weeding or soil steaming) are used to avoid any further soil disturbance.

» **Fatal germination.** Weed seed losses can also occur when seed germination is not followed by seedling emergence, usually because the seed is placed too deep in the soil (when deep ploughing is practised) and has not enough reserves in its endosperm to sustain seedling growth until it reaches the soil surface and becomes autotrophic (Fenner and Thompson, 2005).

» **Preventing production and shedding of new seeds to avoid replenishing the seed bank.** Seed production and shedding can be prevented as an outcome of increased competition or as an effect of a well-planned crop rotation (Légère, Stevenson and Benoit, 2011). It is also important to prevent seed shedding from late emerging weeds, which, although usually unable to diminish crop yield in the same growing season, could create weed problems in subsequent crops or growing seasons through their seed inputs. Similarly, it is important to avoid weed seed shedding (e.g. by stubble cultivation or mowing) in the period between two crop growing cycles, which many farmers tend to disregard.

Table 3. **Methods of ecological weed management**

METHOD	MECHANISM	APPLICATION TIMING	CATEGORY	EXAMPLES
Mulching	Reduced weed emergence Increased crop competitiveness	Before/during crop cycle	Preventive Cultural	Dead mulching Plastic mulching
Sowing/ planting pattern	Increased crop competitiveness	During crop cycle	Cultural	Increased seeding rate Reduced distance between rows
Transplanting	Increased crop competitiveness	During crop cycle	Cultural	Use of transplants instead of seeds
Fertilization (localized)	Increased crop competitiveness	During crop cycle	Cultural	Banded fertilization Seed dressing
Irrigation (localized)	Increased crop competitiveness	During crop cycle	Cultural	Drip row irrigation
Competitive/ resistant genotypes	Increased crop competitiveness	During crop cycle	Cultural	Use of cultivars with higher tillering ratio and/or allelopathic potential, or resistance to parasitic weeds (e.g. *Striga* spp.)
Polycultures	Increased crop competitiveness	During crop cycle	Cultural	Intercropping Living mulches Agroforestry
Seed predation	Reduced weed emergence	Before crop cycle	Preventive	Untilled field margin strips to attract seed predators
Seed decay	Reduced weed emergence	Before crop cycle	Preventive	Incorporation of residues Green manures or composts
Increased germination	Reduced weed emergence	Before crop cycle	Preventive	False or stale seedbed technique Use of germination stimulants
Prevention of seed shedding	Reduced weed emergence	Before crop cycle	Preventive	Stubble cultivation or spraying
Direct weed control methods	Elimination of emerged weeds	During crop cycle	Direct	Chemical applications Physical (e.g. mechanical, thermal) Biological

Possibilities for using biodiversity to address weed management in agro-ecosystems

Biodiversity-based approaches and tools offer ample potential for improving weed management in agro-ecosystems. However, this potential is not yet fully visible because the concept itself is blurred. Talking about "biodiversity" in general does not help in understanding how it can contribute to EWM. A much better term would be "functional biodiversity", defined as "that part of the total biodiversity composed of clusters of elements (at the gene, species or habitat level) providing the same (agro)ecosystem service, that is driven by within-cluster diversity" (Moonen and Bàrberi, 2008). Applied to EWM, this definition highlights the importance of selecting clusters of elements (e.g. cultivars, companion species, management or habitat types) possessing traits that confer better weed suppression ability (i.e. the agro-ecosystem service).

Depending on the context, the weed suppression service can be provided by:

» the traits possessed by a single element, e.g. a *Striga*-resistant cultivar or the use of *Desmodium* sp. as companion crop to maize or sorghum ("functional identity");
» the complementarity of traits between or among elements, e.g. the use of a *Striga*-resistant maize or sorghum cultivar intercropped with *Desmodium* sp.;
» the diversity of traits within an element, e.g. the use of a New Rice for Africa (NERICA) rice cultivar with broad-spectrum resistance against several *Striga* ecotypes ("functional diversity").

Costanzo and Bàrberi (2014) present these functional categories in detail.

The use of sound functional agrobiodiversity approaches and methods in EWM will rely on the improvement of basic knowledge on the autoecology and sinecology of target weed species and communities in target environments and cropping systems, and on a better understanding of soil-climate-crop-weed interactions as shaped by novel management practices. Important progress has been made in understanding the physical, chemical and biological interactions occurring when selected cover or trap crops, soil amendments or crop genotypes are included in cropping systems, unravelling a complex world with huge potential for improved weed management. For example, weeds can be managed by the production of chemicals and semiochemicals or the stimulation of (micro)organisms interfering with key life history traits of weeds such as germination, emergence, vegetative growth, reproduction and propagule survival.

Example: conversion to minimum or no tillage to restore soil ecosystem services while controlling weeds effectively

Studies addressing the issue of reduced or no-tillage in the context of EWM in sub-Saharan Africa are scarce. However, many studies deal with increased soil vegetation cover (Photo 10), for example through:

» improved, legume-based fallows in savannah areas of West Africa;
» introduction of legumes in intercropping or relay cropping systems with staple cereal crops;
» introduction of cover or trap crops as part of more diversified rotations or mulching, e.g. with allelopathic crop or cover crop residues.

Photo 10. **Cover crops terminated mechanically with a crimper roller to allow no-till transplanting of vegetables**

© Paolo Bàrberi

Often, these systems have been seen to improve weed suppression considerably while promoting increased soil fertility and providing the agro-ecosystem services associated with it (e.g. nutrient cycling, soil water regulation and reduction of soil erosion). In the case of some key species, e.g. *Striga* spp., increased soil fertility is considered to be the cornerstone of any weed management strategy.

It is clear that these systems are all useful for reducing the frequency and intensity of tillage owing to the extension of the period in which the soil is covered by vegetation, and they can provide the agro-ecosystem services that are usually expected when shifting from ploughing to reduced or no tillage. Nevertheless, more study is needed to document more clearly the benefits of reducing tillage depth and frequency as an integral part of EWM. This would be of paramount importance for framing EWM as a core component of sustainable/ ecological intensification in the context of tropical agriculture, where deep and frequent tillage has particularly detrimental effects.

The cropping systems mentioned here are all based on greater diversification and are therefore excellent examples of how targeted use of functional agrobiodiversity can improve weed suppression. The mechanisms driving this effect can be different depending on the context and on the target weed species. For example, the production of allelochemicals via the degradation of organic matter incorporated in soil or left on topsoil as surface mulch is a successful mechanism for reducing weed populations. These materials can also trigger soil-plant interactions that are conducive to weed seed decay, e.g. through the enhanced activity of soil-borne bacteria, or to reduction of weed emergence and establishment, e.g. through reinforcement of arbuscular mycorrhizal fungi networks that can stimulate suicidal germination of parasitic weeds. Arbuscular mycorrhizal fungi have also been shown to increase the competitive ability of crops against weeds through enhanced capture of nutrients, an effect often observed in intercropping systems, which eventually leads to reduced weed growth and fecundity.

Trade-offs and synergies of ecological weed management

Several studies have shown that, besides enhanced weed suppression, EWM approaches and methods can simultaneously provide other agro-ecosystem services. However, other studies have shown the existence of trade-offs in which higher weed suppression reduced provision of other agro-ecosystem services (Table 4). Promotion of other agro-ecosystem services can also sometimes have a negative impact on weed management. For example, a *Tithonia diversifolia* living mulch can be beneficial to soil fertility and crop yield but may increase the risk of *Striga hermonthica* infestation (Smestad, Tiessen and Buresh, 2002). Such results are normal in functional agrobiodiversity studies. If acceptable compromises are not possible, conflicts among services can only be resolved by prioritizing one at the expense of the others.

Application of EWM methods is likely to result in more diverse weed communities that can support a more diverse herbivore community providing an effective biological pest control service. The most classic example of synergy between the weed suppression and biological pest control services is the intercropping of maize and *Desmodium* spp. (*D. uncinatum* or *D. intortum*), which can concurrently abate populations of the maize stem borer and of *Striga hermonthica* (Khan and Pickett, 2001). Another example of synergy is the inclusion of legumes in managed fallows, which can significantly suppress weeds while increasing soil nitrogen status and yield of the following cereal crop.

Some studies have addressed the selection of cover crops based on multiple traits that can provide several services, such as weed suppression, soil erosion control, soil water and nutrient provision and biological pest control. This is a very interesting approach that should be fostered in future participatory studies carried out in sub-Saharan Africa.

Table 4. **Trade-offs of EWM: examples where methods for enhanced weed suppression reduced other agro-ecosystem services**

EWM METHOD	AGRO-ECOSYSTEM SERVICE PENALIZED
Reduced row spacing	Crop yield
Grass mulch	Crop yield
Mucuna and *Canavalia* cover crops	Pest control (increased cob borer presence)

Uptake by small-scale farmers

Studies on weed management in sub-Saharan Africa have included basic autoecological studies, often carried out in controlled environments conditions, and auto- and synecological studies carried out at a field, farm or regional scale, in contexts where soil degradation and weed incidence are major problems jeopardizing food security. Many have been conducted in the framework of small-scale farming, including some in East Africa. Farmers have been directly involved in quite a few of the studies, through on-farm research and/or collective participatory actions, although top-down approaches have also been evident (mainly linked to provision of technical inputs such as seeds of improved cultivars or fertilizers). On-farm participatory studies are particularly valuable for observing the attitudes of smallholders regarding EWM-related innovations and their priority options.

The studies indicate that, in general, small-scale farmers are sensitive to EWM methods and are willing to try them in their fields when clear benefits are demonstrated. A few studies, however, showed that farmers' risk aversion increased (and positive attitude towards potential innovation decreased) when climate conditions were harsher, increasing farmers' worries of food insecurity. Risk aversion should always be taken into account in defining the operational context, because it may invalidate technically feasible solutions. Interestingly, some farmers were not worried about increased labour requirements if EWM methods proved to increase benefits for their farm substantially. They tended to prefer multipurpose solutions, i.e. those providing more agro-ecosystem services. For example, the inclusion of silverleaf or greenleaf desmodium as an intercrop with maize or sorghum has been particularly welcomed by small-scale farmers in East Africa because it provides excellent control of *Striga hermonthica*, control of stem borers and forage for cattle. Tactics that can provide more agro-ecosystem services at once ("multifunctional agrobiodiversity") should thus be prioritized in EWM because they will have a higher chance of becoming real innovations.

Challenges to adoption of ecological weed management

A number of factors have been identified that may hinder adoption of EWM, related to its applicability, efficacy, reliability and compatibility with curative weed control measures (Bastiaans, Paolini and Baumann, 2008), as well as the trade-offs between weed suppression and farmers' other objectives mentioned above.

Cultural weed control (or EWM) is more crop specific than the use of chemical herbicides and difficult to standardize. Farmers that are wary of innovation will have more difficulties in embracing EWM approaches and methods. On the other hand, it should not be forgotten that where herbicides are concerned, the standardization of weed management practices is the primary cause of exacerbation of weed problems, specifically the development of herbicide-resistant weed biotypes. Consequently, weed management (as well as cropping system management in general) should be diversified and adapted to local conditions. As to this latter point, it has been seen that successful application of EWM is region specific and depends on local socioeconomic conditions. However, lack of uptake is often not a question of the appropriateness of the EWM approach and methods as such, but rather the lack of a participatory approach to weed management and the limited knowledge exchange between scientists and practitioners. If participatory actions can be strengthened, EWM will have a much broader application than it presently has, with more locally appropriate "tailor-made" weed management.

EWM methods have highly variable effects, which may limit their overall efficacy and reliability. However, the greatest strength of EWM may lie in the integration of methods and their interaction effects, the so-called "many little hammers" approach (Liebman and Gallandt, 1997), which usually shows results in the long-term. A diversified weed management system calls for more complex overall cropping system management, which some farmers may find too complicated to apply. Nevertheless, when serious trouble arises (e.g. herbicide-resistant weeds), the only option is to rely on a plethora of tactics integrated within a sound and targeted overall weed management strategy (Photo 11).

Another possible obstacle to broader adoption of EWM is that some methods (e.g. narrow- or square-row planting) may clash with the application of some direct weed control methods, especially in-crop mechanical weed control. However, this is not a problem if the choice and combination of individual methods is really seen in the context of an overall EWM strategy (which takes into account local weed problems and farmers' attitudes to potential solutions). If the combination of preventive and cultural methods is sufficient to guarantee long-term weed suppression, farmers should not need to apply direct methods. In any case the obstacle is not very relevant in the present context of sub-Saharan Africa, where advanced tools for mechanical weeding are unavailable, although increased labour scarcity may change this perspective. Once more, the ideal combination among preventive, cultural and direct methods for weed management should be designed and tested locally together with farmers.

Some researchers have suggested that EWM strategies have a higher cost-benefit ratio than conventional methods. This assertion may have some validity in the current dominant socioeconomic system of the Western world, but it does not seem to hold true for sub-Saharan

Photo 11. **An exclusion cage used to monitor weed seed predation by soil-borne insects and rodents**

© Paolo Bàrberi

Weed seed predation is an interesting example of EWM yet to be fully exploited.

Africa. In fact, several studies have explicitly addressed the cost-benefit ratio associated with novel EWM-based solutions and demonstrated their economic success in many smallholder farming systems in West and East Africa.

EWM places a strong emphasis on prevention of weed problems, which implies a necessary shift in farmers' attitude to weed management, i.e. from the application of curative (direct) measures to that of preventive measures. Beyond weed management, such a paradigm shift – the basis of the agro-ecological approach – is of paramount importance for the uptake of real sustainable/ecological intensification in future farming anywhere.

A participatory approach to the design, development and testing of EWM innovations has been recognized as a key factor by many authors (Photo 12). Lack of farmer motivation, insecure land tenure status, limited extension capacities and facilities and poor communication among scientists and, in general, among stakeholders have been recognized as serious obstacles to adoption of EWM in some parts of West and East Africa. In addition, farmers are often averse to innovation, especially when it is most needed (Box 7). In the United States of America, a participatory "mental models" approach has been developed to identify the main obstacles to adoption of EWM (Box 8); it would be interesting to apply such an approach to EWM adoption in the socioeconomic contexts of sub-Saharan Africa.

The studies presented in Boxes 7 and 8 illustrate how the long-lasting wall dividing experimental and social sciences is slowly breaking down. Transdisciplinary collaboration and scientists' engagement in participatory research and action will be of fundamental importance to speed up and broaden the adoption of EWM approaches and methods.

Photo 12. **Participatory methods are expected to foster the adoption of EWM innovations by sub-Saharan farmers**

Long-term programmes for screening, selecting and breeding improved crop germplasm can foster EWM. Weed management was a primary objective, for example, in the development of Striga-resistant or -tolerant maize or sorghum cultivars, and a secondary objective in the development of NERICA rice cultivars. Although, overall, research on EWM has been directed more towards occasional funding opportunities than towards coherent regional or transregional long-term funding and policy programmes, it can be expected that once EWM is more clearly defined, it will be fostered as a key component of sustainable/ecological intensification within the context of new policies and programmes established to promote it.

Box 7. **Avoidance of innovation in farming practices by food-insecure farmers in East Africa**

Kristjanson *et al.* (2012) explored the relationship between changes in farming practices over ten years and household food security in East Africa. They examined whether households had introduced new practices related to management of crops, soil, land, water and livestock (e.g. cover crops, microcatchments, ridges, improved rotations and pastures, trees) and/or new technologies (e.g. improved seeds, shorter cycle and drought-tolerant varieties) that are thought to increase food security relative to traditional management. They used data from a baseline household survey carried out in 700 households at five sites in Ethiopia, Kenya, Uganda and United Republic of Tanzania and across a range of agricultural systems and environments. They observed that many households were already adapting to changing circumstances (e.g. climate pattern), but these changes tend to be limited and entail relatively little uptake of existing improved soil, water and land management practices. Interestingly, the number of food deficit months was negatively correlated with uptake of innovation; in other words, the least food-secure households were those making fewer changes in farming practices. Therefore, difficulty to accept new knowledge seems to be hindering the pathway to innovation, especially when innovation would be particularly needed.

Box 8. A "mental models" approach to identify obstacles to adoption of ecological weed management

In the United States of America, a novel participatory approach has been proposed to investigate the adoption of EWM in organic production, where communication and collaboration between the scientific community, extension services and the organic farming community are considered weak. Zwickle, Wilson and Doohan (2014) developed a "mental models" approach to unveil the major obstacles against adoption of EWM. In the first step, they generated an expert model based on interviews with weed scientists and extension personnel and theories from behavioural sciences. This expert model highlighted two main issues:

- EWM is a complex strategy that may encourage farmers to solve their weed problems through an experimental, trial and error, heuristic approach.
- Communication and outreach activities targeting organic farmers should emphasize the long-term benefits rather than the risks of EWM.

This first step should be followed by farmer interviews and development of a farmer decision model.

4
ENHANCING SOIL FERTILITY

Charles Gachene

Historically, the demand for food and fibre has been met by converting natural and semi-natural habitats to cropland and grazing land in order to use fertile soils with significant soil carbon stocks. Over time, agricultural production will diminish soil carbon stocks unless land is fallowed or soil fertility is restored. The current accelerating rate of decline in soil organic carbon (SOC) is mainly attributable to land-use intensification and the conversion of new land for food and fibre production. In Kenya, intensive land uses are also expanding into areas where SOC stocks are less resilient or soil conditions are marginal for agriculture. For example, semi-arid savannahs and grasslands and tropical rainforests are all being converted to arable land at an increasing rate (Gachene *et al.*, 2015). Land conversions have major implications for soil carbon stocks (Lal, 2013); it has been estimated that soil carbon stocks in semi-arid environments can decrease by 30 percent in less than five years when native vegetation or pastures are converted to cropland. A study in Kenya indicated significant differences in SOC and total nitrogen (TN) stocks between natural forest and cropland that had been converted from forest; the surface soil of the natural forest had SOC and TN stocks of 71.6 and 7.1 Mg per ha, while the corresponding figures for cropland were 35.4 and 3.5 Mg per ha (Were, Ram and Dick, 2015).

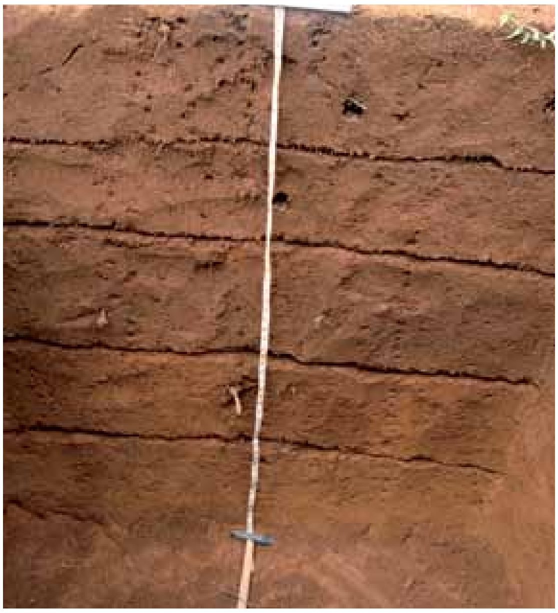
Soil carbon losses result not only in higher atmospheric CO_2 concentrations through accelerated soil carbon oxidation, but also in a general loss of soil functioning and soil biodiversity. Less soil organic matter (SOM) leads to decreased cohesion between soil particles, which increases the susceptibility of soil to water or wind erosion, accelerates losses of bulk soil and alters nutrient and water cycling. Another consequence of soil carbon loss is the loss of soil nutrients; these include nutrient elements within the SOM as well as inorganic nutrients such as phosphorus and potassium that bind to mineral surfaces. Because of SOM's role in forming aggregates, loss of SOM can reduce soil cohesion and allow the breakup of aggregates. This increases the potential to lose bound clays and other minerals, either through bulk erosion or through colloid transport as water percolates through the soil profile.

One-quarter of the global land area has suffered a decline in productivity and in the ability to provide ecosystem services because of soil carbon losses. The top metre of the world's soils stores approximately 2 200 Gt (billion tonnes) of carbon, two-thirds of it in the form of organic matter. This is more than three times the amount of carbon held in the atmosphere. However, soils are vulnerable to carbon losses through degradation. According to Lal (2004), increasing the soil carbon pool of degraded cropland soils by 1 tonne on average can increase crop yield by 10 to 20 kg per ha for maize and 0.5 to 1 kg per ha for cowpeas (on average).

Soils have a vital role in overall ecosystem services, yet these contributions may be somewhat overlooked and undervalued, as most services of soils are considered intermediate services (Robinson, Lebron and Vereecken, 2009; Robinson *et al.*, 2011). This is also true of many other ecosystem services contributing to human well-being. In some analyses, soil ecosystem services thus have no intrinsic value, but are only reflected in the value of final products, such as crop production. Two counterarguments can be raised to this view. First, healthy soil ecosystem services contribute to an important natural asset that can serve as a resource; they are part of an "ecological infrastructure" that is fundamental not just for delivering soil nutrients to a particular year's crop production, but for sustaining crop production over time (Photo 13). Second, in addition to nutrient delivery, soil ecosystem services also contribute to carbon storage and to effective water delivery to plants.

In this role physical properties such as soil horizonation, bulk density and soil structure are the most valuable characteristics. An alternative approach to demonstrate and assign values to soil ecosystem services in their own right from the bottom up might be to try to value soil stocks as soil natural capital with all of the contributions that healthy soil ecosystem services can make. This approach is likely to require monitoring and biophysical modelling to support accounting. It may thus link with current efforts to define and classify soil quality and health, which are used as performance indicators for soil use (Karlen *et al.*, 1997; Gicheru and Kimigo, 2011).

Photo 13. **Soil, an important natural resource for crop production**



© C. Gachene

© C. Gachene

Soil quality and soil health

The concept of soil health is holistic and refers to more than just the vigour of soil biota. It also embraces the physical, chemical/biological and ecological properties of the soil and the ameliorative responses to disturbance of land managers (Doran and Parkin, 1996; Karlen *et al.*, 1997). Soil health also describes the capacity of a soil to meet performance standards relating to nutrient and water storage and supply, biological diversity and function, structural integrity and resistance to degradation. Integrated soil fertility management (ISFM) technology considers all of these soil services and their effect on land productivity. Among the most important of these manageable services are biological nitrogen fixation, the conservation of symbiotic and beneficial organisms, nutrient and moisture supply, carbon storage and protection from erosion.

Ecosystem services of soil

As yet, an agreed and consistent framework for the ecosystem services of soils does not exist (Robinson *et al.*, 2010, 2011). A demanding challenge for soil science over the coming decades would be to develop a framework that conveys the societal value of soil functions in terms of both human well-being and the sustainment of the Earth's life support systems and the diversity of life the planet holds.

Soils have a role in most categories of ecosystem services (Table 5). Soil stocks constitute the soil natural asset or capital; their interaction with the wider environment leads to flows and transformations that result in changes in the stocks. Ecosystem services result from the flows of materials and energy. These include outflows of carbon in food, feed or fibre; inflows of carbon that aid climate regulation; the contribution of soils to water regulation and filtering; and waste disposal and recycling.

Table 5. **Ecosystem services of soil**

CLASSIFICATION	SERVICES
Regulating	Renewal, retention and delivery of nutrients for plants Regulation of major elemental cycles Buffering, filtering and moderation of the hydrologic cycle Disposal of wastes and dead organic matter
Supporting	Habitat for soil biodiversity; gene pools
Provisioning	Building material Physical stability and support for plants
Cultural	Heritage sites, preserver of archaeological artefacts Spiritual value, religious sites, burial grounds

Regulating services

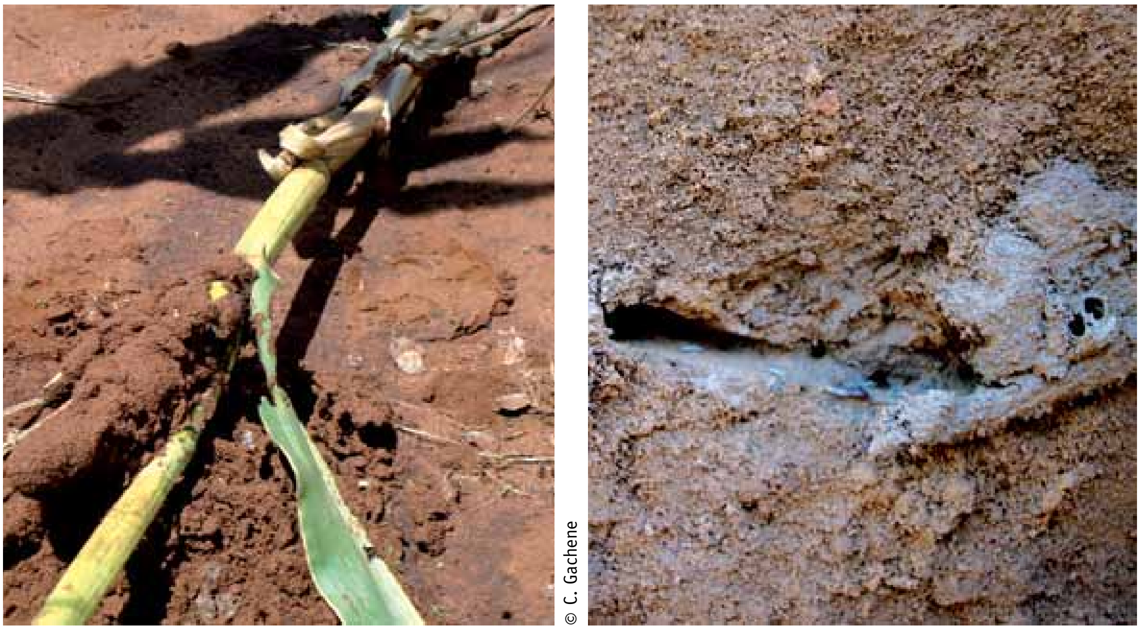
The main regulating services of soils are nutrient cycling, water release and retention, soil formation, exchange of gases with the atmosphere and degradation of complex materials. These services underpin the delivery of all other soil services and contribute substantially to the benefits that humans obtain from the natural environment. SOM is a key attribute influencing soils' capacity to support ecosystem services (Photo 14). The inherent characteristics of soils (e.g. soil fertility, soil biodiversity, the capacity to capture, retain and release water or carbon or to form and release greenhouse gases) are largely determined by the ability of different soils to form and break down soil organic matter (Karanja and Kahindi, 2002; Tabu, Obura and Swift, 2004; Mwenda *et al.*, 2011). In particular, soil quality is underpinned by nutrient cycling, which occurs in all ecosystems and is strongly linked to productivity. A key element is nitrogen, which occurs in enormous quantities in the atmosphere and is converted to a biologically usable form (ammonium) by bacteria, largely living in the soil. SOM also increases resilience to climate change by helping protect plants and the environment against water stress and excess water.

Photo 14. **Increasing SOM through mulching can minimize soil erosion, sequester carbon and improve water capture**

Soil biodiversity has a particularly strong impact on nutrient cycling (Barrios, 2007) (Photo 15). The soil biota is particularly important for ecosystem services and land productivity. Microbial symbionts in soil, such as nitrogen-fixing bacteria and arbuscular mycorrhizal fungi, have strong impacts on crop yields by increasing nutrients available to plants. Nitrogen depletion has resulted from decades of traditional cultivation without replenishment of soil nitrogen, removed through crop harvest or lost through leaching and erosion. Fortunately, several species of bacteria, including symbiotic *Rhizobium* spp., possess the ability to fix atmospheric nitrogen and have coevolved with many of today's important legumes, allowing for management of biological nitrogen fixation. Grain legumes are thought by many experts to have the potential to improve system productivity, yet they are often minor intercrops in comparison with cereals, roots or tubers. In Kenya, commercial legume inoculants are now available and are used for a number of grain and fodder legumes.

Arbuscular mycorrhizal fungi can increase availability of phosphorus to plants. Only a small proportion (5 to 10 percent) of added phosphate is recovered in crops, owing to its strong fixation by soils (Muindi *et al.*, 2015). In natural ecosystems, symbiotic mycorrhizal fungi are the main route of phosphorus transfer from soil to plants, and the diversity of mycorrhizal fungi can regulate plant diversity, nutrient efficiency and possibly water-use efficiency. Sustainable agricultural systems will need to make greater use of mycorrhizal fungi; their diversity is currently very low in arable systems.

Photo 15. **Termites – foes or friends? The debate continues: crop destruction and improvement of soil aeration**



© C. Gachene

© C. Gachene

Supporting services

Some key functions of healthy soils include providing a medium for plant growth, regulating the water cycle (including mediating the flow of surface water, recharging of subsurface aquifers and filtration of runoff), sequestering elements (e.g. carbon) and serving as a growth substrate for beneficial microbes and animals that decompose waste and recycle nutrients. Beyond non-living components such as minerals and SOM, soil also comprises diverse living organisms. The soil biota represents potentially the most species-rich community of organisms on earth; it is estimated to include more than 4 million species. Emphasizing the conservation of soil biota, and soil health in general, can provide multiple agronomic and ecosystem service benefits.

Provisioning services

Soils are the basis of food and fibre production and are of vital importance for recharging water supplies. SOM is necessary to both of these services because it influences nutrient and water availability and soil structure. Carbon-rich peat soils have been a source of fuel throughout history. Today they provide growing media for gardeners, horticulturists and industry. In Kenya, peat from the Ondiri swamp is used as a good carrier material in rhizobial inoculant production.

Cultural services

From ancient times, human cultures have been strongly affected by the ways they use and manage soils. The character and carbon content of soils have influenced the nature of the landscapes and environments in which diverse cultures have developed and thrived (Robinson *et al.*, 2011). SOM also helps soils to retain traces of past cultures and climates and to preserve archaeological remains.

Management practices to sustain the multiple benefits from soil services in smallholder farming systems

Building or improving the natural assets of soils contributes to resilience and maintaining balance in the provision of ecosystem services. It is important that management practices for specific objectives do not favour some services (such as production) at the expense of changes in the stock of natural capital assets that could be ultimately unsustainable. Trade-offs among ecosystem service benefits arise when soil management is focused on a single ecosystem service. For instance, using drained peatlands for biomass production greatly diminishes soil carbon stocks, degrades native habitats and alters the peatlands' capacity to provide climate-regulating services. In contrast, soil carbon can be managed to enhance a range of ecosystem services. Increasing the SOM of degraded soils can simultaneously boost agricultural productivity, sequester CO_2, enhance soil microbial growth and improve water capture and retention (Photo 16).

Soil carbon stocks are highly vulnerable to human activities. They decrease significantly (and often rapidly) in response to changes in land cover and land use such as deforestation, urban development and increased tillage, and as a result of unsustainable agricultural and forestry practices (Miriti *et al.*, 2012; Kalinda *et al.*, 2015; Karuma *et al.*, 2015; Shelukindo *et al.*, 2015; Were, Ram and Dick, 2015). SOC may also be increased (although much more slowly) by afforestation and other activities that decrease the breakdown of SOM (e.g. minimum tillage, perennial pastures, designation of protected areas). Practices that add more organic matter to the soil, such as composting or adding manure, may improve the carbon balance of one site while diminishing that of another. For instance, many ISFM studies have reported the use of tithonia (*Tithonia diversifolia*) as a source of organic materials in a cut-and-carry system; yet potassium is heavily mined where tithonia has been removed (Rutunga, Karanja and Gachene, 2001, 2008).

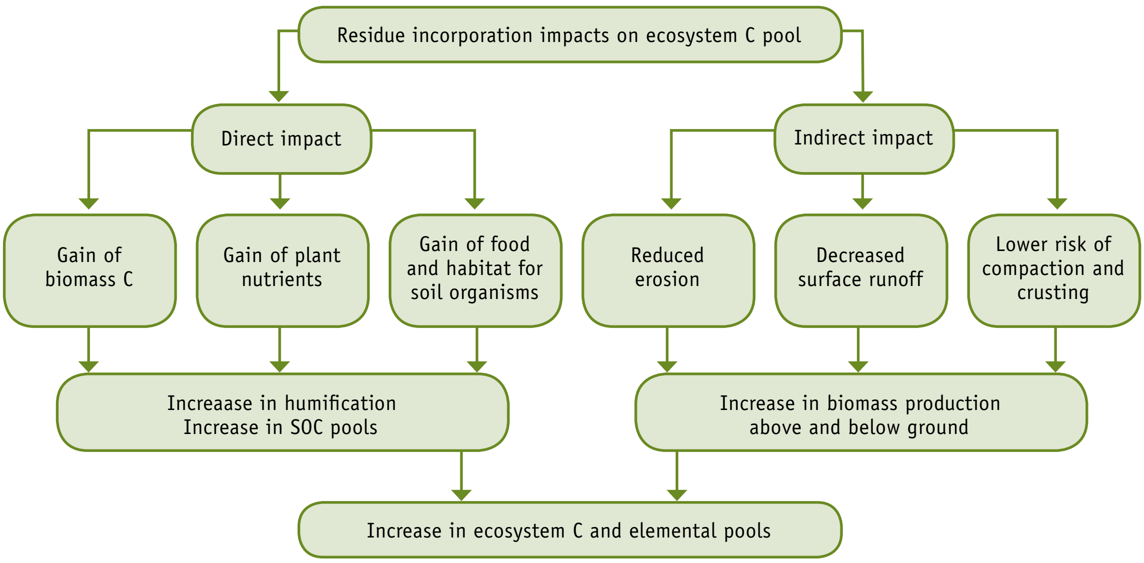
In many areas of Kenya, a near absence or total lack of inputs for improving soil fertility results in a negative nutrient and carbon budget (Nandwa and Bekunda, 1998). In smallholder farming systems, alternative uses of crop residues for fodder and fuel exacerbate the trend of decreasing carbon return to the soil (Photo 17). In addition, on-farm soil fertility gradients (i.e. spatial heterogeneity in soil quality) are a common phenomenon on smallholder farms. Fertile patches are occupied by high-value crops whose products are sold outside the farm, leading to a negative nutrient balance on-farm. The benefits that can be obtained by taking measures to counteract these trends are illustrated in Figure 2.

Photo 16. **Integration of several crops in a field can increase SOM and soil biodiversity**

Photo 17. **Yellow maize, an indicator of Nitrogen depletion without adequate replenishment**

© C. Gachene

Figure 2. **Positive impacts of crop residues incorporation on building the ecosystem carbon pool, increase in ecosystem services, and enhancement of the environment**



Source: Lal, 2004

In view of the many benefits of soil carbon, priority should be given to maintaining SOC levels in soils and, wherever possible, increasing these levels. Soil carbon gains can be achieved in two ways: first, by applying management strategies and technologies that reduce losses of existing soil carbon (particularly important in the case of dryland soils and natural grasslands or savannahs) (Mureithi *et al.*, 2014); and second, by applying sustainable management techniques that increase the levels of carbon in soils, particularly degraded agricultural soils.

In the case of mineral soils, which are typical of major cropping regions in sub-Saharan Africa, reducing tillage can minimize soil carbon losses (Lal, 2013). In addition, carbon in the soil surface can be protected through practices that control erosion, such as shelter belts, contour cultivation and cover crops.

Increasing SOC levels, on the other hand, can be achieved by increasing carbon inputs to soils. In the case of managed soils, this can be done by increasing the input and retention of above-ground biomass (Gachene and Wortman, 2004). Plants also allocate a significant portion of carbon below ground via their roots. This below-ground carbon supports the soil biota in the rooting zone, which in turn facilitates plant nutrient uptake, resulting in improved crop productivity and further increasing flows of carbon into the soil (Karanja and Kahindi, 2002; Ayuke *et al.*, 2003).

Sustainable land management for enhanced SOC levels is thus based on: optimal plant productivity (crop selection, appropriate soil nutrient management, irrigation); minimal losses of organic matter in soil (reduced tillage, erosion control, cover crops); and high carbon returns to the soil (i.e. leaving post-harvest crop residues or importing organic matter such as animal manures and domestic and industrial wastes).

In summary, techniques for increasing SOC and hence SOM in the smallholder farming systems include the following. These measures can avoid SOC losses and even build soil natural assets.

» Mulching can add organic matter. If crop residues are used, mulching also prevents carbon losses from the system. Reduced or no tillage avoids the accelerated decomposition of organic matter and depletion of soil carbon that occurs with intensive tillage (ploughing). Reduced tillage also prevents the breakup of soil aggregates that protect carbon (Karuma *et al.*, 2015). One of the challenges of mulching is the scarcity of on-farm materials such as crop residues because of the many competing uses;
» Judicious use of animal manure or chemical fertilizers can increase plant productivity and thus SOC (Bationo *et al.*, 2011). In all fertilizer additions the long-term effects must be considered. In Kenya, for example, continuous use of DAP (diammonium phosphate) has led to an alarmingly rapid decline in maize yields (Kanyanjua *et al.*, 2002);
» Rotations of cash crops with perennial pastures and the use of cover crops and green manures have the potential to increase biomass returned to the soil and can therefore increase soil carbon stocks (Njarui and Mureithi, 2006). One of the major challenges of using cover crops is the lack of on-farm niches for growing nitrogen-enhancing green manure cover crops (Mureithi, Gachene and Ojiem, 2003);
» Using improved crop varieties can increase productivity above and below ground as well as increasing crop residues, thereby enhancing SOC;

» Site-specific agricultural management can reduce the risk of crop failure and thus improve an area's overall productivity, improving carbon stocks;
» Integration of several crops in a field at the same time can increase organic material, soil biodiversity and soil health, as well as increasing food production, particularly for subsistence farmers (Ojiem, 2006).

Challenges for improved soil fertility

Available technologies and management options for SOC conservation and enhancement will harness ecosystem services to reduce agrochemical inputs and pollution and support a more sustainable agriculture that fosters important crop-associated biodiversity such as the soil biota. But whether they can be widely applied will be determined by the policies and incentives that encourage their use.

Currently, the value of soil carbon (and soils in general) is rarely considered across sectors. In Kenya, there is no policy on soil health or quality. The perceived benefits of soil carbon often reflect only the primary demands of a particular land use such as food production but not associated ecosystem services. For instance, organic inputs to agricultural soils are generally targeted at increasing soil fertility although they can also reduce soil erosion, enhance soil biota activity, achieve soil carbon sequestration and add resilience to smallholder farming systems.

Although much evidence exists in regard to the potential of ISFM to boost crop yields, the uptake of ISFM technologies has remained low. To a large extent, ISFM adoption is driven by availability of and access to appropriate inputs such as legume seeds and extension advice. Policies that can boost the availability of affordable financing will improve farmer access to inputs and uptake of ISFM. In addition to issues related to inputs, farmers need support systems to work together with them to implement such management systems. Effective extension services can contribute to understanding which technologies work where.

The primary challenge is to develop and implement planning processes, policies and incentive mechanisms that balance pressures on the soil from contrasting and (at times) conflicting demands for food, fibre and fuel crops, climate regulation, water, biodiversity conservation, living space and other benefits. In some locations, mechanisms will be needed to protect soils that are important soil carbon stores, such as the Ondiri swamp in Kenya, which is currently undergoing encroachment to allow more land for cultivation. However, in many cases multiple economic, societal and environmental benefits can be obtained on the same land through effective management of soil carbon. Examples from all over the world illustrate how effective soil carbon management can provide multiple benefits. For instance, the World Bank's BioCarbon Fund provided US$350 000 to the Kenya Agricultural Carbon Project to pay smallholder farmers to improve their agricultural practices in order to increase both soil carbon sequestration and food security (World Bank, 2010).

Current scientific knowledge of how local soil properties and climatic conditions affect soil carbon stock changes, soil biota and carbon fluxes is insufficient. Further studies are needed to enable more accurate predictions of the impacts of climate change on soils, soil carbon and associated ecosystem services at scales relevant to local management and to national carbon inventories.

Understanding of the soil species involved in decomposition and which functional groups have the greatest impacts on ecosystem processes is limited. For example, the relationship between the number of species of any soil group and an ecosystem process, such as the rate of decomposition, has not been established in field studies. Thus, knowledge of the effects of soil degradation on soil biological diversity and ecosystem services is largely missing.

In order to fulfil the promise that improved biological nitrogen fixation technology holds for smallholder farmers, quality inoculants need to be readily available and accessible. It can be argued, however, that accessibility can be hindered by current trade barriers.

5
WATER CONSERVATION

Bancy Mati

Freshwater ecosystem services – defined as the benefits obtained by people from rivers, swamps, floodplains and groundwater systems – are central to human well-being. However, as ecosystems are degraded, water problems are increasing. Often the poorest members of society are the hardest hit, as they are the most dependent on natural resources and frequently suffer from limited access (MA, 2005b). The problems are likely to be exacerbated under changing climatic regimes.

Water resources availability and its management are inextricably linked to the agriculture sector. Agriculture is by far the largest user of freshwater in most countries (Molden *et al.*, 2007) and may be the driver behind degradation of catchments, as more marginal land is cleared for farming. Agriculture is also a driver of water pollution, as eroding soils and agricultural chemicals ultimately find their way into streams, rivers, reservoirs and lakes.

At the same time, many promising solutions to water ecosystem problems originate in the agriculture sector. With careful and conscientious planning, the agriculture sector can introduce many practices, often ecologically based, that will conserve water and protect catchments that are the source of freshwater. In many cases, appropriate solutions depend on governance and how decisions are made regarding water ecosystem services. This chapter focuses on Kenya, providing examples from there – however, the issues discussed here can be relevant to other countries in East Africa.

Photo 18. **Rwanda: farmers removing stones from a river to prevent flooding during the rainy season**

Ecosystem services related to water

Water-related ecosystem services include the important watershed or catchment functions and the related provisioning of water to agricultural productivity and productive fisheries (Table 6).

Table 6. **Ecosystem services related to water**

CLASSIFICATION	SERVICES
Regulating	Watershed/catchment functions Water purification Flood regulation/storm protection
Supporting	Wetland habitat for organisms that provide ecosystem services, e.g. filtering of sediments by mangroves
Provisioning	Freshwater Water's essential contribution to agriculture and fisheries
Cultural	Indigenous systems of management under water scarcity and unpredictability

Regulating services

Water towers and catchment management. The concept of mountain ecosystems as "water towers" is increasingly used to underscore how water is managed across a landscape, and the term water towers will therefore be used in this chapter. The water basins that hold most of Kenya's surface water resources drain from its five major water towers, which specifically refer to Mt. Kenya, the Aberdares, the Mau escarpment, Cherangani/Tugen Hills and Mt. Elgon. There are other smaller water towers throughout the country which are also of critical importance in provisioning water to downstream communities and ecosystems. Kenya has approximately 1.24 million ha of closed-canopy indigenous forests. These forests occur in the country's water towers and catchments, where over 75 percent of Kenya's renewable surface water originates (MEWNR, 2014). They have a critical role in water regulation, which is important for human livelihoods, irrigated agriculture and production of hydroelectric power.

However, nearly all of Kenya's water towers have been affected by rapid destruction of forest cover and the encroachment of human settlements in water catchment areas. Forest cover in Kenya has fallen from 12 percent in the 1960s to less than 2 percent in 2010, and the losses have considerably affected the ability of the five main water towers to act as water catchments for major rivers and lakes, which are the main sources of water for rural and urban areas (KWTA, 2015).

The main causes of catchment degradation include population pressure and destruction of natural vegetation through such activities as poor farming practices (over-cultivation and overgrazing), poorly planned infrastructure development, forest excision for settlement, unsustainable woodfuel extraction, illegal logging and human encroachment. Other issues that contribute to catchment degradation include excessive abstraction of surface and groundwater; soil erosion causing turbidity and siltation; high nutrient levels causing eutrophication of lakes, dams and pans; and pollution from toxic chemicals, including agricultural pesticides and heavy metals.

Catchment degradation, as experienced in Kenya, results in the decline of springs, streams and rivers, with catastrophic consequences for human well-being and environmental integrity. Catchment degradation leads to chronic and long-term problems which are not always apparent because of the incremental nature of the degradation and the fact that the effects are often felt at a distance (in time and space) from the time and source of the degradation.

According to FAO's Global Forest Resources Assessment 2010 (FAO, 2010b), the full value of the forestry sector in Kenya was estimated as 3.6 percent of the country's gross domestic product (GDP) (MEWNR, 2014). The report showed that deforestation within this period led to a reduction in water availability of close to 62 million m^3, which in turn led to declines in fish catch, irrigation and hydroelectric power potential, a rise in the cost of water treatment, and increased incidence of malaria. Deforestation in Kenya's water towers deprives the Kenyan economy of about US$ 60 million (6 billion shillings [KES]) annually and threatens more than 70 percent of the country's water supply (Republic of Kenya, 2012).

Regulating services of wetland habitats. Wetlands are described as areas that are permanently or seasonally flooded by water and where plants and animals have become adapted – including swamps, marshlands, peatlands, mountain bogs, riverbanks, and areas of impeded drainage – as well as adjacent riparian and coastal zones. Wetlands can be brackish, salt or alkaline and include areas of marine water not exceeding 6 m in depth at low tide (Ramsar Convention Secretariat, 2011). Kenya has rich wetland ecosystems because of its diverse climate and topography. The area covered by inland wetlands in Kenya is more than 2.6 million ha, far outstripping that covered by marine and coastal wetlands, which occupy 96 100 ha (NEMA, 2012).

Wetlands have a fundamental role in the water sector. They maintain hydrological stability by regulating stream flows; improve water quality by filtering sediment and absorbing heavy metals and other toxic pollutants; and reduce the risk of flooding downstream. They also help to recharge groundwater and aquifers, thereby raising the water table, making groundwater easily available and augmenting stream flows. These services make clean water available for domestic use and for agricultural and commercial activities.

Mangrove ecosystems – which cover about 60 000 ha along the Kenyan coast (NEMA and UNDP, 2009) – provide critically important ecosystem services of nutrient cycling and sediment trapping. By slowing water runoff from the land through their extensive root networks, mangroves cause sediment to settle that could otherwise damage nearby reefs. However, it is estimated that over one-sixth of Kenya's mangrove forests have been lost due to conversion to other land uses, overexploitation and pollution.

Indeed, as wetlands are nutrient-rich ecosystems with water and high productivity, they tend to be vulnerable to exploitation, particularly for agriculture. During the dry season, wetlands are the only distinct areas with quality pasture, providing critical resources for livestock-dependent populations. Because of their relatively flat terrain, river floodplains and estuarine wetlands are easier to urbanize and develop than upland areas, and they tend to have a relatively high concentration of human developments.

Water purification. Agriculture is a major cause of high silt loading and pollution by agrochemicals in Kenya's waterways, thereby threatening water quality and biodiversity in freshwater ecosystems. As an example, the Nyando, Yala and Nzoia river basins, interfacing with Lake Victoria, are heavily farmed right into the fringes of the lake, and farms also encroach on the once biodiversity-rich wetlands that should buffer the lake. The resulting siltation and pollution threaten aquatic biodiversity particularly fish, adversely affecting their breeding sites (NEMA and UNDP, 2009).

Equally, Lake Naivasha, ringed by intensive horticultural farming, faces issues of water pollution from agriculture. The lake and its catchment have the highest concentration of commercial ornamental and vegetable growers in Kenya, making it vulnerable to agricultural waste disposal (e.g. mineral fertilizer, pesticides and other toxic materials) (Nyangena and te Velde, 2012).

Ecologists understand well that appropriately protecting riparian areas improve water quality by capturing, filtering and cleaning up pollutants and silts before they enter water bodies such as streams, reservoirs and lakes. A thick growth of diverse vegetation, plant residues covering the soil surface and non-compacted soils facilitate this freshwater ecosystem function. Riparian habitat can also be used to mitigate impacts from agriculture on water bodies. As documented in the chapter on natural pest control, "constructed wetlands" have been developed and implemented in Kenya as an innovative measure to enhance the water purification function for both urban and agricultural treatment of wastewater (Hunt, Riungu and Mathiu, 2011).

Flood regulation. Floods have increasingly become a major threat to life, property and the environment, a factor associated with land degradation and climate change. The six major drainage basins in Kenya have all experienced floods of various magnitudes and patterns. In the 1980s, floods mainly affected Nyanza Province and western Kenya, with impacts for about 14 000 people in the lower reaches of the Nyando and Nzoia rivers. The worst floods in recent history were the 1997/1998 El Niño floods which covered the entire country. About 1.5 million people suffered displacement, destroyed infrastructure and/or loss of property and livelihoods (Government of Kenya, 2012). In 2012, the long rains came late but heavily, causing floods that resulted in loss of property and lives and displacement. The most badly hit areas in these floods were Nyanza Province, the Nairobi metropolitan area, the Rift Valley and the coastal area. Several rivers burst their banks, an occurrence that can be attributed to increasing siltation, which has made the rivers shallow and unable to contain the flows.

Promotion of watershed functions through agricultural diversity. In many regions, the management of diverse agriculture within landscapes provides critical watershed functions, such as maintaining water quality, regulating water flow, recharging underground aquifers, mitigating flood risks, moderating sediment flows and sustaining freshwater species and ecosystems.

Supporting services: wetland habitats

Riparian areas and other wetlands provide food and habitat for soil, aquatic and terrestrial organisms. A multi-storeyed plant community of annual and perennial plants, shrubs and trees provides a varied habitat for birds and wildlife and a below-ground habitat for burrowing animals. Healthy riparian areas have water storage capacity to release water slowly to flowing streams and soil organisms. Stream banks provide breeding areas for many aquatic species as well as habitat for algae and macroinvertebrates (aquatic insects) which are used as food by fish and other aquatic life.

Provisioning services: water use in agriculture

Kenya, like many countries in East Africa, is endowed with impressive water resources in some areas and critical water-deficit conditions in others. Kenya's renewable water resources are estimated at 20.6 billion m^3 of surface water per year and 56.0 billion m^3 of groundwater per year (Republic of Kenya, 2013).

Agriculture is the largest user of water in Kenya, and water is the primary constraint to agricultural production, along with soil fertility. Kenya needs to expand and intensify irrigated agriculture as the available land for rainfed crops is already overstretched. Agriculture is rapidly spreading into marginal zones, where production risks from lack of water are high, and irrigation will be the answer for increasing food production in the future. The main objective of developing an irrigation system is to supply water to the soil and crop so that moisture will be readily available at all times for crop growth, regardless of the rainfall availability. Thus, crop irrigation is vital in order to provide ever-growing populations with enough food. While changing climatic regimes could result in some increases in water, the projected increases will not match the water use demands occasioned by increasing population, urbanization and commercialization. The amounts of irrigation water that will be needed to meet Kenya's development goals by 2030 are shown in Table 7. To meet this demand, the country's goal under Vision 2030 is to increase the new irrigated area from 105 800 ha in 2006 to 1.2 million ha by 2030.

Table 7. **Future irrigation water demand in Kenya (2030)**

IRRIGATION AREA	TOTAL DEMAND (million m^3/year)
Existing irrigation area	**1 602**
New irrigation area by 2030	**6 461**
Weir	1 150
Large cam	4 748
Groundwater irrigation – borehole	395
Water harvesting irrigation – small dam/water pan	176
TOTAL	**8 063**

Source: NWMP, 2030

However irrigation, if not well planned and managed, can lead to ecosystem loss and other environmental hazards such as salinity build up, creation of artificial wetlands and water-related diseases such as malaria and bilharzia (schistosomiasis). Thus it is critical to understand how ecosystem services might contribute to more ecological, biodiversity-friendly forms of agriculture, from the standpoint of water use.

A concept that is used to examine water use for agriculture is the "water footprint" for crop production. This divides the water used in agriculture into green (surface water), blue (from reservoir storage) and grey (recycled water). The total water footprint related to crop production in Kenya for 1996–2005 was estimated to be more than 18 000 m^3 per year, of which 97 percent was green, 1 percent blue and 2 percent grey (Table 8); thus management of surface water is of paramount importance for Kenya's agriculture.

About 61 percent of Kenya's green-water footprint in agriculture has been attributed to the production of maize, dry beans and coffee. Coffee and rice together account for 40 percent of the blue-water footprint (51 and 35 million m^3 per year, respectively). About 23 percent of the agricultural water footprint goes to export crops, while the remaining 77 percent is used for food production for domestic consumption (Mekonnen and Hoekstra, 2014). Of course any policy decisions made on the basis of water footprints need to address many issues; some crops with low water footprints (such as banana and plantain) may simply grow in areas of high rainfall. Some crops with relatively high footprints, such as beans, may contribute more significantly to food security than some crops with low footprints, such as sugar cane. It may be more important to ask not what is the crop with the lowest footprint, but how ecosystem services can contribute to reducing water use by the crops that contribute most to food security and livelihoods.

Photo 19. **Road runoff harvesting into pan**

© Bancy Mati

Table 8. **Water footprint of crop production in Kenya (1996–2005)**

CROP	TOTAL WATER FOOTPRINT (million m³/year)				WATER FOOTPRINT PER TONNE OF CROP (m³)			
	Green	Blue	Grey	Total	Green	Blue	Grey	Total
Maize	6 688	11	96	6 794	2 703	4.4	39	2 746
Beans, dry	2 774	0	0.1	2 774	8 319	0	0.3	8 319
Coffee	1 426	51	35	1 513	22 222	802	549	23 573
Tea	1 131	1	25	1 157	4 061	3.6	89	4 154
Wheat	439	0	20	460	1 492	0	70	1 562
Sorghum	453	0	0	453	4 359	0	0	4 359
Sugarcane	416	8.8	8.9	433	95	2	2	99
Potato	316	0	29	345	342	0	31	373
Banana	283	6.5	5.5	295	545	12	11	568
Plantain	284	0	5.5	289	546	0	11	556
Millet	260	0	0	260	5 375	0	0	5 375
Pigeon peas	240	0	0	240	3 200	0	0.3	3 200
Cassava	234	0	0	234	431	0	0	431
Other crops	2 646	140	75	2 861				
TOTAL	**17 590**	**219**	**300**	**18 109**				

Source: Mekonnen and Hoekstra, 2014

Cultural services: traditional knowledge related to water management

Local and traditional knowledge is an invaluable resource for managing scarce water resources in Kenya, and indeed in all ecosystems of East Africa, from arid and semi-arid lands to the water towers or mountain ranges providing key watershed services (UNEP, 2008). Underlying all effective land and water management practices is the place-based knowledge of local communities on optimizing practices and dealing with uncertainty. Many local communities have a refined appreciation of how to deal with their local ecologies and have evolved governance structures to reflect this knowledge. Thus communities observe certain water management practices that protect watercourses as well as wetlands and ensure sustainable utilization of water sources including rivers and lakes. Many of the practices are based on taboos and prohibitions. The following are some examples (UNEP, 2008):

» In western Kenya, communities have strong rules for protecting forests associated with rivers, considered as shrines. The River Chalua on Mfangano Island (Lake Victoria), for instance, is protected by traditional rules and prohibitions, and the river remains healthy.

» On Lamu Island (Indian Ocean), elders protect sand dunes, which are the only source of freshwater for the coastal town. No one is allowed to dig water wells without the permission of the elders.

Management practices to sustain multiple benefits from water-related ecosystem services

Water availability is a basic requirement for the survival of all organisms and for thriving agriculture, biodiversity and ecosystems. Water quantities and quality affect and are affected by human activities. There is ample evidence to show that water use demands can be met without causing undue negative impacts on biodiversity, the environment and thus human livelihoods. A wide range of technologies, practices and initiatives exist which, if well applied, can result in balanced agricultural, industrial and commercial use of water, with consideration for resilient ecosystems and the environment. Effective water management means ensuring the optimal utility of every drop of water, be it from rainfall or irrigation.

Sustainable ecological intensification of agriculture can be achieved in East Africa using a wide range of water management practices designed to suit different agro-climatic and socio-economic needs. These practices include various combinations of technologies and approaches for sustained control of water and its conveyance and application from such sources as rainfall, surface runoff and subterranean aquifers.

Water harvesting (Table 9) encompasses all activities where water is collected, stored and used in either the blue or green form. It includes both rainwater harvesting and floodwater harvesting. It is achieved in many ways, and the water can be stored in tanks, ponds and dams or channelled into the soil profile (Critchley and Siegert, 1991).

Rainwater harvesting can be distinguished as the collection of rainfall runoff from various sources such as roofs, the ground surface, rocks, valleys and water sources and its storage in structures such as tanks, dams and rock catchments (blue water), to provide water for domestic use, livestock, commercial purposes or supplemental irrigation (Mati, 2012). The term includes floodwater harvesting as well as water harnessed from direct rainfall and stored within the soil profile for plant use (green water).

Rainwater harvesting is applicable in almost all parts of Kenya, especially in arid and semi-arid regions where rainfall is erratic or insufficient to sustain a good crop and pasture growth. It is especially useful to minimize the risk of crop failure in drought-prone areas.

Water harvesting benefits Kenyan farmers in many ways. It makes rainfall, which occurs for only a few days a year, available throughout the year. It reduces runoff losses and thus curbs soil erosion. It helps to mitigate against natural disasters such as drought and floods. Rainwater harvesting at catchment level protects dams from siltation.

In the discussion of technologies below, water harvesting methods are grouped into those using storage structures (blue water) and *in situ* systems (green water). A third water management approach consists of agronomic conservation measures, including the use of manures, fertilizers and mulching and the use of drought-tolerant crop varieties, which should be complemented with IPM and a general focus on agro-ecosystems, e.g. agroforestry.

Table 9. **Overview of the main types of rainwater harvesting systems**

WATER HARVESTING SYSTEM	FLOW	SURFACE	CATCHMENT SIZE	CATCHMENT TO CROPPING AREA RATIO	WATER STORAGE TYPE	WATER USE
Rooftop	Sheet flow	Roofs of all kinds	Small	N/A	Tanks, jars, cisterns	Drinking, domestic, livestock
For animal consumption	Sheet flow	Treated ground surfaces	>3 ha	Extremely varied	Tanks, cisterns	Livestock
Inter-row	Sheet flow	Treated ground surfaces	1-5 m²	1:1–7:1	Soil profile (reservoirs, cisterns)	Tree, bush, vegetable and field crops
Micro catchment	Sheet and rill flow	Treated and untreated ground surfaces	2-1 000 m²	1:1–25:1	Soil profile (reservoirs, cisterns)	Tree, bush, vegetable and field crops
Medium-sized catchment	Turbulent runoff/ channel flow	Treated and untreated ground surfaces	0.1–200 ha	10:1–100:1	Soil profile (reservoirs, cisterns)	Tree, bush, vegetable and field crops
Large catchment	Floodwater flow	Untreated ground surfaces	200–5 000 ha	100:1–10 000:1	Soil profile	Tree, bush, vegetable and field crops

Source: Prinz. 1996

Water harvesting with storage structures (blue water)

Structures for water harvesting include surface and underground tanks (Photo 20) and larger, engineered structures such as pans and ponds, weirs and earth dams, and sand and subsurface dams. The Kenya Vision 2030 proposes to increase such water holding capacity to 2 billion m^3 to help the country meet its drinking water targets as well as to expand irrigation to further improve food security and reduce poverty. However, the impacts of such an effort on riparian ecosystems and human livelihoods, especially of downstream communities, may be highly negative if it is not well planned. In general, helping communities to access water through small-scale water harvesting structures may be the first priority. Interventions by individuals should be encouraged, as they are sustainable. Larger structures should occur further downstream and should only correspond to the precise needs of downstream users, and the contribution of upstream communities to downstream use should be recognized. Kenya has had some highly innovative experiences with subsurface dams, in which water is stored under the sand and is thus protected from significant evaporation losses and is also less liable to be contaminated.

Photo 20. **Structures for water harvesting: (A) Roof catchment tank for household water in Embu, Kenya; (B) Rainwater harvesting from roof catchment for institution in Nyando, Kenya**

© Bancy Mati

© Bancy Mati

In situ water harvesting and conservation (green water)

In situ water harvesting and conservation include the process of concentrating rainfall as runoff from a larger area for supplemental irrigation and conservation measures that ensure that all rainfall infiltrates the soil (Critchley, Reij and Seznec, 1992; Oweis and Hachum, 2006). This approach is called runoff farming because water is stored in the soil profile as soil moisture. All methods of water harvesting involving the soil profile are highly dependent on ecosystem services within the soil and watershed.

Runoff farming is distinguished from conventional irrigation by three key features:

» The catchment area is contiguous with the runoff receiving area (called run-on area, cropped area or cultivated area), which is relatively small.

» Water application to the cropped area is essentially uncontrolled. The objective is simply to capture as much runoff as possible and to store it within the reach of the plant roots, in the soil profile of a cultivated area.

» Water harvesting can be used to concentrate rainfall for purposes other than crop production.

Systems for *in situ* water harvesting include terraces, pits, basins and trenches as well as deep tillage. This approach is particularly useful in areas with fragile soils and high rainfall intensity. Moreover, *in situ* water harvesting and conservation systems can be implemented by farmers themselves.

The following are some specific measures employed in green water management.

Retention ditches. Retention ditches – also called infiltration ditches, diversion ditches or, in Kenya, cutoff ditches – may be a feature of in situ water harvesting. They are open channels dug along the contour to catch and retain incoming runoff and hold it until it seeps into the ground. The source of runoff can be open fields, home compounds or roads (Mati, 2005).

The water retained in the ditch slowly seeps vertically and laterally to augment soil moisture in the adjacent cropped land, while also reducing soil erosion. Tree crops may be grown within the channel, while moisture seeps to adjacent cultivated lands to benefit field crops. These water harvesting and conservation structures also provide space for diversifying crop production and investing in areas of natural habitat which may have other benefits, for example for pollinators.

In ditch construction, a channel is excavated across the slope and the spoil is thrown on the downhill side to form an embankment (the opposite of *fanya juu* terraces – see below). The embankment is then stabilized by planting grass or another cover crop on it.

Road runoff. Roads, footpaths, animal tracks, railway lines and other infrastructure, paved or made of compacted soil, are an underused source of runoff in many agro-ecosystems. These features often have surface crusts that produce a high volume of runoff. The runoff tends to be concentrated into channels, putting its harvesting in the category of "floodwater harvesting". This approach has great potential for replicability. Road runoff harvesting systems vary from simple diversion structures directing surface water into crop fields (Photo 21) to deep trenches with check dams enabling both flood and spate irrigation, usually combined with bunded basins. A ditch system can be adopted for tree crops. The use of road runoff could be enhanced and farmers trained on various ways of handling the huge runoff flows and how to avoid erosion damage. The complexity of handling turbulent channel flows laden with high sediment yields is a major challenge to wider adoption of road runoff harvesting.

Photo 21. **Road runoff harvesting into ditch with banana plants in Mbeere, Kenya**

© Bancy Mati

Microcatchment water harvesting practices. In microcatchment water harvesting systems, a relatively small portion of upslope land is allocated for collection of runoff, which is harvested and directed to a cultivated area (runon area or cropped area) downslope (Critchley and Siegert, 1991). The cropped area may be prepared as basins, pits, bunds or contour-tilled land. Microcatchments are normally within-field systems since runoff comes from within the vicinity of the cropped area. In design, micro-catchment systems usually have a ratio of catchment to cultivated area ranging from 1:1 to 5:1 (Oweis, Prinz and Hachum, 2001). These systems are suitable for growing crops in dry areas having intense storms and high production of runoff. They are usually appropriate for field crops such as maize, sorghum or groundnuts as well as tree crops. In East Africa, relatively few of the available microcatchment water harvesting technologies are in use (Mati, 2010). The most common are pitting systems popularized by NGOs and the government (Photo 22), especially *zai* pits. However, adoption has been low owing to the tedious manual labour require to excavate them.

Terracing. Kenya has some of the most challenging natural conditions for soil and water conservation, i.e. highly erodible soils, erratic and intense storms, steeply sloping hillsides and high population densities resulting in overcultivation of catchment areas. Despite (or because of) these challenges, extensive soil conservation activities have been implemented in the country since the colonial days. Terracing has been particularly successful; it has been adopted extensively in many parts of Kenya (Muranga, Kitui, Kiambu, Makueni and Machakos, among others).

The most common type of terrace is the *fanya juu* terrace, found on many farms in Kenya, including those on gentle slopes (Mati, 2010). A *fanya juu* terrace is created by excavating a channel and throwing the soil uphill to create an earthen bund, which acts as a barrier to soil erosion while also retaining runoff water. Other types of terraces commonly found on Kenyan

Photo 22. **Pitting systems: (A) Maize in *zai* pits in Machakos; (B) *Tumbukiza* pits with banana crop, Kirinyaga, Kenya**

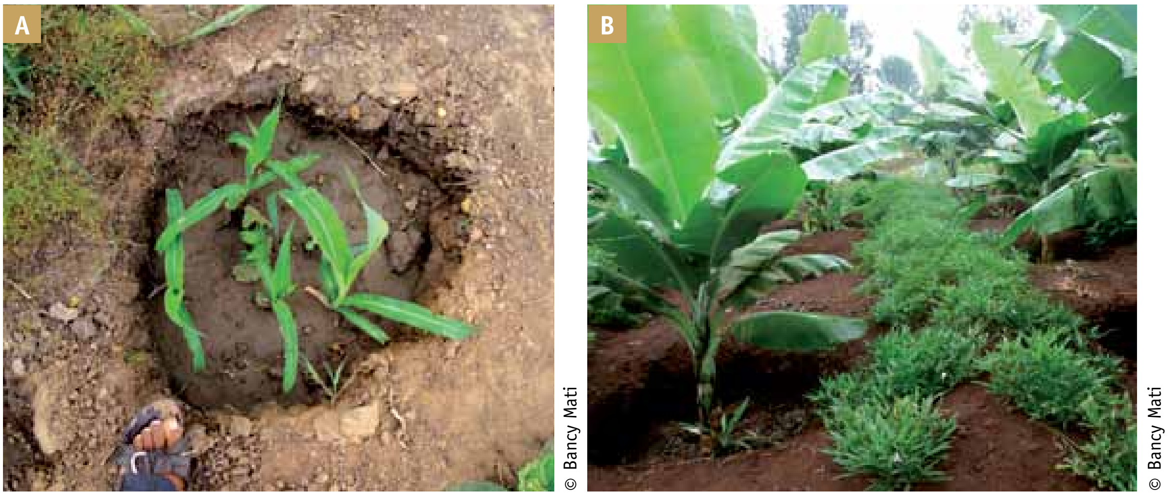


Photo 23. **Terracing: (A) *Fanya juu* terraces in Machakos; (B) Terraces developed from grass strips with fruit trees in Makueni**

© Bancy Mati

© Bancy Mati

farms include reverse-slope bench terraces, *fanya chini* terraces (where excavated earth is thrown downhill, as in retention ditches), vegetative barriers and grass strips (Photo 23). The main limitation with some of the terraces in arid and semi-arid lands is the lack of bank stabilization, which poses a danger of breached banks and excessive runoff across exposed surfaces. However, the farmers are well informed and understand the importance of rebuilding the embankments each year. Terracing is a useful intervention for retarding surface runoff, reducing erosion and conserving rainwater *in situ*.

Agronomic conservation measures

Conservation tillage. Conservation tillage is aimed at preserving the soil, water, crop residues and biological status of the soil with as little disturbance as necessary, while also saving energy used in tillage operations. These days, the term "conservation agriculture" or "conservation farming" is more commonly used, in reference to the holistic application of conservation tillage alongside other agronomic practices (e.g. manuring, crop rotations, mulching) to reduce labour and preserve the natural state of the soil. Conservation tillage deviates from "conventional" or normal tillage in that the land preparation involves a soil turning operation such as digging, ploughing, discing, harrowing, rotavating or a combination of these, depending on the crops to be grown. Conservation tillage is thus intended to reduce the negative effects of conventional tillage such as soil compaction, formation of pans, disturbance of soil fauna and moisture loss (Biamah, Rockstrom and Okwach, 2000; Duveskog, 2001). Conservation tillage is commonly practiced in Laikipia and Machakos (Photo 24), especially deep tillage or subsoiling. Farmers that practiced deep tillage indicated that the practice significantly increased crop yields and was particularly beneficial in seasons with poor rainfall.

Photo 24. **Maize–groundnut intercrop grown with compost in Bondo, Kenya**

© Bancy Mati

Agroforestry and tree planting. Agroforestry is defined as a dynamic, ecologically based natural resources management system of trees on farms and in the landscape, diversified and sustained for increased social, economic and environmental benefits for land use at all levels (FAO, 2015). It involves planting trees or shrubs on the farm or keeping those that are already there (Photo 25). Agroforestry systems can take the form of interspaced trees, borders or shelterbelts. An agroforestry system should hold a diversity of plants with different rooting systems, drawing water from different soil layers with different growing periods, and thus can be beneficial to agriculture in semi-arid zones. The utility of agroforestry relies on the fact that tree roots are deeper than most agricultural crops, and can therefore reach water and nutrients from deeper soil layers than crops.

Photo 25. **Agroforestry: (A) Agroforestry tree cover landscape in Machakos; (B) Agroforestry with indigenous trees in Embu**

A

© Bancy Mati

B

© Bancy Mati

Challenges to water governance

Many countries are in the process of devolving authority over natural resources to local government. Aligning emerging issues in the water sector with devolution will have far reaching impacts on the agriculture–water quality and health nexus. Throughout East Africa, water is an essential resource to support future development activities. Thus a proper system is needed for planning and implementing water resources management, to meet the increasing demand for water for domestic and commercial uses, irrigation and industries while conserving the catchments sustainably. Because of the competing uses, water resources management also contributes to peace and conflict resolution, especially among pastoralists and major users of water resources.

Rights and responsibilities over water resources are being elaborated at multiple levels in Kenya. Kenya's Constitution of 2010 grants citizens the right to a clean and healthy environment, and the current Water Act 2002 establishes the right to clean and safe water. The Constitution of Kenya, 2010, states that: "Every water resource is hereby vested in and shall be held by the National Government in trust for the people of Kenya". A new Water Bill under negotiation espouses the administrative and regulatory structures to support water resources management and retains water resources users associations (WRUAs). The new bill also stipulates the use of the water catchment area (rather than county) as the basic planning unit. Thus, while water resources belong to the national government, it is envisaged that governance will be devolved to local structures.

Integrated water resources management (IWRM) is seen as a means of guiding water governance issues and is incorporated in Kenya's Water Policy of 1999. Principles of IWRM support the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. IWRM has its roots in the International Conference on Water and Development, which in 1992 gave rise to the following four principles, which have been the basis for many of the subsequent water sector reforms in the world, including in East Africa.

- **Principle 1.** Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment.
- **Principle 2.** Water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels.
- **Principle 3.** Women play a central part in the provision, management and safeguarding of water.
- **Principle 4.** Water has an economic value in all its competing uses and should be recognized as an economic good as well as a social good.

In particular, IWRM should assist the water sector by raising awareness among other users of the needs of ecosystems and the water-related benefits that ecosystems generate for them, such as clean water provisioning. Often these ecosystem services are undervalued and are not incorporated into planning and decision-making. The ecosystem approach provides a valuable framework for IWRM, focusing attention on protection of upper catchments (e.g. reforestation, good land husbandry, soil erosion control), pollution control (e.g. point source reduction, non-point source incentives, groundwater protection) and environmental flows.

The following mechanisms for supporting water-related ecosystem services have been explored in Kenya.

Green Water Credits

Green Water Credits (GWCs) are "a mechanism to pay rural people for specified land and soil management activities that determine all freshwater resources at source" (Geertsma, Wilschut and Kauffman, 2010). GWCs are based on the premise that green water resources can be much increased and downstream delivery of freshwater better regulated by making two fundamental improvements in rainfed farming: increasing the infiltration of rainwater, thereby cutting runoff; and reducing unproductive evaporation. More infiltration means more water banked in soils and aquifers and better river base flow. Less runoff means less erosion, less flooding and less siltation. Low-cost soil and water management packages can significantly increase available water resources.

The interventions considered under GWCs include:

- **agronomy:** crop rotation, hybrid maize, cover crop (lablab beans), mosaic-resistant cassava, ground nuts, tissue-culture banana, intercropping (maize-beans, maize-groundnuts, maize-potatoes), fodder banks (Napier grass, *Calliandra* spp., *Sesbania* spp.), IPM;
- **nutrient management:** mulch (weed) management (cowpea, beans, sweet potato), improved fallow, manure, compost management, replacing inorganic with organic fertilizer, targeted application of fertilizer;
- **tillage/residue management:** minimum soil disturbance (spot preparation, subsoilers, jab planters), maize residue management in trash lines, drainage channels, contour lines, ridging;
- **water management**: water harvesting for agriculture (small dams, ponds, half moons), double-dug beds, terracing, erosion control, tied ridges;
- **agroforestry:** hedges (contour planting, boundary planting, *Jatropha* spp.), woodlots (fruit orchid, fuelwood trees, timber trees), trees in agricultural systems (fruit-trees, fuelwood trees, timber trees);
- **restoration of degraded agricultural lands:** area enclosure, riverbank tree planting, gully control, fallows (grass planting).

A GWC project was implemented in Kenya in 2007, involving payments for water management services to farmers in upstream areas of the Tana basin. The project was funded by the International Fund for Agricultural Development (IFAD) and the Swiss Agency for Development and Cooperation (SDC). Partners included the Ministry of Water and Irrigation, the Ministry of Agriculture, the Water Resources Management Authority (WRMA), the Nairobi City Water and Sewerage Company (NWSC) and the Kenya Electricity Generating Company (KenGen). It was originally intended that downstream water users (companies based in Nairobi) would make small cash transfers to enable farmers to adopt sustainable management of land and water and to diversify income, thus also combating rural poverty. However, in reality, the money was not paid to farmers. Instead, the project supported community-based activities such as tree nurseries and planting and water harvesting for schools. As a result, the farmers' expectations raised by the project were not fulfilled.

Equitable Payment for Watershed Services

The Equitable Payment for Watershed Services (EPWS) programme, introduced by the World Wide Fund for Nature (WWF) Kenya in partnership with CARE–Kenya, has been in operation in the Lake Naivasha basin in Kenya since 2006. The implementation phase commenced in 2008 with 565 pilot farmers. The goal of EPWS is to improve the livelihoods of targeted households in the Malewa Catchment area by introducing payments for watershed services. The payment scheme involves two WRUAs representing sellers located in the Turasha and Wanjohi sub-catchments of the Malewa River at the western foothills of the Aberdare range. The two WRUAs receive financial rewards for implementing water conservation measures from the Lake Naivasha Water Resource Users Association (LANAWRUA), which represents private-sector water users around Lake Naivasha. Farms are inspected to verify that measures have been implemented as agreed in the buyer-seller contract. Payments are made through a voucher system.

After the first payments in 2012, more stakeholders joined the programme, including WRMA, UNEP, the World Agroforestry Centre (ICRAF), government line ministries (for water and for agriculture and livestock), provincial administration and public schools. WWF is the main project intermediary.

Other than the Lake Naivasha Growers Group, the main buyer, more potential buyers have joined the scheme including ranchers and other flower companies. The benefits have included:

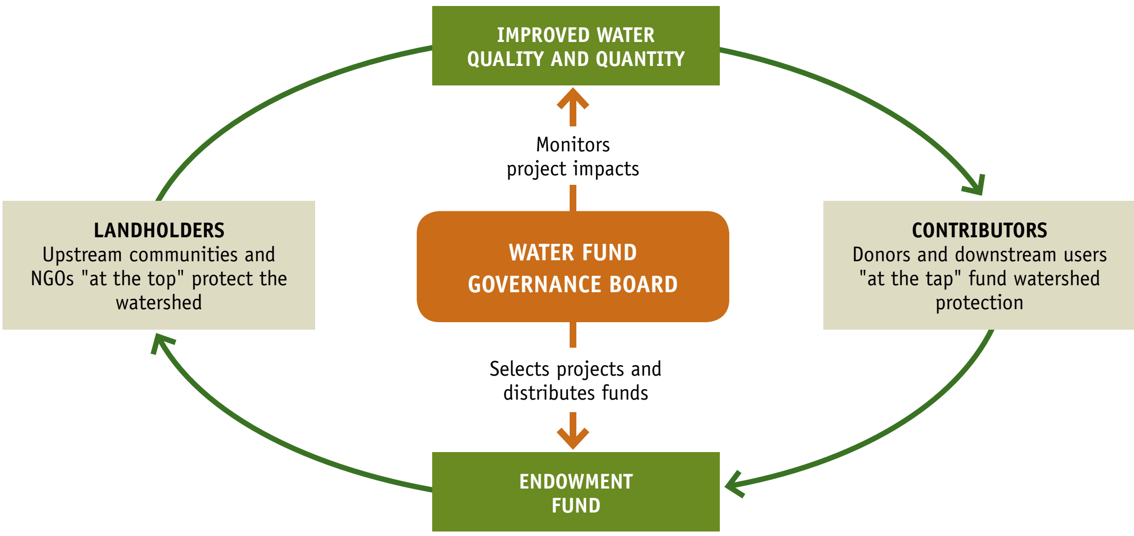
- reduced soil erosion;
- increased farm productivity (an indicator of improved soil fertility) and improved food security;
- increased income for landowners from different on-farm green enterprises;
- improved quality of water in the rivers and less turbidity, confirming silt load reduction;
- community acquisition of skills and knowledge on good land management practices to protect land and water ecosystems for future sustainable agricultural activities.

Upper Tana – Nairobi Water Fund

A water fund is a financial mechanism to fund land conservation measures upstream. A public–private partnership of donors and major water consumers contribute to the endowment. Funds are then used to support water and soil conservation measures at the source, to reduce soil erosion for increased agricultural yields and improved downstream water quality and supply, thus improving rural livelihoods. Water funds are based on the principle that it is cheaper to prevent water problems at the source than it is to address them further downstream. Investments in green infrastructure, i.e. natural systems to trap sediment and regulate water, are often more cost effective than relying solely on "grey" infrastructure such as reservoirs and treatment systems.

Water funds have been successfully implemented to help secure the water quality and supply of major cities in various parts of the world, such as Quito, Ecuador and Rio de Janeiro, Brazil. The Upper Tana–Nairobi Water Fund, launched in 2015, is the first in Africa (Figure 3). Among the interventions to be facilitated include: vegetation buffer zones along riverbanks, agroforestry, terracing of steep and very steep farmlands, reforestation of degraded lands at forest edges, grass buffer strips in farmlands and mitigation of erosion from dirt roads.

Figure 3. **Design of the Upper Tana-Nairobi Water Fund**



Source: Apse and Bryant, 2015

6

POLLINATION

Muo Kasina

Agricultural biodiversity is often understood as crop genetic resources, yet agro-ecosystems hold a wide diversity of other organisms that contribute towards their productivity and sustainability. Among these are pollinators, which are animals that carry pollen from the male to the female parts of plants and thus ensure that fruit or seeds are formed. In recent decades, the importance of pollinators as an element of agricultural diversity supporting human livelihoods has been increasingly recognized. Yet mounting evidence points to a potentially serious decline in numbers and diversity of biotic pollinators. Better conservation and management of pollinators, to maintain and increase yields in horticultural crops, seeds and pastures, is critically important to health, nutrition, food security and better incomes for resource-limited farmers.

In agro-ecosystems, pollinators are essential for orchard, horticultural and forage production, as well as for the production of seed for many root and fibre crops. Pollinators such as bees, birds and bats affect 35 percent of the world's crop production, increasing outputs of 87 of the leading food crops worldwide as well as many plant-derived medicines (FAO, 2016).

Food security, food diversity, human nutrition and food prices are all impacted strongly by pollinators. This is particularly important for horticultural crops. Diversification of horticultural crops is becoming an avenue for poverty alleviation among many farmers around the world (Photo 26).

Trade in horticultural crops accounts for over 20 percent of developing countries' agricultural exports, more than double that of cereal crops. Unlike the historical increase in cereal production, the expansion of fruit and vegetable production has come primarily from increases in the area cropped, not from yield increases. Pollinator declines, if not prevented, are likely to have negative consequences for the production and costs of vitamin-rich fruit and vegetable crops, leading to increasingly unbalanced diets and health problems. Already this awareness is increasing in public domain (Figure 4), which may allow engagement on its management.

Photo 26. **Insect-pollinated horticultural produce being sold at a road stand near Nairobi, Kenya**

© B. Vaissière

Figure 4. **A newspaper article demonstrates growing public awareness of the consequences of a decline in pollinators**

DAILY NATION | NEWS | BUSINESS | COUNTIES | SPORTS | BLOGS & OPINION | LIFE AND

home 〉 news 〉

TUESDAY, OCTOBER 30, 2012

Lack of bees blamed for poor crop yields

Economic contribution to crop production

Biotic pollinators such as bees, butterflies, moths, flies and beetles are only important for crops that cannot reproduce without external pollen vectors; crops that can significantly increase fruiting and seeding with additional pollen deposition augmenting self-pollination; and crops that cannot produce viable seeds without cross-pollination. Crops that do not need pollen vectors (such as cereals, which are wind pollinated) have no risk of reduced pollination service.

Until recently, the value of pollination – a service provided by nature – has rarely been accounted for (or paid for) by farmers. While pollinators carry out pollination incidentally (in seeking floral resources for their own needs), crops gain from such activity through enhanced reproductive potential. This is the key link between pollinators and farmers. Farmers' ultimate interest is income from crop yields, which they seek to maximize by reducing production costs. Farmers would not want to jeopardize their productivity by failing to invest in production factors unless they have no idea of what is required. More importantly, farmers only want to invest their resources where they can recoup more benefits in a given period of time. Therefore, it is essential for farmers, and all stakeholders at large, to understand the economic contribution of pollinators to their well-being if they are to invest in protecting and using them.

Over the years, scientists have documented the gains that emanate from sufficient crop pollination, mainly by bees, so as to enlighten farmers and policymakers on the importance of protecting pollinators. A recent analysis of the global economic importance of pollinators estimated that the agriculture sector would lose EUR153 billion (about US$216 billion) if pollination services are lost (Gallai *et al.*, 2009).

In East Africa, a few studies have documented the economic contribution of pollination to household livelihoods. For example, it was estimated that net benefits to farmers growing capsicum, tomatoes, beans, cowpea, sunflower, green gram, Bambara nut, squash butternut and passion fruit in Kenya could increase by 40 percent when pollination is optimized (Kasina *et al.*, 2009b).

The economic contribution of pollination in East Africa as a whole has not yet been calculated, but it can be expected to be significant. Mixed farming is common in East Africa, with crops and livestock often kept on the same farm. Different crops, many of them horticultural, are grown on same portion of land in varying mixtures, e.g. intercropping, relay cropping, strip cropping, rotational cropping and companion cropping, depending on the area of land and ecological zone. Such rich diversity of horticultural crop production is highly dependent on pollinators to ensure good production. The need is greater for indigenous crops, since their seeds are not available in the market. Sufficient pollination is thus critical to sustain the crop presence in farmers' fields.

Ecosystem services related to pollination

Ecosystem services related to pollination are characterized in Table 10.

Table 10. **Ecosystem services related to pollination**

CLASSIFICATION	SERVICES AND RELATED ASPECTS
Supporting (also includes Regulating, as per the MEA)	Crop pollination Forage pollination Indigenous fruits and vegetables Flood and storm management
Provisioning	Honey and other bee products
Cultural	Traditional knowledge of bees and pollination Recreation and tourist sectors
Habitat	Conservation/regeneration of wild and semi-wild habitats

Regulating services

Crop and forage pollination. In addition to the value of pollination to crop yields as described above, pollinators make important contributions to other aspects of crop production. Good pollination improves the quality of both fruit and fibre crops, such as cotton. Pollination in chilli peppers contributes to increased speed of ripening, which can enable farmers to market peppers at a higher off-season price and to obtain one additional flush of fruit over the course of a growing season (Photo 27).

Photo 27. **Well pollinated chilli peppers**

Bees and other pollinators are also important for reproduction of non-crop plants such as forage plants. Especially in arid and semi-arid areas of East Africa, farmers use a wide range of forage plants for their animals, both natural and cultivated. *Acacia* trees are an example of a pollination-dependent component of natural pastures; fruits of various *Acacia* spp. are an important part of the diet for animals during the dry period.

Studies in other parts of the world have documented the economic importance of bee pollination of legume forage for dairy productivity. This is widespread particularly in countries that grow alfalfa/lucerne (*Medicago sativa*), which is highly reliant on bees for seed production (for example, contribution of legume forage to dairy productivity in the USA has been documented [Martin, 1975]). In East Africa, some farmers grow alfalfa as a dairy feed, although the market in alfalfa seed is not well developed. Alfalfa requires pollinators (leafcutter bees) to produce viable seeds and is so economically important that farmers deliberately manage pollination by bringing in leafcutter bees.

Indigenous fruits and vegetables. Many communities in East Africa live on non-arable land, and indigenous plants are important components of their diets. Most wild fruits and vegetables depend on pollinators for reproduction. Insufficient pollination would lower fruiting, which would affect the time spent in sourcing fruits and vegetables of similar quality and the nutritional and food security status of these people.

Other regulating services. Pollinators have a number of other less direct roles in regulating ecosystems, including the following:

- **Storm management.** In coastal areas, mangroves aid in reducing damage from storms. Many species of mangrove require pollinators for reproduction; thus without pollinators, people would be exposed to the danger of high currents. In inland areas, trees and shrubs in riparian areas – of which most require pollinators – reduce the extent of damage by floods.
- **Prevention of soil erosion.** Mitigation of erosion and land degradation is of great concern for human livelihoods in East Africa, and shrubs and low-lying vegetation are important for soil erosion control. Much of the native vegetation depends on bee pollination for reproduction. Without these plants, farmers would need to spend a lot of money on other soil erosion control methods. In extreme circumstances, land could be rendered unusable due to large gullies.
- **Climate management.** Pollinators' role in ensuring the reproductive success of plants constitutes a major contribution to climate change management through plant life.
- **Nutrient recycling.** By supporting plant life, pollinators contribute to nutrient recycling.

Supporting services: conservation and regeneration of wild and semi-wild habitats

In nature, the vast majority of flowering plant species only produce seeds if animal pollinators move pollen from the anthers to the stigmas of their flowers. Without this service, many interconnected species and processes within an ecosystem would collapse. With well over 200 000 flowering plant species dependent on pollination from over 100 000 pollinating species, pollination is critical to the overall maintenance of biodiversity (Photo 28). Approximately 80 percent of all flowering plant species are specialized for pollination by animals, mostly insects.

Tropical ecosystems are more dependent on animal pollinators than the global average; less than 3 percent of all tropical lowland plants rely on wind for pollination. Arid and mountain ecosystems often have highly diverse pollinator communities as well, with finely tuned adaptations to ensure that pollination is effective even when climatic conditions are erratic.

Photo 28. **Bee pollinating onion seed in South Africa**

© N. Azzu

Provisioning services: honey and other bee products

Most areas of East Africa are suitable for beekeeping. The apiculture industry is not modernized; most of the farmers practice traditional beekeeping methods, and only an estimated one-fifth of the full potential of the sector is utilized. The sector has potential for improving the food and economic security of many people living in the region, and interest in enhancing the growth of this sector has increased. Beekeepers' associations and government sectors are developing strategies to enhance the productivity of the sector.

Photo 29. **Stingless bee hive**

© N. Azzu

Apart from honey bees, stingless bees (tribe Meliponini) also produce honey, although in small quantities compared with the former. Domestication of these bees is gaining ground and is expected to expand in the years to come. Huge challenges remain in determining the best husbandry methods for these bees (Photo 29).

In addition, other pollination products include wild fruits, which are a common delicacy in all African cultures. Examples of wild fruit trees include tamarind (*Tamarindus indica*), black plum (*Vitex payos*), *Berchemia discolor* and baobab (*Adansonia digitata*). In many parts of East Africa, animals are free range, and depend on wild forage for feed. Pollination contributes immensely to the provision of this feed. Another aspect is the dependence of populations on fuel wood and timber, some of which come from plants that continue to thrive due to effective pollination.

Cultural services: traditional knowledge of bees and pollination

Traditional knowledge of native honeybees and stingless bees can be found in all cultures in East Africa, although such traditions are dying out. Elderly people still recount how as children they knew how to harvest honey from wild bee nests. Many cultures have recognized and appreciated the medicinal properties of honey, particularly stingless bee honey for skin wounds.

Pollinators help in the reproduction of many plants (including trees) that are important in the cultural lives of many people in East Africa, where ecosystem sustenance is a part of local cultures. Indigenous plants producing wild fruit support a large diversity of animals, which contribute to sustaining the food chain in an ecosystem. These food chains are also an attraction for tourists, providing important income for many East African countries. Natural habitats and landscapes are becoming important as recreation areas for a growing middle class. Many flowering shrubs that require pollination enhance the beauty of these areas.

Practices to improve ecosystem services from pollinators

Considering the wide range of economic, social and environmental benefits from pollinators, it is prudent for farmers and all stakeholders to protect them and enhance their presence.

Farmers must first understand the function of pollinators in their agro-ecosystems and their interaction with other practices adopted by farmers.

The following describe some key important considerations while planning to enhance pollination services provision:

» **Crop of interest.** It is important to know the pollination requirement of the crop and/or the crop variety. Does the crop require pollinators? What kind of a pollinator? Over what period does it require pollinators to visit?

» **Pollinator(s).** What is the effective pollinator or pollinator guild? Are pollinators available in sufficient number? Is supplementation required? How can the pollinator presence be increased at the time the crop requires pollinators? How can a farmer encourage floral constancy?

» **Farm practices.** Are farm activities friendly to the pollinator? If not, are there mitigation measures that can prevent pollinator loss? What can be done to enhance the pollinator number? Are natural habitats being maintained for pollinators?

» **Societal needs.** Are family and farm workers aware of pollinators (Photo 30)? Do they appreciate pollinators' role in crop productivity? Do neighbours act in a manner to protect pollinators? Is there a cultural tradition of appreciating pollinators, which can be emphasized to promote their conservation?

Photo 30. **(A) Field training with farmers in Kenya on beneficial insects; (B) Parataxonomy training in Kenya**

A

© C. Odhiambo

B

© Sara Manetto

Crop management systems that capture synergistic benefits

Various crop management systems can contribute to conserving pollinators while at the same time enhancing other ecosystem functions or services.

Pollination and natural pest control. Pest control presents one of the main challenges in conservation of pollinators in agricultural systems. During flowering periods, pollinators visit crop flowers at times when the crop is also vulnerable to infestation by pests. A study documenting farmers' knowledge about bees in Kenya (Kasina *et al.*, 2009a) noted that most farmers could not differentiate pollinators from pests. The farmers were reportedly applying pesticides indiscriminately to control the flower visitors, assuming they were all destroying crops. Another recent study (Kasina *et al.*, unpublished data) in Kenya indicated that farmers growing leading horticultural crops did not consider pollinators while managing crop pests. Foremost among the reasons given for not considering pollinators is lack of awareness about them and how to manage them. In East Africa, farmers' first source of information is the government extension services. However, in Kenya, extension officers themselves lack information about pollinators and how to manage them (Kasina, 2012), so the information is not being shared with farmers. Other East African countries share similar constraints.

In crop management, therefore, a knowledge system should be adopted in which pollinators are considered as part of farm practices. For example, national policies can be developed to support farmer education and instil in farmers a sense of responsibility for managing pollinators through proper use of pest control products. Pesticides are a major component of horticultural production. Farmers should be encouraged to use natural products; synthetic products should only be used when they cannot be avoided (e.g. when pest pressure surpasses threshold limits). In addition, government registration agencies for pest control products should ensure that product labels provide clear information for users on risks for pollinators and how to avoid direct poisoning. International trade regulations currently have a crucial role in the use of pest control products and adoption of IPM by small-scale farmers in East Africa, particularly in Kenya. EurepGAP (now GlobalGAP) procedures have revolutionized smallholder farming, especially among horticultural producers who target export markets, through enforcement of procedures that are friendly to pollinators and natural enemies.

Pollination and soil health. Soil management, long practised in East Africa, is one of the most important factors in crop production. While farmers understand the value of improving soil health to get more yields, they are not usually aware that some practices might affect pollinators in their fields. Several species of pollinators, particularly bees, make their nests on the ground where crops are growing (Photo 31). Such bees require soil of specific pH levels, which can be highly influenced by soil fertility management practices. For example, fertilizer application and incorporation in the soil may change the soil salinity status and affect the soil nesting bees, which require a specific soil PH range. In addition, the method of incorporation

Photo 31. **Ground-nesting bee entry tube, Kenya**

© B. Gemmill-Herren

(e.g. through tillage) may destroy nests, reducing bee populations. Suggested practices to avoid these impacts include target application of fertility products, e.g. on the base or the plant, or foliar application with drip irrigation. Organic fertilizers may have less impact on soil pH than chemical fertilizers.

Soil erosion management (stabilization of ground cover) may also play an important role in supporting pollinator life in agricultural systems, ensuring that bee nests are protected.

Pollination and weed control. Weeds are a major problem in horticultural production. Most smallholder farmers in East Africa manage weeds manually, tilling the land to physically remove weeds, whereas large enterprises commonly use herbicides, especially before planting.

However, weeds also provide bees with floral resources and thus can contribute to supporting bee life when crops are not in season. Thus economic assessment may be necessary to understand the best way to manage bees and weeds for the benefit of farmers.

One way of ensuring benefits from pollinators in a cropping system with low-level weed problems is the use of conservation agriculture, in which tillage is reduced to the minimum to eliminate soil disturbance as much as possible (thereby protecting soil-dwelling bees). This system also enhances soil water retention, which may favour bee presence since soil temperatures are thus kept lower than those of tilled land. In addition, slashing of flowering weeds ensures that they do not flower, which can reduce seed inoculum in the following seasons. Weeds that are important for pollinators can be maintained at the farm edges.

Pollination and water use. Water management is crucial in rainfed and irrigated crop production systems, which are both present in East Africa. Most production in the region has long been rainfed, and the unreliability of rainfall contributes immensely to low productivity. Thus the governments in the region are investing in irrigated agriculture to improve production. Flooding and flood irrigation may drown ground-nesting bees. Thus farms that have terraces to manage water movement may have enhanced presence of these bees relative to farms where water is not managed. Drip irrigation interferes only minimally with bee life, while sprinkler irrigation is better than flooding.

Other relevant crop management systems

A number of other practices may enhance pollinator presence on farms. For example, agroforestry, which combines annuals and perennials, including important wood/timber trees, provides year-round floral resources for pollinators since the different crops and trees flower at different times. In addition, the diversity of annuals and perennials ensures floral diversity and thus supports a diversity of pollinators at any given time of the year.

Hedgerows serve multiple purposes in East Africa (e.g. providing traditional medicines, browse or forage for livestock, fuelwood, border demarcation, windbreaks, aesthetic and security purposes) and can also be managed to conserve or augment pollinators on farmland. Hedges can support a high diversity of bees and/or other pollinators if they include diverse plant species that are known to provide the best resources for them. A recent study in Kenya showed a high diversity of bees in farm hedges (Mwangi *et al.*, 2012). For example, farmers in the Kerio Valley maintain and plant highly diverse hedgerows that include both nectar forage plants and host plants for hawkmoths (Lepidoptera: Sphingidae), which pollinate the dioecious papaya crop. Another indirect effect of hedges is the reduction of wind speed, which allows pollinators to fly with ease.

Semi-natural patches in farmland can provide pollinator habitats all year round. In some parts of East Africa, farmers have large tracks of land, and natural patches are always seen on the farm. These patches are not maintained specifically as a pollinator management practice, but it would be of benefit if farmers recognized their role in pollination management. Avoiding fires would be necessary to ensure the continued use of such habitats for pollinators.

Overall, plant diversity in hedges and semi-natural patches should be planned to provide a diversity of flowers supporting different pollinators, with overlapping blooming periods in a year and different shapes and colours. The area should also provide nesting sites for the bees (e.g. hollow wood, appropriate ground cover). In some areas, farmers have learned the importance of pollinators and have used such habitat management to manage them.

Challenges to the uptake of pollination management systems

Farmers require knowledge support to understand pollinators and their management practices. To this end, extension officers need to be equipped with such information. In East Africa, there is no policy on pollination management that may be used to bring information about pollinators to farmers and stakeholders.

Pest management in crop production also has effects on pollinator presence, especially in horticultural crops, which account for most use of pest control products. Farmers that do not consider bees while implementing their spray schedule generally lack awareness about the value of pollinators and cannot differentiate them from crop pests. However, farmers also depend on the information provided on the pest control product package to make decisions on when to spray and how to use the products. The information content on the label can be improved to include pollinator protection.

Another important challenge is the lack of tested pollinator management plans for crops grown in East Africa. Provision of such information to farmers, well packaged, would enhance conservation and protection of the pollinators.

7

MANAGEMENT OF AGROPASTORAL PRODUCTION SYSTEMS

Staline Kibet and
Pauline Nantongo

More than 80 percent of Kenya's land area is classified as arid and semi-arid, and pastoral production systems are the main human land use. Besides coexisting with diverse species of wildlife, pastoral production systems sustain significant ecosystem services within the rangelands such as nutrient cycling, seed dispersal, and maintenance of a heterogeneous ecosystem that supports high species diversity, among others. The role of agropastoralists in safeguarding and enhancing these ecosystem services is therefore paramount.

Many of the management practices in agropastoral production systems derive from farmers' traditional knowledge. This chapter examines both traditional and innovative practices used in the management of ecosystem services in agropastoral systems. It also addresses the benefits of, but also the challenges that agropastoralists face in, undertaking ecological practices.

Ecosystem services of agropastoral systems

Biodiversity

Communities living in marginalized regions of the world are keepers of biodiversity. They keep local breeds of animals and crops, some of these not yet described or documented by science. With climate variability and change, efforts to conserve this diversity are becoming more crucial than ever (FAO, 2009).

Most pastoral communities in general keep a mixture of species (e.g. camel, cattle, goats and sheep) not only to maximize utilization of range resources but also to spread risk from disease outbreaks or drought impacts, given that different species have different levels of susceptibility (Oba and Lusigi, 1987; Oba, 1994; Huho, Ngaira and Ogindo, 2011). Communities raise livestock breeds that are hardy, that are able to withstand unfavourable conditions and that can survive with minimal external inputs such as agrochemicals or supplemental feeds. In this way they promote biodiversity at the genetic, species and ecosystem levels.

Nutrient cycling

Pastoral mobility and establishment of corrals (*bomas*) in various part of the landscape is predicated by the need to secure quality pastures and water for livestock and at times to avoid conflicts, disease outbreaks or drought. Mobility plays a significant role in nutrient cycling within the ecosystem. After *bomas* are used for a number of years, they are abandoned for a new site. Abandoned sites are nutrient hotspots where nutritious grass and forb species preferred by both livestock and wildlife herbivores grow, contributing to maintenance of wildlife biodiversity (Augustine and McNaughton, 2004; Augustine *et al.*, 2011; Porensky *et al.*, 2013; Riginos *et al.*, 2012). In addition to ensuring the maintenance of a heterogeneous environment that supports high species diversity, pastoral mobility keeps in check potential woody species encroachment (Mancilla-Leytón, Pino Mejías and Vicente, 2012).

Seed dispersal and regeneration of forage

Contrary to common perceptions, pastoralists are not responsible for rangeland degradation, but rather promote regeneration of vegetation (Reid and Ellis, 1995). For example, the *boma* system promotes the regeneration of *Vachellia tortilis* (previously *Acacia tortilis*), a critical dry-season forage species in drylands. Animals feed on the pods; the seeds go through the animals' digestive system unharmed and are deposited in the dung accumulating in the *bomas*. The seeds readily germinate when enough moisture level is attained.

Practices that enhance the ecosystem services of agropastoral systems

Animal and landrace selection and breeding

Knowledge of selection and breeding of livestock rests with experienced elders. Irrespective of the species of livestock, the community selects individuals that possess certain traits, such as suitability for a given environment (available forage, water availability, temperature, parasites and disease pressure), high yield and/or ability to fulfil certain cultural requirements.

Prevention of soil degradation

Knowledge of soil properties influences its use as well as its management strategies. Agropastoral communities recognize the suitability of different soils for different species of livestock. The Borana pastoral community of Marsabit County, Kenya, for example, has traditionally classified rangelands into use types – "cattle country" (*laaf looni*), "goat country" (*laaf ree*) and "camel country" (*laaf gaala*) – based on the soil properties, the plant species present and farmers' traditional knowledge of the suitability of these for different kinds of livestock (Dabasso, 2006). The community recognizes the vulnerability of different soils to degradation, and therefore regulates the condition of the rangelands by changing the frequency and intensity of grazing.

Enclosures

Pastoralism is a complex form of natural resource management which requires maintaining an ecological balance between pastures, livestock and people, basically being an adaptive strategy for a stressful environment (Nori and Davis, 2007). Pastoral communities often house livestock in protective corral enclosures at night to keep them away from predators. Daytime attacks on livestock are rare because livestock are herded. Different communities have adopted different corral designs; however, all make use of thorny plants, especially *Vachellia* and *Senegalia* species (formerly considered *Acacia* species), for fencing. Some communities have attempted to use metal fencing for corrals and thus cause less degradation from tree felling, with mixed results.

A young Maasai boy recently invented a *boma* modification that has caused much excitement: the use of flashing lights attached to corral posts, timed to flash sequentially to mimic movement to scare away lions from attacking livestock in the corrals at night (Kermeliotis, 2013). In another *boma* innovation, a farmer in Yala, western Kenya, designed a livestock shed used not only to keep animals safe from raiders and rain, but also as a processing plant for farmyard manure (Photo 32). All the maize stalks and other crop residues from zero grazing units are used

Photo 32. **Modified cattle *boma* for housing cattle as well as processing farmyard manure**

© S.Kibet

as bedding for the cattle. The floor of the structure is cement so that leaching of nutrients is controlled. Once the crop wastes are fully mixed with dung and urine, they are taken to the farm for further curing before being applied to crops.

Thus innovations to the *boma* system have:

- reduced losses due to wildlife predation and minimized human-wildlife conflicts, enabling pastoral production systems to coexist side by side with wildlife conservation in many regions of Kenya (Western, Groom and Worden 2009);
- enhanced pastoral communities' ability to use the range evenly and to spread nutrients for maintenance of soil productivity, thus maintaining heterogeneous ecosystems that support high species diversity of flora and fauna.

Disease management

Pastoralists' use their indigenous knowledge of zoonotic diseases, such as malignant catarrh associated with the calving season of wildebeest (*Connochaetes taurinus*), to plan their grazing regime (Imbahale *et al.*, 2008), thus avoiding unnecessary deaths of livestock without resorting to the use of agrochemicals.

Fisheries production systems

In the Lake Victoria region, an innovative fishing trap locally called a *kira* is used to capture mature fish in shallow water. The trap is made using reed stems stuck into the mud in a maze design, along the lake shores during low tide. Fish are caught in the trap during high tide and are easily harvested when the water recedes at low tide (Kibet and Oyieke, 2009). A similar technology is used by fishing communities in coastal Kenya and is referred to as *uzio*.

The *kira* technology has a number of ecosystem benefits. The reeds re-establish vegetatively after they are stuck in the mud, thus controlling erosion from lake waves as well as from runoff during heavy rains. They also provide wildlife habitat and fibres for thatching houses and other uses. The technology promotes sustainable harvesting, as only mature fish are trapped in the *kira*.

A more recent innovation in fisheries production systems is the integration of poultry keeping with fish farming. Poultry housing units are built above fish ponds so that chicken droppings fall into the water, where they promote growth of algae and other aquatic plants that serve as fish food (Photo 33).

Photo 33. **Poultry house suspended above a fish pond to provide manure to aquatic plants**

© S.Kibet

Challenges and opportunities of appropriate range management

Pastoralists possess wide-ranging systems based on indigenous knowledge, which is not well valued in the current policy narrative in East Africa. More value should be given to farmers' knowledge in landscape mapping and planning, predicting change and monitoring changes in the landscape as well as in using the landscape.

In the conditions under which the pastoralists of East Africa derive their livelihoods, mobility of people and livestock is key to production, and it needs to be effectively protected and promoted. Herd mobility in indigenous range management is a traditional management strategy necessary to maximize livestock productivity in the spatially and temporally varying landscape of most rangelands. Mobility is critical if pastoralists are to make the best use of water and grazing in dryland areas.

Pastoral communities have clear governance processes allocating responsibilities for decision-making over control, use and access to resources. These processes are respected by all stakeholders since they are owned by the communities and decisions are based on consensus.

They need to be integrated into formal decision-making processes, including statutory laws. If livestock are to move freely across the range and between different grazing areas, the land must remain under some form of collective control, either through customary or government tenure arrangements.

Since pastoralists have traditionally lived under climate variability and adapted to extreme weather patterns, their practices can provide a basis for designing climate change adaptation initiatives.

Policymakers and other government officials have often viewed rangeland management from the perspective of conflicts and security. This mindset needs to be reoriented to a view of agropastoralism as a productive livelihood. To this end, capacity building will be necessary to improve policymakers' and local governments' understanding of the ecological dynamics, economics and sociocultural aspects of drylands. Such capacity building could focus on improving climate-resilient planning in dryland areas and using herder knowledge in seasonal forecasts for community and government planning.

Although there is evidence of gender-differentiated roles among the pastoral communities in East Africa, there is little evidence of the involvement of women in control over key political, economic and social factors of production and reproduction. Ways to provide positive support for women to participate in decision-making processes and to make customary decision-making processes more gender equitable need to be identified.

8

FARM-LEVEL MANAGEMENT: CROP, TREE AND LIVESTOCK INTEGRATION

Abigael Otinga

One way of increasing agricultural production to meet Africa's growing population while preserving habitats and other ecosystem services is to diversify farming systems through integration of crops with animals and/or trees. Diversified farming systems promote agrobiodiversity at multiple spatial and/or temporal scales in order to maintain ecosystem services that provide critical inputs to agriculture, such as soil fertility, pest and disease control, water use efficiency and pollination, thus reducing the need for off-farm inputs (Kremen, Iles and Bacon, 2012). Ecosystem services are generated and regenerated within a diversified farming system; the resulting social benefits in turn support the maintenance of the system, enhancing its ability to provide these services sustainably. These aspects have been incorporated in the principles of agricultural systems for a long time. Diversified or integrated farming could pave the way for more sustainable use of ecosystem services in providing food while conserving the environment for future generations.

Integrating crops, trees and livestock can enhance environmental resilience through biological diversity, increase water infiltration and control of runoff and erosion, improve nutrient cycling and soil health, and contribute to adaptation and mitigation of climate change (FAO, 2010a). From the economic point of view, such integrated systems enhance livelihood diversification and production efficiency through optimization of inputs (e.g. labour). From the sociocultural perspective, they can help farmers to meet their livelihood aspirations, promote equitable social dynamics (particularly for elders, women and youth) and increase nutrition security.

This chapter examines the opportunities of integrating farming systems in East Africa to produce food sustainably while conserving habitats. It looks at the outcomes of some integrated farming systems, analysing how their components interact and their potential for sustainable food production and enhancement of ecosystem services. Cases are drawn particularly from Kenya and the United Republic of Tanzania.

Types of diversified or integrated farming systems

Integrated farming systems include various combination of crops with trees, crops with livestock, and crops with trees and livestock. Other integrated systems include agropastoral systems with or without trees, landscape level sectoral activities that require functional re-integration of components and smallholder systems that include animal traction (FAO, 2010a).

Agroforestry: integration of trees in agricultural systems

One of Africa's largest challenges is deforestation, which strips the soil of minerals, reduces water supply and threatens food security in a region largely dependent on small-scale agriculture. Deforestation also contributes to climate change, which is altering the planet's weather patterns. Currently, the deforestation rate in Africa is four times that of the world (AWF, 2015). Agriculture has also been criticized as an important contributor to deforestation when forest land is cleared to pave way for crop production. While increased food productivity in other parts of the world has resulted from higher yields per unit of cultivated area (Nziguheba, 2001), in sub-Saharan Africa it has depended on the expansion of cropped land (Borlaug and Dowswell, 1994). Traditional agricultural systems depended on shifting cultivation to maintain food security. Consequently, 4 million ha of forest were cleared annually (Quinones, Borlaug and Dowswell *et al.*, 1997).

Perhaps the biggest loser when forests are cleared for agricultural production is biodiversity. Clearing of forests for agricultural intensification affects biodiversity directly through continuous destruction of natural habitat of organisms and through negative environmental effects of intensive agriculture such as toxification from pesticides and fertilizer and generation of greenhouse gases from fossil fuels. This scenario depicts a gloomy picture for humankind, yet food production has to continue if the world is to feed its projected population of 9 billion in 2050. Research has shown that the persistence of numerous organisms living within protected areas or natural habitats depends very much on the habitat outside these areas, in other words the matrix of surrounding landscape, which in most cases is under agriculture. A coherent approach to biodiversity conservation therefore needs to incorporate management of the agricultural areas. Integrating crops, livestock and trees can provide such an opportunity, and it is now more important than ever for agriculturists and foresters to work together.

Agroforestry is defined as "the inclusion of trees in farming systems and their management in rural landscapes to enhance productivity, profitability, diversity and ecosystem sustainability"; the term "describes practices developed and employed by farmers over many centuries to cultivate trees on farmland in different combinations with crops and livestock" (ICRAF, 2013). Farmers have practised agroforestry to provide shade; to permit a steady and diversified supply of food and income throughout the year; to protect soils, springs and watersheds; to arrest degradation and maintain soil fertility; to enhance efficiency of the use of soil nutrients, water and radiation; and to provide regular employment (Rao, Verchot and Laarman, 2007; Jamnadass *et al.*, 2013). Agroforestry also supports other ecosystem services such as pollination and carbon sequestration and storage. Jamnadass *et al*. (2013) outlined the role of agroforestry in supporting food and nutritional security, demonstrating that agroforestry contributes greatly in alleviating poverty and food insecurity in developing countries. Agroforestry directly provides tree foods such as fruits and leaves and supports production of staple crops. These systems enable farmers to increase their incomes through the sale of tree products such as timber, charcoal and plywood as well as fruits and surplus food produced. In subsistence agriculture, they provide fuels for cooking such as charcoal and fuelwood. Agroforestry systems are also potential sources of biofuel.

Kitalyi, Wambugu and Kimaro (2013) identified seven traditional agroforestry systems in Kenya: the intensive agroforestry systems of central Kenya; Taita agricultural landscapes; Ameru agroforestry systems; the traditional furrow irrigation system of the Marakwet; the Amaya irrigation system in Samburu; the Ngebotok irrigation system in Turkana County; and agropastoral and fishing systems of the Ilchamus of Baringo County. The communities in Kenya's Central Highlands have had a unique traditional agroforestry system which has been important in meeting their diverse needs and protecting their sloping terrain. From time immemorial these communities have incorporated crops, livestock and trees on the same piece of land, using a system in which the upper layer is dominated by trees, the middle layer by shrubs, bananas and fodder shrubs, and the ground layer by annual crops and grasses (e.g. maize, beans, Napier grass and root crops) (Photo 34). The crops are chosen carefully to reduce competition. The tree species include *Cordia africana*, *Grevillea robusta*, *Commiphora zimmermannii* and *Trema orientalis*.

Photo 34. **Different components of an integrated cropping system provide many benefits**

© A. Otinga

Beginning in the 1990s, various research and development agencies (e.g. the Swedish International Development Agency [SIDA], the German Agency for Technical Cooperation [then GTZ, now GIZ], the Kenya Woodfuel and Agroforestry Programme [KWAP] and FAO) began to team up with government agencies to promote agroforestry practices in Kenya. The challenges faced in promotion of agroforestry include lack of access to tree germplasm of good or at least adequate quality, especially for indigenous trees; lack of knowledge and skills in germination and management of agroforestry species; and low investment by government and NGOs in germplasm multiplication. The opportunities include private landownership, which offers incentives for tree planting, and increased global attention to climate change (Kitalyi, Wambugu and Kimaro, 2013).

Integrated crop–livestock systems

Iiyama, Kariuki and Maitima (2007) characterized crop–livestock diversification patterns in Keiyo District in the Rift Valley, Kenya. They found five dominant crop–livestock diversification patterns, based on the analysis of their main components: maize and indigenous cattle; improved (exotic) cattle and fruits; extensive crop production; sheep and goats; and dairy goats. The degree of integration among crop types determined the intensification of manure use. The pattern of improved cattle and fruits was found to be associated with more intensive manure use and higher household income, and thus demonstrated greater inherent incentive for mutual intensification for enhanced human welfare and environmental sustainability. The crop–livestock diversification pattern of staple crops with or without indigenous cattle provided little incentive to apply manure, because the indigenous cattle were extensively grazed on open commons and their dung was difficult to collect. The authors concluded that the pattern of improved cattle and fruits is economical in the long term, but that it may not be practical to recommend it to farmers in the short term because it requires high capital outlay and appropriate support for technology transfer.

Contribution to household incomes

Integrated farming systems increase yields of the individual components and consequently farmers' incomes. A study of the effects of fodder shrubs on milk production and on their value at household and regional levels indicated that 6 kg of fresh shrubs resulted in a mean increase of 0.7 kg of milk per day. The fodder crops were used for fuelwood, improved animal health, control of soil erosion, fencing, improved creaminess of milk, improved soil fertility and revenue generation from the sale of seedlings and stakes. It was estimated that between 1993 and 2008, the annual impact to dairy farmers adopting fodder shrubs in Kenya ranged from US$ 29.29 – US$29.6 million. The use of fodder shrubs spread throughout the region to just over 200 000 smallholder dairy farmers by 2005, although not all of these used the shrubs for fodder (Place *et al.*, 2009).

Franzel and Wambugu (2007) found that substituting dairy meals with *Calliandra* increased farmer's net income by about US$ 101, and by US$ 122 in the second year when 500 calliandra shrubs were planted. In general, farmers with 500 *Calliandra* shrubs increased their net income by between US$62 and US$122 depending on whether they used it as a substitute or a supplement and depending on where they were located. The authors highlighted five elements that are critical in the successful dissemination of such technology: promotion of fodder shrubs by large NGOs; training of trainers and support to extension workers to facilitate dissemination; farmer-to-farmer dissemination; availability of seeds through private seed vendors; and civil society campaigns that bring together a range of different stakeholders to sensitize and train farmers.

Ecosystem services of integrated farming systems

Resilience of agricultural systems

It has been argued that an integrated crop–tree–livestock system enhances the resilience of an agricultural system. When trees are integrated in a cropping system, competition among the various components of the system for nutrients, water and sunlight is a concern. However, Lott, Ong and Black (2009) indicated that resource capture was increased in agroforestry systems. According to these authors, trees suffer competition from the crops during the initial phases of growth, but eventually they become the dominant component and help buffer understorey crops against climatic extremes, reducing their transpiration rates and minimizing water stress. These potential benefits are not realized when below-ground competition is severe. Deciduous and semi-deciduous trees offer temporal complementarity and thus provide a better solution to below-ground competition because of the asynchronous demand for resources by trees and crops due to their differing leaf phenologies. The trees do not initially compete with the understorey crops but may benefit them by providing partial shade and increasing soil organic matter and fertility. A study on the influence of evergreen *Grevillea robusta* and deciduous *Alnus acuminata* and *Paulownia fortunei* on understorey maize crops at sites in Naro Moru and Thika, Kenya, showed that maize yield reductions in agroforestry systems associated with *P. fortunei* were minimal (Muthuri *et al.*, 2005). Interestingly, the agroforestry systems based on *P. fortunei* performed better during short rains, as this was when the trees shed their leaves. In an earlier study, Muthuri *et al*. (2004) concluded that contrary to what was believed, agroforestry trees did not necessarily reduce the water uptake of crops.

Other systems incorporate different crops that benefit mutually from each other. Wairegi *et al*. (2014) observed that banana provided shade for coffee, and the shade was beneficial in reducing stresses caused by extreme temperatures and strong winds. Moderate shade of less than 50 percent was found of help in reducing occurrence of overbearing dieback and losses caused by drought in coffee. Banana provided mulch that improved root development in both banana and coffee and improved availability of potassium in the topsoil. The permanent canopy and root systems of banana reduced the impact of rainfall on the topsoil, hence reducing soil losses due to erosion and surface wash. In conclusion, these authors found that when the soil fertility was poor, coffee grown under shade yielded better and was a more resilient system than coffee grown without shade.

Nutrient use efficiency. According to Lehman *et al*. (1998), agroforestry systems exhibit higher nutrient use efficiency since they help in nutrient retrieval and reduction of nutrient leaching. One of the key factors for effective nutrient recycling is the spatial and temporal nutrient uptake patterns of trees. To achieve a positive balance of nitrogen, phosphorus and potassium, at least part of the harvested biomass such as leaves and branches should be returned to the system through mulching. However, Lehman *et al*. (1998) observed that the system could not recycle enough nutrients in the short term for maximum crop production. In comparison with a crop monoculture, the lower leaching losses in the agroforestry system could not compensate for the additional nutrient export in tree biomass. A nutrient return through mulching with crop residues and acacia leaves was essential for a positive nutrient balance in the agroforestry system. Combining annual and perennial crops provided higher internal nutrient cycling than the monoculture.

Carbon sequestration. A review of the carbon sequestration potential of tropical agroforestry systems in various parts of the world (Albrecht and Kandji, 2003) noted that agroforestry, if adopted on a global scale, could help to remove between 1.1 and 2.2 petagrams (Pg) of carbon from the atmosphere over the next 50 years.

Reduced use of agrochemicals. In agriculture, a healthy agro-ecosystem devoid of large external applications of inorganic pesticides and herbicides is desirable. Research into biological control (methods using minimal external inputs or none at all to manage pests and diseases) should be given attention. An example of a system that controls pests biologically is the "push-pull technology" described in Chapter 2. However, while this technology provides high and robust economic benefits to smallholder farmers in western Kenya, it requires relatively high labour investment, both for establishment and for maintenance during subsequent seasons (Kifuko-Koech *et al*., 2012).

Kifuko-Koech *et al*. (2012) tested a modified push-pull technology involving intercropped maize with two *Desmodium* species, *D. uncinatum* and *D. intortum*, but without Napier grass, at two sites in western Kenya to check the effect of different cutting regimes of the fodder crops on soil fertility improvement and consequent crop (maize and fodder) yields, *Striga* management and economic benefits. The study found that with *Desmodium* intercropping, cumulative maize grain yield over four seasons was significantly higher than or comparable to that of a maize monocrop (Table 11) (Photo 35). Average net benefits were also higher with *Desmodium* intercropping. Biomass yields were significantly higher for *D. intortum* than for *D. uncinatum*. Varying the time of the third *Desmodium* cutting had little effect on *Desmodium* biomass yields or maize grain yields in Busia, while in Siaya, *D. intortum* biomass yields were highest when cut 12 weeks after planting. In the *Desmodium* intercropping systems *Striga* counts were significantly reduced; in Siaya, the reductions were greater when the legume plants were cut 18 weeks after planting.

In the region around the Lake Victoria basin, it was found that intercropping bananas with sweet potatoes reduced the incidence of the root lesion nematode (*Pratylenchus goodey*).

Photo 35. **Maize at maturity in the intercrop**

© A. Otinga

Table 11. **Benefits of a push-pull system involving *Desmodium* spp. intercropped with maize**

SITE	MAIZE GRAIN YIELD[a] (tonnes/ha)			INCREASE IN AVERAGE NET BENEFITS FROM *DESMODIUM* INTERCROPPING[b] (US$/ha)	REDUCTION OF *STRIGA* COUNTS WITH *DESMODIUM* INTERCROPPING (%)
	With *D. intortum* intercrop	With *D. uncinatum* intercrop	Maize monocrop		
Busia	6.3	7.0	5.8	1 290	95
Siaya	10.9	11.6	11.8	918	65–90

[a] Cumulative over four seasons
[b] Relative to monocrop, over four seasons

Source: Based on Kifuko-Koech, 2012

Soil fertility. Both non-nitrogen-fixing shrubs and nitrogen-fixing shrubs can be used to improve fertility in agroforestry systems, albeit with varying degrees of success.

Research in western Kenya showed that the use of *Tithonia diversifolia* green manure resulted in higher production of vegetables and maize than the use of inorganic fertilizers (Mwangi and Mathenge, 2014). This benefit was confirmed in research comparing *Tithonia* spp. and chicken manure with inorganic sources of nitrogen (calcium ammonium nitrate, ammonium sulphate nitrate and urea) in Nyeri County (Mwangi and Mathenge, 2014); kale grown with *Tithonia* spp. outperformed kale grown with all the other sources of nitrogen. In addition, *Tithonia* spp. ameliorated soil acidity, increasing soil nutrients. However, Mwangi and Mathenge (2014) noted that the use of *Tithonia* spp. could not be adopted easily because the plants were not available during the traditional planting time. They recommended, somewhat unrealistically, that the government provide land for production and processing of *Tithonia* spp. into pellets and advocated that poultry farmers use the manure on their farms. Jama *et al.* (2000) concluded that *Tithonia* spp. represented the best option in production systems of high-value vegetables but not of cereals; however, they noted that if applied at low rates, this green manure can be profitable in maize production systems.

Rao and Mathuva (2000) found mixed systems based on pigeon pea to be more profitable since they required less labour for cultivation and were less risky in the occurrence of drought. They concluded that in the semi-arid tropics, cropping systems based on grain legumes are more profitable, in terms of returns to land and labour, than continuous cropping of cereals with or without green manuring and hedgerow intercropping. They also concluded that legume-based cropping systems should be attractive in a wide range of situations since the legumes are drought tolerant and command two to four times the price of maize, making such a system useful in case of drought.

Mutegi *et al.* (2008) found that *Calliandra* spp. and *Leucaena* spp. increased the inorganic nitrogen levels in the soils in relation to the control. The increase was attributed to the ability of the two leguminous shrubs to fix and recycle nitrogen as well as to prevent nitrogen leaching. *Calliandra* spp. and *Leucaena* spp. increased maize yields but did not help to reduce soil erosion significantly in the first year. Napier grass was the most effective in controlling soil erosion in the first year but did not increase maize crop yields. A combination of either *Calliandra* spp. or *Leucaena* spp. with Napier grass provided the best win–win scenario for reducing soil erosion, improving soil fertility and enhancing crop yield.

Tittonell *et al.* (2009) noted that integrated crop–tree–livestock systems improve soil fertility because they generate manures and composts. They found that livestock management can have a large impact on the recycling of nutrients and on the efficiency of nutrient use at farm scale, provided that enough nutrients are present in, or enter the system to be redistributed. Increasing nitrogen by 25 to 50 percent through improved manure handling could improve nitrogen cycling efficiency.

Biofuel. Biofuel crops planted in Kenya include castor (*Ricinus communis*), croton (*Croton megalocarpus*) and jatropha (*Jatropha curcas*) (Obiero *et al.*, 2013). While monocropping is the preferred cropping system for these biofuel crops, it may prove environmentally unsustainable in terms of soil and biodiversity degradation. Some farmers intercrop biofuel crops with food crops, and castor and croton are sometimes grown in fence and boundary cropping systems. Most of the farmers interviewed by Obiero *et al*. (2013) preferred growing jatropha together with maize, cowpea, common beans and green gram, while castor was grown together with maize, beans and Irish potato. With croton, Irish potato was the preferred intercrop and to a lesser extent maize. Most of these farmers did not apply fertilizers to biofuels, but those who did preferred manure, mostly with jatropha. This study indicated that intercropping of biofuels may augment smallholder farmers' income, but it may also have a negative impact on the growth and yield of both the biofuel crop and the companion food crops, aggravating rural food insecurity. The authors concluded that there is need for further research on the dynamics of the intercropping systems of the different biofuel and food crops.

Obiero *et al*. (2013) indicated that most of the farmers in the surveyed areas were planting croton, because an existing local biodiesel factory was purchasing and processing seed from the farmers, and jatropha, because it had been a subject of lobbying from the government and NGOs. Fewer farmers were planting castor, possibly because of a lack of promotion of castor or of a ready market for it.

Increasing yield of integrated crop–tree–livestock systems

Mwangi and Mathenge (2014) evaluated ways of promoting integration of herbaceous forage legumes into a Napier grass fodder system with the aim of increasing forage quantity and quality on smallholder dairy farms in central Kenya. The herbaceous legumes *Desmodium intortum* cGreenleaf (ILRI 104), *Macrotyloma axillare* cAxillare (ILRI 6756) and *Neonotonia wightit* cTSnaroo (ILRI 9794) were intercropped with Napier grass and evaluated for yield and quality (chemical composition and digestibility) of the fodder at two harvesting frequencies (8 and 16 weeks) and two cutting heights (0 and 10 cm above ground). Only *D. intortum* competed successfully with Napier grass, reducing the dry matter yield of the grass. Because of the large forage contribution of *D. intortum* (15 750 kg per ha), the Napier grass–*D. intortum* mixture had significantly higher total forage dry matter yield (45 910 kg per ha) than the mixture with *N. wightii* (38 840 kg per ha). Increasing the cutting interval from 8 to 16 weeks gave significantly higher grass dry matter yield but decreased nitrogen concentrations (from 11.3 to 8.9 g per kg dry matter for Napier grass and from 21.2 to 18.8 g per kg dry matter for legumes) and reduced legume yields.

Njoka-Njiru *et al*. (2006) carried out an experiment in eastern Kenya to investigate the contribution of two legumes, seca (*Stylosanthes scabra* cv. *Seca*) and siratro (*Macroptilium atropurpureum* cv. *Bana*), to seasonal total fodder productivity and nutritive value when intercropped with Napier grass. They planted Napier grass as a pure stand and intercropped with the two legumes. They found no consistent beneficial effect of legumes on dry matter yield because of rainfall variation. The beneficial effect of the legumes increased with increase in rainfall; the leguminous plants used in the short rains depressed dry matter of Napier grass. According to these authors, intercropping legumes with Napier grass produces forage with higher crude protein and low fibre content, and thus increased nutritive value and digestibility.

Mureithi *et al.* (1998) found that livestock feeds mainly comprised natural pasture grasses and broadleaved weeds (60 percent and 75 percent during the wet and dry seasons, respectively), which were of poorer quality than the introduced forages. The introduced forages were used to different degrees depending on the agroclimatic zone, but they contributed less than 40 percent and 25 percent of dairy cattle feeding during the wet and dry seasons, respectively. Farmers knew that the introduced forages had higher nutritional value but preferred to plant maize for food security.

In a study carried out in Burundi, intercropping bananas, *Grevillia robusta* and beans resulted in an increase in wood volume of *G. robusta* after three years (Ouma, 2009).

Opportunities and challenges in promoting integrated crop–tree–livestock systems

Traditional agricultural heritage systems incorporating crop, livestock and agroforestry components (often inadvertently) have proved able to sustain the livelihoods of the communities that implement them; nevertheless, they have not been well characterized (Kitalyi, Wambugu and Kimaro, 2013). To understand the opportunities and challenges of using an integrated farming system, adequate knowledge of the individual components would be of great help.

Dissemination of information on integrated crop–tree–livestock systems is important for their uptake and use by farmers. Passing of information is influenced by many factors, including age, education, gender and wealth status. Sinja *et al.* (2004) evaluated the farm and farmer characteristics that influence farmer-to-farmer extension in central Kenya with the aim of identifying the type of farmers that can disseminate fodder legume technologies. They found that individuals in leadership positions were most able to disseminate information and materials effectively, as they interacted with many people. They also found that farmers with more goats were more likely to give away *Calliandra* seeds, but the more cattle farmers had, the less likely they were to give away *Desmodium* plants (Photo 36).

The amount of *Desmodium* spp. on the farm had the greatest influence on both the extent and probability of farmers sharing them, because these species are propagated vegetatively and farmers needed to keep enough for themselves. On the other hand, time influenced the transfer of *Calliandra* spp. between farmers, because it must be mature to produce seeds. The farther farmers were from roads and markets, the higher the likelihood of their sharing materials. Age and education had no significant effect in sharing of *Desmodium* or *Calliandra* species, probably because older farmers were not active in farmer group meetings or in interacting with others to share information. The educated farmers preferred to use concentrates and termed the use of fodder legumes as a bother.

Photo 36. **Greenleaf *Desmodium intortum* leaves**

© A. Otinga

Appiah and Pappinen (2010) noted that in recent decades, farm forestry has been promoted locally in Kenya through pilot projects, but its adoption has been limited outside the project locations because farm forestry improvement measures have focused mainly on biological concerns (e.g. succession, biodiversity, traditional industrial timber production) and technical aspects (e.g. material input delivery such as providing free tree seedlings for field planting) rather than local values and interests and the constraints facing farmers. These authors examined local farm priorities and constraints and prospects for the wider implementation of farm-level tree planting in four communities in Rachuonyo District, Kenya. They showed that farm labourers were mainly young (56.3 percent under the age of 40) and were engaged in small-scale mixed cropping integrated with multipurpose trees and some livestock. Tree products contributed about 32 percent of household cash income, more than any other source (e.g. agricultural products, labour sales). Farmers preferred exotic tree species because of their ability to provide short-term cash income, fuel and shade. Farmers' concerns included population pressure on limited farmlands and credit for agricultural inputs. Given their secure tenure arrangements and the influence of tree products on the household economy, farmers were willing to make long-term investments, but they were more likely to invest in efficient land uses such as farm forestry if consideration was given to local priorities. Notably, women headed more households than men and had considerable influence over productive activities (including the types of crops to be grown and resource allocation), thus representing an important target group in farm forestry development. In this aspect the study area contrasted with the situation in many developing countries, where women are precluded from having direct control over land, production activities and agricultural decision-making.

Community involvement is critical in promotion of integrated farming systems. Ng'endo *et al*. (2013) described a land rehabilitation initiative involving soil conservation, trees, apiculture and soil fertility management in which the community was given a central role in identifying constraints, prioritizing felt needs and devising a community action plan, complete with schedules and frameworks for proposed incentives. The benefits derived included individualization of land tenure, reduced nomadism, improved animal health and increased enrolment in schools. Ng'endo *et al*. (2013) attributed the success of Vi-agroforestry, a Swedish development NGO in West Pokot, Kenya, to its policy of cooperation with the people and local development partners.

It is clear from these examples that reaping maximum benefits from an integrated crop–tree–livestock system requires a platform for all relevant stakeholders within the community to engage in the process. In addition, successful uptake requires enabling conditions such as governance, gender synergies, secured land tenure, investment and markets for inputs and outputs (Mbow *et al*., 2014).

Many farmers may see such a system as labour intensive, but they may eventually adopt the system if they are continuously educated on its benefits and observe them directly.

9

FARMERS' TRADITIONAL KNOWLEDGE AND INNOVATION

Staline Kibet and
Pauline Nantongo

In East Africa, farmers' traditional knowledge, and innovations based on this knowledge, are vital resources contributing to ecological management of agro-ecosystems and minimized use of external inputs.

Farmers' knowledge consists of tacit knowledge obtained from experiential learning and/or explicit knowledge gained from more formal training and/or reading. Farmers' innovations have largely been inspired by indigenous knowledge and enriched through integration with scientific knowledge systems.

Traditional ecological knowledge is a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment (Berkes, Colding and Folke, 2000).

Indigenous technical knowledge concerns technologies, skills or strategies that developed *in situ* in response to people's needs. An example is the ability to predict weather patterns based on biotic indicators such as insect and bird movement, plant phenology or non-biotic indicators (e.g. wind movement and direction) – a useful skill enabling farmers to time agricultural activities (e.g. land preparation, planting, harvesting). Many innovations are based on traditional knowledge; some examples that have been successfully adopted and scaled up include bio-extracts, "emerging" crops, "push-pull" technology (see Chapter 2) and selection of local crop landraces.

In addition, some farmer innovations in selecting and breeding certain varieties of crops or breeds of animals have been inspired by cultural values, tastes or traditions concerning the use or manufacture of particular plant or animal products, which may lead farmers to maintain diversity within species (Maundu and Morimoto 2008). Similarly, food cultures among many communities in Kenya have led to adoption and cultivation of certain landraces for subsistence and tradition (e.g. for dowries) in addition to main crops grown for markets. In these examples, knowledge has been preserved and biodiversity conserved through generations by communities' cultural value systems. Agrobiodiversity in smallholder home gardens is attributable to "traditional" crops serving societal nutritional and cultural needs. Most of these crops are organically grown with no or minimal external inputs such as inorganic fertilizers, pesticides or herbicides.

This chapter looks at the contributions of indigenous knowledge to agro-ecosystem management in East Africa, particularly Kenya, as well as its contribution to management innovations. The chapter also considers benefits and trade-offs that influence uptake and upscaling of traditional knowledge-based practices and innovations.

Contribution of farmers' traditional knowledge to agro-ecosystem services

Biological diversity

Conservation of crop landraces is common on smallholder farms in Kenya. Many communities prefer local crop landraces to hybrid varieties supplied by seed companies because they are cheap and easily accessed; mature early; are adapted to prevailing soils and climatic conditions and therefore ensure harvest even under unpredictable weather; give better yields with limited use of inorganic fertilizers and other inputs; are highly resistant to both field and storage pests (as compared to high-yielding varieties); and have better product qualities (e.g. they taste better, are more filling, are easy to dehusk without breakage) (Achiando, 2012; Bellon, Gotor and Caracciolo,2015; Maundu and Morimoto, 2008).

Alongside food values, cultural values are also credited for the on-farm conservation of a number of crop landraces in Kenya. A rich biological diversity is often associated with a rich knowledge of its uses, and the loss of any variety or landrace creates a disconnect that renders such knowledge of little value, leading to its erosion and final loss (Maundu and Morimoto, 2008). For example, among the Kamba, Mijikenda, Luo and Luhya ethnic communities in Kenya, elderly women hold the responsibility of selecting the best seeds for the next planting season (Achiando, 2012; Swiderska *et al.*, 2011).

Knowledge of soil taxonomy and uses

In central Kenya, Mairura *et al.* (2008) observed that farming communities over the years have developed the knowledge and skills to identify not only fertile and non-fertile soils but also suitable crops to grow in each soil type. Based on this knowledge, communities in the region grow maize (*Zea mays*) and beans (*Phaseolus vulgaris*), which have high staple and economic value, in fertile soils, while in poor fields they grow fodder crops (e.g. Napier grass [*Pennisetum purpureum*]), low-value crops (e.g. cassava [*Manihot esculenta*]) or sweet potatoes (*Ipomoea batatas*), which do well in less fertile soils. Similarly, as described in Chapter 7, agropastoral communities recognize the suitability of different soils for different species of livestock.

Farmers in Machakos County, Kenya used their knowledge of soil taxonomy and uses in developing soil management innovations to cope with high soil erodibility and low fertility, such as hedging, fencing, bush and indigenous tree management and scratch ploughing (Tiffen, Mortimore and Gichuki, 1994). Farmers of the Giriama ethnic group practise minimum tillage to reduce the intensity of disturbance so as to conserve soil and water. They clear land by hand using simple tools such as machetes or fire, and then dig planting holes using a small traditional hoe, locally called *kiserema* (Achiando, 2012).

Pest and disease management

Farmers have built on their traditional knowledge to innovate ways to control both field and storage pests. Examples from various parts of Kenya include the use of plant extracts, cow dung and ashes to control pests (Achiando, 2012; Mihale *et al.*, 2009), the use of the *umuomo* termite trap by the Luhya community (Photo 37) and the maize drying technology used by the Kikuyu community in the Kieni area of Mount Kenya (Nyeri County) to avoid post-harvest losses.

Termites are a big problem for farmers in western Kenya, and the *umuomo* trap is an ingenious innovation. The trap is made of fresh leaves of *Dracaena* sp. Inside are maize stalks bound together using a nylon string to make a cone-shaped structure, locally referred to as *umuomo*.

Photo 37. **Termite trap (*umuomo*) used in western Kenya**

© S.Kibet

This structure is set on the termite mound and fastened to the ground with a stick inserted through the centre of the cone. The fresh leaves used to cover the maize stalks create darkness inside the cone. The termites invade the trap to feed on the maize stalks inside; they do not eat the outer leaves because they prefer the dry maize stalks. After three days, when the trap is full of termites, it is removed and used to feed chickens or quails.

Kikuyu farmers in Naro Moru have innovated unenclosed structures for drying maize to avoid post-harvest losses from aflatoxin and pests such as weevils (Photo 38). Use of ordinary granaries can encourage mould growth if the stores are not properly designed. Furthermore, weevils prefer sheltered places for warmth. In the system shown in Photo 38, many of the flying weevils blow away on windy days. Another method for avoiding insect infestation in maize is to select large cobs and place them above the fireplace, where the smoke controls the insects. Some members of these communities store seeds in clay pots in mixture with ashes to prevent post-harvest pest attack (Nyamwamu, Shiundu and Kibet, 2005).

Photo 38. **Maize drying technology used in Nyeri County, Kenya**

© S.Kibet

Benefits and trade-offs of traditional knowledge and technologies

Learning from farmers' traditional knowledge and upscaling related technologies and innovations can offer a variety of benefits.

Social benefits include enhanced persistence of cultural values. In addition, the social value of traditional knowledge can be used to create "social pressure" to encourage upscaling of innovations based on it (e.g. ecotourism). Such social pressure resulted in a government policy review that legalized the burning and sale of charcoal made from *Prosopis* spp. (Chengole *et al.*, 2014).

Economic benefits have also resulted – for example, through ecotourism and charcoal in the examples above. Agronomic benefits include improved soil structure and fertility through the use of farmyard manure (thus reducing the reliance on inorganic fertilizers) (Roba, 2013); erosion control and improved soil pH through growing of *Suaeda monoica* in alkaline soils; and reduced losses to pests and diseases through the use of biopesticides.

Environmental benefits are also numerous. Preserving on-farm biodiversity enhances the provision of ecosystem services. Integrated soil fertility management and conservation agriculture, cross-slope barriers on sloping lands in the form of earth or soil bunds, *fanya juu* terraces, stone lines and vegetative strips – all methods based on traditional knowledge – reduce runoff velocity and hence control soil erosion (Smalling, 1993; Tiffen, Mortimore and Gichuki, 1994). The use of local crop landraces with minimal requirements for external agrochemical inputs is beneficial to the environment.

Trade-offs, on the other hand, include resilience at the cost of high yield. Local crop landraces are well adapted to local conditions and require minimal external inputs; this is not true of high-yielding varieties. The opportunity costs of maintaining diversity may increase and/or market niches may disappear as bulk markets become dominant; this tends to support increased specialization in one variety, as farmers reach a new equilibrium with a smaller number of crop varieties (Bellon, Gotor and Caracciolo, 2015). Monocultures offer ease of mechanization as well as bulking. As an example of a cost–benefit trade-off, *fanya juu* terracing is effective in controlling soil erosion and enhancing crop production but is labour intensive to develop and maintain.

There are also negative externalities to consider. For example, *Jatropha curcas* is often used as a live hedge to protect crops from animal damage and to conserve soil and water in semi-arid environments in Kenya. The species is hardy and can survive well in areas with unreliable rainfall. It is deciduous and therefore helps in accelerating the soil nutrient cycle through leaf litter. Unfortunately, *J. curcas* is known to harbour crop pests, especially those associated with cassava (e.g. cassava superelongation disease, *Sphaceloma manihoticola* [teleomorph *Elsinoe brasiliensis*]) (Heller, 1996).

Practices based on traditional knowledge: case study

This section examines the agropastoral practices of the Karamajong (Uganda) and Borana (Kenya), which provide an excellent example of how traditional practices and knowledge contribute to the healthy functioning of ecosystem services and support the role of ecosystems in reducing people's vulnerability to external factors.

For centuries, pastoralists have demonstrated tremendous ability to cope with climate variability, often employing sophisticated and continually evolving adaptive processes and practices to take advantage of new opportunities (Wasonga *et al.*, 2012). A key characteristic of the livelihood system of pastoral families is the maintenance of an optimal balance between pastures, livestock and people in a highly uncertain and variable environment, to meet both their immediate and future livelihood needs. The ability to maintain this balance within acceptable limits is based on complex social, economic and environmental strategies. Pastoral communities have developed a wealth of indigenous knowledge and practices which they apply in the management of landscapes and vegetation. Their application of indigenous ecological knowledge in designing strategies focuses not only on adaptive measures to ensure herd health and herd well-being, but also on ensuring sustained resilience of ecological resources.

Indigenous knowledge of range management is defined in terms of space and time (Oba, 2009). Spatially, livestock grazing movements may be organized at multiple scales, involving movements of the herds between different agro-ecological zones and fine-scale movements between heterogeneous landscapes. The pastoral space may also include political landscapes, which the communities negotiate in order to respond to variable rainfall and risk of droughts, for example when groups access resources outside their traditional resource borders or across international political boundaries. Time as a management variable is related to social functions, including rituals, movement of herds, season of rains, dry season and drought periods. Time is also important for building management skills and understanding of the ecology of indigenous range management.

This case study illustrates how traditional knowledge and practices of the Karamajong of Uganda and the Borana of Kenya support their adaptation to climate change and enhance the resilience of ecological resources. The focus is not just on land and landscapes, but on functioning ecosystems. In addition to management practices, social and institutional practices related to the regulation of rights of access and the use and control of livelihood resources are also examined.

Management practices that enhance the resilience of ecological resources and contribute to adaptation to climate change

Range classification. The pastoral ecosystems in East Africa are endowed with diverse grazing landscapes. In Karamoja, for example, they vary from marshes to dry valleys and uplands. The herding range in the landscapes of Karamoja is classified into drought reserves, wet-season grazing areas and watering points. Livestock grazing is geographically distributed in terms of the mountain grazing lands allocated to the dry season and the plains grazed during the wet season (Oba, 2009). The Karamajong categorize their grazing landscapes according to the conditions of the soil and vegetation type. In addition to home areas and grazing areas, some areas with the best pasture are kept unused, as a buffer against the ever-present possibility that a dry period could stretch into a fully fledged drought (Dyer, Omondi and Wantsusi, 2008).

Borana herders categorize their landscape into two macro landscapes, namely *badhaa* (cool subhumid uplands) and *gamoji* (warm lowlands), which have contrasting microclimates. The two macro landscapes are used in different seasons and allow spatial distribution of grazing pressure. *Badhaa* is used as dry-season grazing while *gamoji* is used for wet-season grazing (Dabasso, Oba and Roba, 2012).

Herders are able to apply their intricate traditional knowledge to characterize their landscapes based on the environmental variability. By categorizing these landscapes, they are able to allocate land use that can be supported by that particular landscape in a given season, thus enhancing their adaptive capacity and resilience as a community. Tellingly, under pastoral classification systems the areas of best pasture are often unused, as a hedge against environmental variability. Under conventional agricultural development, these are the areas that are preferentially, and most intensively, developed.

Range assessment. Pastoralists in East Africa use sophisticated but efficient indigenous systems that enable them to observe environmental changes to assess the suitability of grazing lands. The Karamajong in Uganda use comprehensive assessments to guide the traditional range scouts (*ngikerebo*) to determine the seasonal livestock grazing movements; these scouts also consider the condition of the grazing landscapes, evaluating both quality and quantity of available forage (Oba, 2009). Borana herders interpret vegetation changes in terms of rainfall variability, utilitarian values and intensification of land use; land degradation is expressed mainly in terms of declines in woody plant species, while spatial and temporal dynamics of herbaceous species reflect the effects of seasonality (Dabasso, Oba and Roba, 2012). Herders are also knowledgeable in monitoring the trends of livestock-preferred forage plants in a given landscape (Hallo, Oba and Guyo, 2011).

The Karamajong and Borana have the knowledge to assess and value their environmental resources effectively at spatial and temporal scales. They use knowledge of soils and vegetation to assess livestock production performance and are able to link land degradation with land use at the level of classified landscapes. In a sense, the knowledge is applied through what is now termed "participatory action research", involving cycles of planning activities; acting and observing processes and consequences; reflecting on these processes and consequences; and planning, acting and observing again. However, when pastoral communities are faced with decisions that restrict their access to resources, the cycles of planning, acting and reflecting are clearly disrupted, as options are reduced.

Range exploitation. Over the years pastoral communities in East Africa have learned to exploit their environment to achieve sustainable livelihoods. Exploitation of ecosystem variability and diversity, including the cycles of flood and drought, is their main risk management strategy. The pastoralists have developed a basket of adaptation strategies to maintain the animal genetic resources in the rangelands. Key livestock management strategies include herd mobility, herd diversification (including raising several species of animals in one herd, herd splitting, and maintenance of a high proportion of female livestock) and management of feeding and watering regimes (Mbuku, Kahi and Kosgey, 2012). Indeed, whereas conventional ranching would consider shrubs as an impediment, pastoralists would look at it as a source of forage for animals such as goats which are browsers. This enables them to use different environmental niches in different seasons, while conserving the ecosystem and enhancing diversity.

Indigenous practices related to rights of access, use and control of livelihood resources

Social security institutions. Studies show that the success of the drought-resilient livelihoods of the Karamojong is dependent on their social institutions. Social security networks between bond friends, relatives and in-laws form a strong foundation for traditional household livelihood coping strategies (Oba, 2009). Individuals build wide-ranging networks of bond friends in their lifetime which serve as insurance against loss of livelihoods due to raids and droughts. Wealthier households have more numerous bond friends than poor households. The social security webs shared among the Karamojong imply that individuals with limited means would remain within the pastoral system (Oba, 2009). Social networks provide social capital, which is vital in enhancing resilience to environmental change.

Indigenous institutions for decision-making. Pastoral communities have indigenous institutions or traditional structures for regulating grazing and making society-wide decisions on strategies for coping with droughts (Oba, 2009). Among both Borana and Karamajong herders, elders are the custodians of traditional institutions. Customary institutions were shown to have the knowledge, the skills and, most critically, the legitimacy to make and enforce informed decisions on livestock mobility and the management of water and pastures. (The Borana traditional institutions also have an elaborate system for making environmental management decisions and enforcing these.) Moreover, they have a formal, indigenous practice of handing over responsibility and knowledge to the next age set with little disruption. This practice is very useful in strengthening the adaptive capacity of these communities, as it ensures continuity of learned practices and skills.

Decision-making process. The decision-making process among pastoral communities is guided by elders with specialized knowledge. In Karamoja these specialized elders include readers of livestock entrails, shoe-throwers, astrologers and foreseers who predict coming drought events as well as raids by neighbours or grazing routes to be used. The elders then prepare the community to activate different drought coping strategies, such as migration. After the livestock has reached new grazing sites, their performance is monitored for parameters such as milk yield, bull activities, conditions of previously drought-weakened livestock, cattle rumen fill and the animals' behaviour when they return to the *kraals* at night and when they leave for grazing in the morning. Daily monitoring of livestock production performance influences herder management decisions. The decision-making process of the Borana is governed by the *gada* system (council of elders) (Fayo, 2011).

Tenure rules. Customary rules and regulations govern access to and ownership of clan assets including land and livestock. Ultimately all property belongs to the clan, and decisions pertaining to it reflect the maximization of benefits for the clan. Access is not restricted by ownership; everyone is able to access much of the property of the others in the household and indeed in the clan. It is unlikely that anyone within the clan (and usually even those outside the clan) will be denied access to resources in time of genuine need (Flintan, 2011). All Borana are entitled to the access and use of pasture on an equal basis in any part of the Borana land. The only limiting factor is that there must be an assured source of water supply in the area of pasture access. In Karamoja, the grazing grounds are communal while the home gardens (*eekuroro amana a ekal*) are private lands owned and managed by women. Also associated with settlement lands are semi-private grazing enclosures (*Ngaperor*), which are owned by men, for grazing sick, old and drought-weakened livestock. The owners have exclusive use, but they might accommodate their bond friends through social networks (Oba, 2009).

Decision-making over the access to and control and use of resources (especially communal resources), including land, is the responsibility of men. Under customary arrangements land tends to be inherited through the paternal line of descent, but it remains under the control of clan elders. On the death of her husband, a woman may be allowed to hold on to communal land, especially if she has sons (or other male kin) who can plough the land for her (Flintan, 2011). Land is a collective communal property for all Borana. The *gada* upholds this virtue and emphasizes at all times that this should be the case (Fayo, 2011).

Dispute resolution. Pastoralists in East Africa apply traditional justice systems confined to their locality in resolving disputes. These traditional justice systems use a variety of dispute resolution mechanisms such as negotiation, mediation and conciliation. The perception of the local people regarding these traditional systems is that it is owned by them and that it is principled. The proceedings and language are familiar to everyone, easily accessible at all times and affordable, and they use indigenous resources. Decisions are based on consensus and seek to heal and unite disputing parties. The *gada* system used by the Borana community is based on conflict prevention and resolution.

Part III

Policy measures for mainstreaming ecosystem services in agriculture

© FAO/Giulio Napolitano

10

USING POLICY TO HARNESS SYNERGIES BETWEEN CHEMICAL MANAGEMENT AND BIODIVERSITY CONSERVATION: INTERNATIONAL CONTEXT

Arthur Getz-Escudero,
Barbara Gemmill-Herren,
David Colozza and
Benjamin Graub

Issues related to the use of, and indeed overdependence on, external inputs (e.g. pesticides, herbicides) include pollution of the environment; negative impacts on the health of both animals and humans; reduced genetic diversity; and decreased ecosystem resilience in the face of stresses such as climate change. Chemical inputs might also reduce options for adaptation to climate change and have impacts on other ecosystem services such as soil fertility, pollination and water.

Biodiversity provides the ecosystem services that sustain agricultural production, such as nutrient cycling and pest and disease regulation. The use of chemicals in agriculture can be highly detrimental to biodiversity. Enhancing reliance on ecosystem services and biological interactions, however, can minimize the use of these chemicals. Encouraging forms of food production that build on biodiversity and the ecosystem services that sustain agriculture – such as nutrient cycling, pest control, pollination and watershed and flood control – can create more resilient and regenerative agriculture, with less pollution to the environment. Reducing reliance on external inputs is but one aspect in maintaining or restoring ecosystem resilience. An underlying institutional, policy and legislative framework is also required to support farmers and land managers. Broader consideration of policy requirements is critical at varying scales and levels of management and governance.

The most immediate entry point is to address the underlying motivations of farmers and other land managers to engage with the management of biodiversity and ecosystem services. An effective transition with uptake of ecological practices hinges on the signals and information that are transmitted and received, as well as on the attitudes, values and behaviours of both producers and consumers, and how these might be informed by research. Indeed, while policy can influence farmers' decisions, evidence provided from the field level can influence policy.

Beyond the immediate stakeholders of farmers and other land managers, it is critical to identify key policy levers and their relevant stakeholder groups. Policy involves a range of formal and informal institutions, and policy considerations include the forms of market organization and the power and roles of certain actors in the food system. Facilitation of an effective transition by policymakers also hinges on the stimuli or incentives presented to policymakers encouraging them to make effective arguments in relation to the valuation of environmental services and the design of rewards for the provision of benefits that accrue not just to farmers but also to the wider society.

International policy framework

Policy concerned with food systems governance must effectively confront mismatches in the local, regional, national and global scales at which food systems operate; the environmental and social feedback from the different levels do not necessarily match up. At the international level, a range of multilateral environmental agreements (MEAs) provide a framework for countries to develop regional and/or national policy on specific environmental issues. The main MEA relevant to the management of biodiversity and ecosystem services is the CBD; indeed this Technical Guidance Document was produced to assist countries in fulfilling their obligations to the CBD in developing their NBSAPs (see Part I). The preparation of NBSAPs provides an opportunity to review linkages with other international policies, conventions and instruments. Management to address reliance on external chemical inputs, for example, is the realm of other MEAs on chemical management. Most African countries have ratified the MEAs that deal with aspects of pesticides and chemicals management: The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal; The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade; and the Stockholm Convention on Persistent Organic Pollutants. Most also adhere to voluntary international initiatives such as the Strategic Approach to International Chemicals Management (SAICM) and the FAO/WHO International Code of Conduct on Pesticide Management. While these international instruments provide a sound framework for the management of chemicals, their enforcement, implementation and harmonization with existing national laws require comprehensive guidance and capacity-building at national level and regional coordination.

Other international instruments that are relevant to agriculture, biodiversity, ecosystem services and chemical waste include, but are not limited to:

- the International Treaty on Plant Genetic Resources for Food and Agriculture;
- the International Plant Protection Convention;
- the Global Plans of Action on Plant, Animal and Forest Genetic Resources for Food and Agriculture.

Above and beyond the national level: some examples of the handling of agro-ecosystem services in Europe

One region where some highly innovative measures have been developed, over decades, to build in incentive measures for the reduction of chemical pollution and enhancement of biodiversity, has been the European Union. Thus, we provide some details about these measures as an example of experiences in policy measures at the intersection of chemicals management and biodiversity. In addition, there are examples of experiences being carried out at the subnational level, of which several are profiled in Box 9.

Box 9. **European examples of policies at the subnational level**

The city of Malmö, Sweden, supports ecosystem services in agricultural landscapes indirectly, for example by increasing the share of organic foods in food procurement tenders. The city modified its food procurement policies based on five guidelines that combine health, nutrition, energy, ecological and transport objectives, made memorable through the acronym SMART:

» **S**maller amounts of meat;
» **M**inimize intake of junk food and empty calories;
» **A**n increase in organic;
» **R**ight sort of meat and vegetables;
» **T**ransport efficient.

This innovative approach to harnessing ecosystem services for local benefits meets a number of challenges, however, in that most of that organic food procured through the policy does not come from around the city, but from another part of Sweden.

On the island of Hoeksche Waard in the Netherlands, the local government, through a participatory process, brought together local citizens (mostly farmers), researchers, the water board and environmentalists to discuss and develop a regional biodiversity action plan, which resulted in a number of projects and strategies affecting the provision of on-farm and landscape ecosystem services and the conservation of biodiversity in the agriculture sector.

The city of Milan, Italy, sought to develop an urban food policy on the model of similar initiatives already in place in North American cities, by assessing the current status and

CONTINUES →

trends in the local food system and identifying existing projects and policies of interest to define indicators and mechanisms to monitor the food policy initiative and support its implementation. The following elements have contributed to a strong city-region food system effort: concerns regarding local economic development; solidarity regarding flood control; a willingness to rethink local food systems; and an appreciation of heritage farming systems, and particularly of Milan's historical links with the surrounding peri-urban countryside.

The city of Stockholm, Sweden, has incorporated considerations on ecosystem services into urban planning and urban green management decisions (Guerry *et al.*, 2015).

A very recent example is the decision by the town of Pickering in the UK to build flood control measures around recreating past environmental conditions that slowed the flow of water across the land, including working with farmers and landowners to improve soil cover and forested watersheds. In the torrential floods of December 2016, Pickering managed to avoid the calamitous flooding that impacted many other regions locally (Lean, 2016).

Subnational policies in Germany at the level of the 16 German Federal States and in Italy at the level of the 20 Italian Regions directly influence landscape and farm biodiversity through the adaptation of agri-environment measures to local contexts.

The European Union's Common Agricultural Policy

In Europe, these issues are addressed at the regional level, in the European Union's Common Agricultural Policy (CAP). The most recent reform to the CAP was made in 2013, and is valid for the period 2014 to 2020.

The (CAP) is the largest of the European policy mechanisms shaping land use patterns across the region. It influences land management on around 180 million ha of land across the 28 EU Member States. On an annual basis, budgetary expenditure on the CAP is close to 40 percent of the total EU budget. The current budgetary crisis increases pressure to identify measures for greater cost effectiveness and to demonstrate that these expenditures generate public benefits beyond direct support to farmers.

Funds are committed to support farmers, both through income support and through incentivizes and (indirect) regulation for outcomes that reduce negative externalities and generate public goods. The emphasis is on farmers as providers of public goods. In this regard, calls for clearer methods of valuation and payment for ecosystem services appear with increasing frequency in recent literature (e.g. Cooper, Hart and Baldock, 2009), and interventions spatially targeting ecosystem services efficiency and incentivizing collaboration at wider spatial scales beyond the individual farm are on the increase.

The original aims of the CAP were to increase production and to provide a stable, secure and cheap food supply for EU consumers while providing safeguards for a fair standard of living for farmers. Over several decades, pressures have arisen for policy reforms, including efforts to reduce the surpluses that spiked in the 1990s (referred to in the popular press and policy statements as "lakes of milk, mountains of butter") and to encourage more environmentally benign production practices. These pressures led to revisions in the policy at the turn of the millennium to decouple subsidies from the volume of production; eventually subsidies took the form of direct payments to farmers for reducing production to fixed limits, and funding mechanisms were created for wider rural development measures.

Two pillars supporting production and environmental goals in the CAP. The present configuration of the CAP has two separate funds or "pillars", differing in terms of financing, structure and functions. Pillar 1 deals with market stability and income support, and Pillar 2 addresses facets of rural development. Both pillars can have direct and indirect impacts on biodiversity and other environmental parameters, with direct payments decoupled from production quantities and "cross-compliance" rules focusing on making farm operations less environmentally damaging (Table 12).

For Pillar 1 payments, farmers have to meet the following cross-compliance requirements:

» compliance with statutory management requirements (SMRs) in relation to 19 EU regulations and directives;
» maintenance of good agricultural and environmental conditions (GAECs), as defined by individual Member States.

GAECs of specific relevance to ecological intensification can include maintenance of soil cover, buffer strips along watercourses, bans on conversion of permanent grassland and planting of crop varieties, among others.

The 2013 reform of CAP established so-called "greening measures", including a green direct payment to farmers, given on the condition that they undertake practices that are beneficial to the climate and to the environment. Member States must allocate 30 percent of their direct payment envelope to green direct payments. The basic practices that farmers must undertake are:

» maintaining permanent grassland;
» crop diversification;
» keeping 5 percent (later 7 percent) of their land as an ecological focus area (EFA).

EU Member States have the power to offer alternative options ("equivalent practices") that a farmer can apply instead of the basic practices (e.g. crop rotation instead of crop diversification); these should be considered as having equivalent or higher benefits.

Under Pillar 2, biodiversity issues are addressed via targeted instruments, including agri-environmental measures (AEMs). Leading up to the 2014-2020 cycle of the CAP reform process, the European Commission proposed two specific rural development policy priorities:

» restoring, preserving and enhancing ecosystems;
» resource efficiency and climate change mitigation.

Table 12. **How measures to enhance ecosystem services in agriculture can be encouraged or rewarded under the two CAP pillars**

ECOSYSTEM SERVICE	PILLAR 1		PILLAR 2	FORWARD-LOOKING RECOMMENDATIONS
	Cross-compliance with SMRs	**Measure or GAEC (national certification scheme or equivalent practices)**	**AEMs**	
Pest regulation	Cross-compliance with the Pesticides Directive, which could make biological pest control more attractive as more toxic pesticides are eliminated from the list of permitted substances	Protection of permanent grassland or EFAs under green payments, which could result in habitat for beneficial insects Petitioning for, recommending or adopting biological controls as GAECs, which could preserve habitat for beneficial insects in areas in hedgerows	Buffer strips or other habitat (e.g. field margins, hedgerows) to harbour beneficial insects	Efforts to promote organic farming in less-favoured areas and rural development schemes to incentivize adoption of biological pest control
Soil health	Cross-compliance with the Nitrates Directive	Crop diversification requirement in greening measures, which may reduce uniformity of nutrient removal and add nitrogen with legume rotations	The agri-environment-climate measure (Article 28) on carbon sequestration in soils, which aims to preserve and promote the necessary changes to agricultural practices that make a positive contribution to the environment and climate	Maintaining the diversity in high-value habitats through more extensive farming practices (already existing), which could involve low external input use for lower impact on soil quality Preservation of landscape features (e.g. woods) and management of low-intensity pasture systems, which may help preserve and enhance soil quality
Water conservation	Cross-compliance with the Water Directive, Pesticides Directive and Nitrates Directive	Environmental cover along riparian corridors Hedgerows and slopes in farmed areas (France) Terrace maintenance for soil erosion control (Italy)	Potentially positive impacts on soil and water conservation from practices such as the liquid manure drag hose method instead of spraying, or the use of autumn/winter greening	More extensive use of practices aimed at maintaining local biodiversity and involving reduced use of chemicals, which may help to preserve water quality (e.g. through reduced infiltration in groundwater sources) Maintaining specific landscape elements such as woods, ditches and hedgerows, which may help to capture water on the farm, hence reducing runoff of potentially damaging nutrients to nearby streams

11

NATIONAL POLICIES AND LEGISLATION SUPPORTING ECOSYSTEM SERVICES FOR AGRICULTURE IN KENYA

Stella Simiyu and
David Colozza

Kenya is endowed with diverse ecosystems and habitats that are home to unique and diverse flora and fauna. About 70 percent of the national biodiversity resources is found outside protected areas, while 30 percent is within protected areas – including national parks, reserves, sanctuaries, gazetted forests and heritage forests. While the Kenyan government recognizes the use of ecosystem approaches as the best method for conserving biodiversity, the country has inadequate environment- and biodiversity-related laws, policies and instructional frameworks that target this end. The agriculture sector in Kenya contributes 26 percent of GDP directly and another 25 percent indirectly. It employs formally around 18 percent, and informally over 70 percent of the total population (Republic of Kenya, 2010). It accounts for 65 percent of the total earnings and provides livelihoods for 80 percent of the Kenyan people. Besides providing food to the ever-increasing population, the sector provides raw materials to agro-based industries and subsequent employment, as well as for export – mainly from smallholder farms. Therefore, an effective and enabling policy and regulatory framework for ecologically sound practices in agriculture holds great promise for both the Kenyan people and the national economy.

Some of the key threats to biodiversity and natural ecosystems arising in the agriculture sector include:

- excessive use of inorganic fertilizers and pesticides, which cause soil and water pollution and a decline in pollinators and soil-enriching microbes, thus reducing productivity as well as wetland biodiversity;
- poor farming methods that lead to massive soil erosion, leading to loss of crop yields and sedimentation in rivers and ultimately in lakes and the Indian Ocean;
- inappropriate crops, especially in the drylands, where the choice of crops is often not based on the capacity of the land, and as a result large areas of natural habitat are converted to crop fields to make up for low harvests;
- the unregulated expansion of agricultural land for farming or pastures, which contributes to deforestation, loss of biodiversity and water and soil degradation (MA, 2005a);
- poor livestock husbandry, marred by overstocking and overgrazing, exacerbating soil erosion problems;

- large areas of bioenergy crops taking up substantial areas of natural habitat, replacing wildlife habitats in community lands and causing serious impacts associated with climate change.

  Less direct drivers of change exacerbate the pressure. These include:
- population pressures;
- lack of an agricultural spatial land use plan, leading to land uses not based on agricultural capacity;
- poverty, resulting in low capital investment in sustainable production technologies;
- poor policy implementation, because institutions are weak as a result of insufficient political will to prioritize resource allocation to sustainable food production.

  The impacts arising from this insufficient recognition of sustainable production systems include:
- loss of wildlife habitat, with associated economic losses;
- food insecurity and hunger, with famines overstretching the economy and the cost of food interfering with provision of other government services;
- soil infertility, which leads to low farm yields for food and pasture, leading to serious loss of livestock and wildlife at times of drought;
- loss of biodiversity, including soil micro-organisms that should enhance fertility and pollinators that should boost production;
- eutrophication of lakes and the ocean, with serious impacts for freshwater and marine biodiversity.

A major policy shift is needed, together with institutional capacity building, agricultural extension services and sound water use and planning for irrigation to achieve the goal of meeting the needs of people while preserving ecosystem services and biodiversity resources.

To unlock the country's economic potentials, the Government of Kenya initiated an ambitious development blueprint, "Vision 2030". Revitalizing agriculture is one of its key focal points. A policy to harness about 50 "orphan and/or emerging crops" for food, medicine, fibre, biodiesel, timber, fodder, aromatics and ornamentals, among other uses, has been drafted and awaits Cabinet and National Assembly approval to take effect (Republic of Kenya, 2015).

Policy framework

Vision 2030

Vision 2030 is the overarching framework guiding policy formulation and implementation in Kenya. It is predicated in the New Constitution of Kenya, which has embedded environmental conservation as a right for the people of Kenya.

The Vision 2030 has identified agriculture as a key sector in achieving economic growth targets. The priority for implementation is the transformation of smallholder agriculture from subsistence to innovative, commercially oriented and modern agriculture.

The revision of the Strategy for Revitalizing Agriculture (2004–2014) led to the development of the Agriculture Sector Development Strategy (ASDS) 2010-2020, whose goal is a food secure and prosperous nation by 2020, to be achieved through a shift from subsistence to agriculture as a business.

In line with the Vision 2030 Medium Term Implementation Plan (MTP) and the Comprehensive Africa Agriculture Development Programme (CAADP) Compact, ASDS has the following thematic areas:

» CAADP Pillar 1: Land and water management (sustainable land and natural resource management);
» CAADP Pillar 2: Market access (agribusiness, access to markets and value addition);
» CAADP Pillar 3: Food supply and hunger (food and nutrition security);
» CAADP Pillar 4: Agricultural research, technology dissemination and adoption (research and extension, but with two additional strategic focuses on legal, regulatory and institutional reform and on inputs and financial services).

The development of ASDS led to the revision and consolidation of 131 pieces of legislation that governed the sector. With the elimination of overlaps, duplication, contradictions and gaps, these were consolidated into four pieces of legislation, namely the Agriculture, Livestock and Food Authority Bill; the Livestock and Fisheries Bill; the Crop Bill; and the Agriculture Research Bill.

Parallel to this process was the reorganization of the national governance structures, in line with the new constitution, into a two-tier governance system with one national government and 47 county governments. The national government has authority over policy issues, capacity building, finance and technical assistance, while the county governments are responsible for priority setting, financial management, agricultural production and extension services in their respective counties.

Kenya's budget allocation to the ministries in the agriculture sector has been rising, in line with its pledge in the Maputo Declaration to increase allocation to agriculture to 10 percent of the national budget. This allocation is set to increase to meet the aspirations of Vision 2030.

The government has noted that key challenges in the agriculture sector include unreliable weather patterns and effects of climate change, low adoption of technology, uncoordinated research and development, availability and affordability of energy and conversion of agricultural land to other competing land uses.

Vision 2030 – second Medium Term Plan

Flagship projects implemented under the first Vision 2030 Medium Term Plan (MTP) (2008-2012) included enactment of the Agricultural Reform Bill, which consolidates existing policies and legislations in the sector, a fertilizer cost reduction strategy and expansion of irrigation coverage. In a review of the first MTP, the following challenges were noted as significant and needing priority attention in the second MTP:

» low per capita income growth;
» high levels of unemployment;
» high energy costs (up to US$0.21 per kilowatt hour, as compared, for example, to US$0.06 per kilowatt hour in India);
» high costs of finance;
» a rapid population growth rate;
» high dependence on rainfed agriculture and low agricultural productivity.

Under the second MTP (2013-2017), the priority for agriculture and livestock is to increase the area under irrigation in order to reduce dependence on rainfed agriculture. A total of 404 800 ha will be put under irrigation. Other measures include mechanization of agriculture and subsidies for farm inputs to raise productivity.

The agriculture sector is expected to grow by an annual average of about 6.4 percent during this period. The sector will benefit from output and productivity gains through institutional reform such as land reforms that have already started. Priority will be given to the implementation of the fertilizer cost reduction strategy, expansion of land under irrigation, construction of the High Grand Falls Dam, increased access of Kenya's livestock products to regional and international markets, support to extension services, and establishment of greenhouses and agroprocessing plants in counties. In addition, the national government will continue to promote value addition in farm products and to increase exports of agricultural and livestock products.

The National Land Policy of 2007 will be reviewed and revised to align it with the constitution, and hence to address issues such as adjudication, titling to enhance secure landownership and increased investment. Among the flagship projects for the second MTP are preparation of national and country spatial plans, guidelines and standards, with related policies and bills.

The second MTP aspires to integrate sustainable development goals for post-2015, which include:

- achieving development and prosperity without ruining the environment;
- increasing agricultural production in an environmentally sustainable manner, to achieve food security and rural prosperity;
- making cities productive and environmentally sustainable;
- curbing human-induced climate change with sustainable energy;
- protecting ecosystems and ensuring sound management of natural resources.

As part of its employment creation strategy, the government will exploit, among other options, green employment opportunities in industries producing organic products, organic farming, resource-efficient clean production, renewable energy, forestry, environmental planning and urban water management.

A census of agriculture will be a priority under the second MTP, to improve the quality of data. Flagship projects will include the implementation of the consolidated agricultural reform legislation and development of arid and semi-arid lands, mainly through irrigation and fertilizer cost reduction. Priority programmes will include agricultural development along the Lamu Port – South Sudan – Ethiopia Transport (LAPSSET) Corridor, the National Agricultural Sector Extension Programme, the Agri-business Development Programme, the Accelerated Agricultural Inputs Access Programme and Agriculture Finance and Insurance.

Furthermore, the sector will undertake institutional and policy reforms aimed at strengthening the sustainability of agriculture and will guide the county governments in developing their policies, especially on agriculture, livestock, urban and peri-urban agriculture and organic agriculture, among others.

Policy instruments supporting biodiversity and ecosystem services across sectors in Kenya

A number of policy initiatives that could serve as entry points for effective conservation, sustainable use and development of biodiversity in Kenya are already in place.

The National Constitution of Kenya (Article 69) mandates a number of specific measures that are directly relevant to biodiversity conservation, including the requirement to maintain tree cover of at least 10 percent of the national land area and the requirement to preserve communities' traditional knowledge of biodiversity and genetic resources.

In broad policies

The Environmental Management and Coordination Act (1999) mandates the establishment of an appropriate legal and institutional framework for the management of the environment and related matters. It establishes appropriate legal and institutional mechanisms for the management of the environment, recognizing that this constitutes the foundation of national economic, social, cultural and spiritual advancement.

The Wildlife Conservation and Management Act (2013) has, as one of its guiding principles, the devolution of conservation and management of wildlife to landowners and managers in areas where wildlife occurs. It recognizes wildlife conservation as a form of land use, pursues better access to benefits from wildlife conservation and adherence to the principles of sustainable use, and establishes harsh penalties for poachers, among other provisions.

The Heritage Act (2006) consolidates the law relating to national museums and heritage, to provide for the establishment, control, management and development of national museums on transmission of the cultural and natural heritage of Kenya.

Other policy initiatives that are relevant to target biodiversity conservation efforts include, for example:

» the Land Act (2012), which focuses on conservation and protection of ecologically sensitive areas such as riparian reserves (defined as land adjacent to the ocean, lake, sea, dams and watercourses) and sustainable and productive management of land resources;
» the Water Act (2002), which regulates the use and control of and rights over water resources;
» the Forest Act (2005), which provides for the establishment, development and sustainable management (including conservation and rational use) of forest resources for the socioeconomic development of the country.

In sectoral policies

The Agriculture Act (revised in 2012) does not mention biodiversity specifically but mandates that, in order to target the preservation of soil and its fertility, the Minister may issue Land Preservation Rules or Orders, as well as general schemes for land preservation and development.

Similarly, the 2013 Crops Act – targeting the growth and development of agriculture and rural incomes in general – while not including specific mention of biodiversity, mandates that all levels of government must ensure that landowners and leasers manage and cultivate land in a sustainable and environmentally friendly manner. Provisions for agricultural research targeting, among other things, the promotion of balanced and diversified agricultural development are included in the Agriculture and Livestock Research Act (2013). This act established the Kenya Agricultural and Livestock Research Organization, comprising semi-autonomous thematic institutes, including one on genetic resources with the mandate to conserve them. The Biosafety Act (2009) established the National Biosafety Authority, which regulates the transfer, handling and use of genetically modified organisms.

Specific to the agriculture sector, and the findings in this document, there would be considerable scope for agriculture policy in Kenya, and East Africa, to address priority concerns such as excessive use of agrochemicals and other poor farming methods, through supporting and enhancing ecosystems services, of soil conservation and fertility processes, natural pest control, and watershed functions. For example, the concerns with fertilizer cost reduction could conceivably be met through investment in natural forms of soil fertility management (recycling of nutrients, compost management and others as described above).

12

ADDRESSING ECOSYSTEM SERVICES IN NATIONAL BIODIVERSITY STRATEGIES AND ACTION PLANS

Raffaele D'Annolfo,
Agnès Bernis-Fonteneau and
Nadine Azzu

Since the adoption of the CBD's revised Strategic Plan for Biodiversity 2011-2020 (COP Decision X/2) and the Aichi Biodiversity Targets in Nagoya, Japan in 2010, identifying gaps in light of the Strategic Plan has an even greater relevance. Indeed, Parties agreed to translate this overarching international framework into revised and updated National Biodiversity Strategies and Action Plans (NBSAPs) within two years. Updating NBSAPs involves, as a first step, identifying existing gaps in their coverage.

Representation of ecosystem services in existing National Biodiversity Strategies and Action Plans

In September 2015, FAO undertook a non-exhaustive, basic assessment to provide quantitative data and qualitative findings on how ecosystem services and biodiversity important for agriculture are currently addressed in NBSAPs. It was envisaged that this basic assessment could assist countries in identifying gaps in their current NBSAPs.

Quantitative analysis

The quantitative analysis considered 166 NBSAPs (CBD, 2016b) and used word counting for selected keywords (in English, French, Spanish and Portuguese). The keywords were selected on the basis of their relevance to ecosystem services directly relevant for agriculture. However, in order to provide a better overall picture of the NBSAPs considered in the study, some keywords were added to the list at a later stage, after the review of several NBSAPs and the identification of other relevant issues (e.g. agroforestry, local/indigenous/traditional knowledge, biotechnology, climate change, gender).

Broadly speaking, the findings from the keyword analysis show how elements relating to agricultural biodiversity are entirely reflected in NBSAPs (Figure 5). While the term "ecosystem" is mentioned quite extensively (15 232 times), it is mostly mentioned alone rather than as part of a broader concept such as "ecosystem services" (including "ecosystem functions" and "ecosystem processes"). Moreover, terms relating specifically to agricultural components of biodiversity management such as "pest", "disease" or "weed", "agroforestry" (including "agro-forestry") and "agrochemical" (including "agro-chemical", "pesticide", "fertilizer" and "herbicide") appear far less frequently. The word "soil" on its own is found almost ten times more often than "soil biodiversity" (including "soil fertility").

A comparison was then made of the appearance of keywords in 1995-2010 and in 2011-2014, to observe differences before and after the 2010 Nagoya meeting (Figure 6). The biggest changes concerned the keywords "ecosystem services" (including "ecosystem functions" and "ecosystem processes") and "climate change", whose relative frequency increased from 2.9 to 14.1 percent and from 3.5 to 12.4 percent, respectively.

As most of the countries (66 percent) have published only one NBSAP version without any further updates, this suggests that many countries had not yet integrated the Aichi Biodiversity Targets in their national biodiversity plans. Figure 6 corroborated this finding to a certain extent. The mentioned figure provides the keyword comparisons 1995-2010 and 2011-2014: only the last NBSAP version for each country has been considered in the analysis. The aim of this comparison is to show if changes have occurred in the use of keywords before and after the Nagoya meeting in 2010. Figure 6 shows a general negative trend concerning most of the selected keywords after 2010, with an increase in the mention of very few keywords.

Figure 5. **Overview of keyword analysis conducted in 166 NBSAPs**

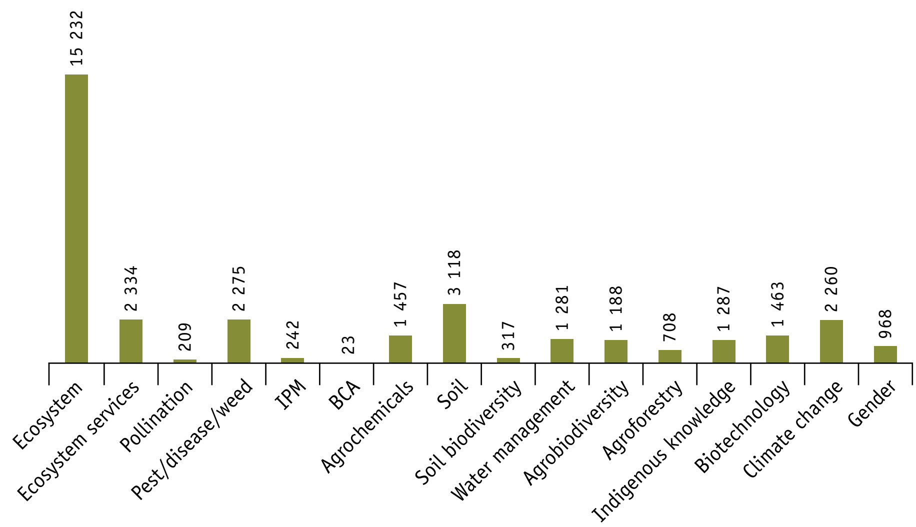


Figure 6. **Comparison of keyword appearance in NBSAPs before and after 2010 (relative frequency)**

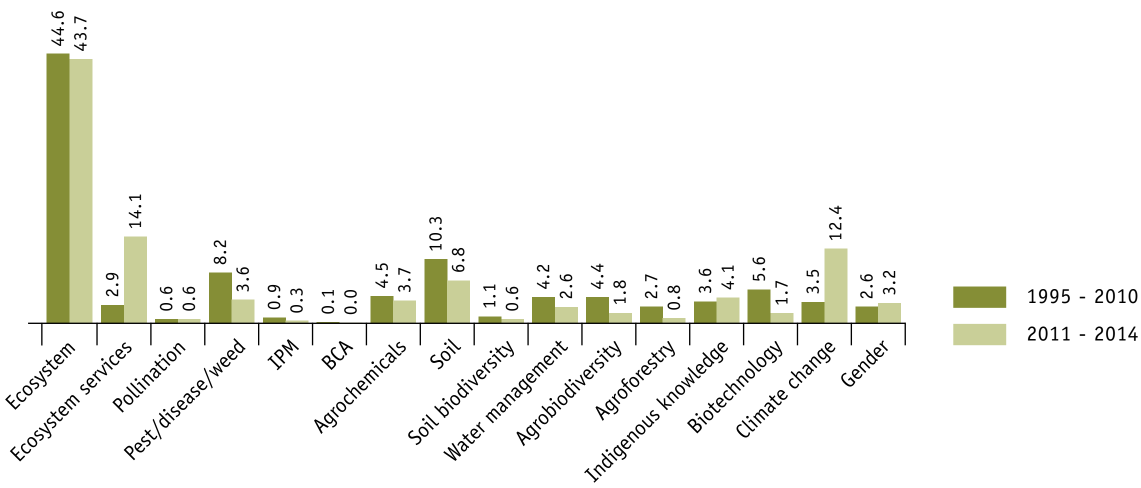


Table 13. **Trends in keyword appearance in NBSAPs: percentage change from 1995-2010 to 2011-2014**

KEYWORD	%
Declining trend	
Agroforestry	-70.8
Biotechnology	-69.3
IPM	-69.2
BCA	-60.3
Agrobiodiversity	-59.8
Pest/disease/weed	-55.7
Soil biodiversity	-47.6
Water management	-39.1
Soil	-33.7
Agrochemical	-18.5
Pollination	-5.2
Ecosystem	-2.0
Increasing trend	
Ecosystem services	384.8
Climate change	251.8
Gender	23.3
Indigenous knowledge	13.9

Qualitative analysis

A qualitative, non-exhaustive snapshot assessment was also undertaken for 62 NBSAPs[1] which were read and evaluated by an expert, specifically to look at how ecosystems, biodiversity and specific agricultural aspects were handled. This assessment showed that even if an NBSAP has at least one mention of ecosystem services in its introductory section where the country acknowledges the importance of biodiversity and the role of ecosystem services, it is often copied from a CBD document and no further details are given in the body of the NBSAP. When ecosystem services are mentioned in the body of an NBSAP, it is usually in reference to natural ecosystems. Indeed, ecosystem services are almost exclusively referred to as services of natural ecosystems, mainly forest and water ecosystems. Very few countries (for example Argentina, Italy, Uganda) make reference to ecosystem services within agro-ecosystems.

Many NBSAPs show an interest in the economic valuation of biodiversity and ecosystem services. On the one hand, the economic valuation of biodiversity and ecosystem services is recognized as a promising tool for improving the conservation of the natural environment; on the other hand, several countries focus on the difficulties that might be encountered with valuation (i.e. determining the economic value of biodiversity and ecosystem services). The Annex provides a summary of the increasing work being carried out on the valuation of ecosystem services and a specific example of a protocol for valuing ecosystem services in agriculture using multiple dimensions.

Although agricultural biodiversity includes "all the components of biodiversity that have relevance to agriculture and food, and all the components of biodiversity that constitute the agro-ecosystems: the variety and variability of animals, plants, and microorganisms, at the genetic, species and ecosystem levels, necessary for sustaining key functions of the agro-ecosystems, their structures, and their processes" (CBD Decision V/5, Appendix), the term "agrobiodiversity" and its variants are used in most NBSAPs to refer to genetic resources for food and agriculture. All other components and services are often overlooked or reduced to a brief general sentence.

Agriculture is still globally seen as oriented towards intensive production practices and is thus often only listed in relation to activities that are threats to biodiversity conservation and sustainable use of resources (e.g. agrochemical use, tillage, encroachment, poor land and water

---

[1] These 62 NBSAPs were selected for their affiliations to projects in which the Plant Production and Protection Division (AGP) of FAO is involved. The countries include: Antigua and Barbuda, Argentina, Bahamas, Barbados, Belgium, Belize, Bhutan, Brazil, Burundi, Cambodia, Cameroon, Chad, China, Colombia, Cook Islands, Costa Rica, Côte d'Ivoire, Cuba, Democratic Republic of the Congo, Dominica, Dominican Republic, Ecuador, Ethiopia, Fiji, Germany, Ghana, Grenada, Guyana, Haiti, India, Indonesia, Jamaica, Japan, Jordan, Kenya, Kiribati, Liberia, Marshall Islands, Micronesia (Federated States of), Niue, Pakistan, Palau, Papua New Guinea, Philippines, Rwanda, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Senegal, Solomon Islands, South Africa, Suriname, Timor-Leste, Tonga, Trinidad and Tobago, Tuvalu, Uganda, United Kingdom, United Republic of Tanzania, Vanuatu and Zimbabwe.

management). Some NBSAPs mention the importance of adopting more friendly practices aimed at preserving biodiversity in agriculture.

Countries that can afford agrochemicals and access to other inputs (e.g. water) still observe a conflict between environmental protection and intensive food production. These countries do not seem ready to see ecosystem services as a fundamental asset for increased sustainable food production.

Financial aspects of biodiversity conservation and sustainable use are also regularly discussed in the reviewed NBSAPs. Many countries lack human and financial resources for biodiversity conservation. However, some Small Island Developing States (SIDS), which are greatly affected by biodiversity threats (e.g. from climate change), identify possible strategies for promoting conservation and sustainable use of biodiversity, such as ecotourism and organic farming practices.

Policy recommendations for promoting biodiversity and ecosystem services in agro-ecosystem management

The benefits of functional agrobiodiversity or ecological intensification do not revolve solely around issues of production, yield and profitability. The current productivist model of conventional agriculture needs to transition to a model that respects the multidimensional values of farming systems and agriculture, be these cultural traditions, rural employment or providing watershed services beyond the farm gate. To this end, this section gives recommendations for the various policy objectives discussed in this document, while the final section provides recommendations for how these dimensions can be integrated in a holistic approach.

Pest and disease control

Agro-ecological approaches to natural pest control have many benefits, for farmers and for national governments alike. Governments can take action to support such approaches by strengthening the regulatory measures that encourage the agricultural inputs that do the least harm to the environment and by phasing out highly hazardous pesticides and removing unregistered products from sale. Farmers should be encouraged to reconsider their approaches to pest control, from "therapeutic" approaches to whole-system management that considers interactions among crops and areas of habitat on farm, over time as well as space.

Suppliers of traditional and conventional inputs should be encouraged to shift to biological inputs such as cover crop seeds and biological control agents, and to evolve as brokers of knowledge and ecological understanding. The move to privatize extension agents does not mean that they should derive income only from the sale of agricultural chemicals; if they become accomplished scouters or monitors and trusted advisers for ecological inputs they will create potential for great value.

Ecological weed management

Conservation of overall biodiversity is not generally considered a priority service when the primary objective is to improve weed suppression or food security. However, when it is fully understood that functional biodiversity is an integral part of overall biodiversity, the link between biodiversity and weed management will become clear, possibly opening prospects for including ecological weed management in NBSAPs. To date, however, the importance and possibility of reconciling the protection of biodiversity with the use of biodiversity has been little recognized, both in science and in practice (Bàrberi, 2015). Increasing opportunities for research on ecological weed management should be encouraged.

Enhancing soil fertility

Good management practices for agricultural soils, such as providing organic inputs, are generally targeted at increasing soil fertility, but can also provide other benefits such as reduced soil erosion, enhanced soil biota activity, soil carbon sequestration and resilience of smallholder farming systems. There is a clear opportunity to use existing mechanisms, individually and in combination, to expand the range of potential benefits, for example to encourage active management of soil carbon. Policy measures could include:

- land-use planning that excludes vulnerable soils from land uses that lead to SOC losses;
- promotion of proper soil fertility management practices to protect and enhance soil organic matter as an essential element of good soil and environmental quality;
- promotion of sources of plant nutrients (e.g. cover crops, legumes) that enhance SOC stocks;
- use of financial incentives (such as payments for carbon storage, improvement of water quality, conservation of soil biodiversity and other ecosystem services) to target better allocation of soil resources to different land uses and management practices;
- ensuring that technical advisory systems (extension services) for agriculture and forestry to address the full range of ecosystem services that are supported by soils;
- promotion of research on the impacts of climate change on soils, soil carbon and associated ecosystem services and on the effect of soil degradation on soil biological diversity and ecosystem services;
- addressing the effect of trade barriers on the availability and accessibility of quality soil inoculants.

Water management

The water-related benefits generated by ecosystems, such as clean water provisioning, are often undervalued and are not incorporated into planning and decision-making. The ecosystem approach provides a valuable framework for IWRM, focusing attention on protection of upper catchments (e.g. reforestation, good land husbandry, soil erosion control), pollution control (e.g. point source reduction, non-point source incentives, groundwater protection) and environmental flows. Mechanisms for supporting water-related ecosystem services include payment for watershed services, water funds, and Green Water Credits, in which rural people pay for specified land and soil management activities that determine freshwater resources at source – including activities not only in water management, but also in agronomy, nutrient management, tillage/residue management, agroforestry and restoration of degraded agricultural lands.

Pollination

Pollination is valuable and can play a major role not only in people's livelihoods but also in the economic growth of East African countries. However, for this to happen, policies are required to enhance awareness among farmers about pollinators and to support extension services in provision of related information. Such a policy could be within an IPM policy or farm policy that incorporates all aspects of managing pollinators such as pest control, soil and water management, and hedgerow and habitat management on farms. It could also be reinforced in an NBSAP.

Policy is also required to include pollinator management in school curricula; instead of teaching only about the importance of pollination in the reproduction of plants, schools should present it as part of the inputs of production.

Several institutions can enhance uptake of information about the use of pollinators in agriculture. Pesticide registration authorities can play an important role through ensuring that product labels include information on impacts on pollinators. Universities and research institutes could include targeted research on pollination in their projects and train young people to increase capacity in pollination management. Extension service providers, once empowered with knowledge, can play a major role in promotion of best pollination management packages for farmers.

Existing policy interventions include protected areas, which provide a refuge for pollinators. However, conservation of pollinators in protected areas may not benefit many farmers, since pollinators are not known to fly long distances daily for their food.

Land-tenure policies may be a hindrance to pollinator management, particularly where it would be necessary to invest in plant diversity on farmland, as most farmers do not own their land. Female farmers are disadvantaged compared to male farmers, since decision-making on land use, in many communities, is seen as men's role. Yet often women farmers have a greater appreciation and understanding of the importance of local biodiversity, which provides food and medicinal resources for their families.

A number of European countries have developed agri-environmental schemes that specifically target pollination services and pollinator conservation (Box 10).

Box 10. Examples from Europe of policies targeted at conserving pollination services

The United Kingdom, Switzerland and Finland cover the costs of planting flower strips within or around fields. However, uptake of this practice has been low with respect to other practices such as establishment of grasslands, fallow strips or fields.

Serbia encourages the planting of flowering trees as windbreaks in new agricultural areas.

In the United Kingdom, the National Pollinator Strategy for England is based on recognition of the close link between farming and the protection and enhancement of pollinator communities. The strategy targets farmers in areas known to have declining rates of wild bee species, offering them financial incentives to apply certain measures such as designating a predetermined amount of land for flowery, pollinator-enhancing habitats.

Source: Dicks, Vaughan and Lee-Mäder, in press

Appropriate range management

Investment in policies that integrate the knowledge and practices of pastoral communities can be expected to reduce losses related to environmental degradation, recurrent natural disasters and climate change among these communities. The government can support indigenous range management knowledge by acknowledging the indigenous systems of land use, supporting community empowerment and promoting participatory resource planning. More value should be given to pastoralists' indigenous knowledge in landscape mapping and planning, predicting change and monitoring changes in the landscape, as well as in using the landscape. Herder knowledge can be used, for example, in seasonal forecasts for community and government planning and in designing climate change adaptation initiatives, since pastoralists have traditionally lived under climate variability and adapted to extreme weather patterns.

Other important measures include the following:

» Mobility of pastoralists and livestock needs to be effectively protected and promoted.
» Traditional consensus-based governance processes of pastoral communities – determining decision-making over control, use and access to resources – need to be integrated into formal decision-making processes, including statutory laws. However, ways to make customary decision-making processes more gender equitable need to be identified.
» For free movement of livestock, grazing land should remain under some form of collective control, either through customary or government tenure arrangements. There is a need for investment in making tenure arrangement processes user friendly.

» Capacity building is needed to improve policymakers' understanding of the ecological dynamics, economics and sociocultural aspects of drylands, with a focus on improving climate-resilient planning in dryland areas.

Farming systems integrating crops, trees and livestock

The products and services flowing from the integration of trees within farming systems can contribute to food security, farmer livelihoods and environmental resilience. Policies should not hinder this integration. The most favourable policy scenario is one in which governance of food production is multisectoral and based on a systems approach.

Conservation agriculture with trees (CAWT) is an approach that combines conservation agriculture practices with those of agroforestry. Ng'endo *et al.* (2013) reviewed six agricultural policies related to CAWT in Kenya:

» Agriculture Act (Chapter 318);
» Agriculture (Basic Land Usage) Rules;
» Agriculture (Farm Forestry) Rules;
» Forest Act 2005,
» National Land Policy;
» Agricultural Sector Development Strategy.

Based on interviews with 26 national-level government officials and technical people and 120 small-scale farmers in Kibwezi and Meru counties in eastern Kenya, they concluded that the incentives contained in these policies are general in nature and favour both rich and poor farmers, but that they are more accessible to rich or large-scale farmers who are capital endowed and can invest in and adopt sustainable agricultural practices.

Small-scale farmers were more likely to adopt CAWT for the direct benefits they gain than for the incentives provided by these policies. The Agriculture (Farm Forestry) Rules policy of 2009, for example, offers a compliance certificate as an incentive to farmers who maintain 10 percent forest cover on their farms. Since the certificate does not translate to any tangible gain, it does not provide any real motivation. Farmers prefer indirect incentives such as security of land tenure, provision of improved extension services and market development over direct incentives. However, incentives targeted to smallholder farmers remain limited.

Institutional innovations in forestry and fisheries, such as joint management between government agencies and local communities, have boosted compliance with resource use regulations and, in the process, promote conservation of biodiversity.

Box 11 gives an example of recommendations that could inform the development of policy for promoting farming systems integrating crops, trees and livestock.

Box 11. Recommendations for an agroforestry policy in the United Republic of Tanzania

The following recommendations have been drawn up to facilitate development of an agroforestry policy in the United Republic of Tanzania:

» Reinforce the National Agroforestry Steering Committee (NASCO) to make it more intersectoral;
» Create public awareness of the importance of an agroforestry policy.
» Set aside agroforestry funds at different levels.
» Integrate indigenous and modern technologies in the agroforestry policy.
» Institutionalize NASCO in the government structure and plans, as an overseer of agroforestry activities.
» Institutionalize the National Agroforestry Strategy in the country's legal framework.
» Consider redefining agroforestry in the Tanzanian context because the country has already proposed a new forest definition ("an area of land with at least 0.05 ha, with a minimum tree crown cover of 10 percent or with existing tree species, planted or natural, having the potential of attaining more than 10 percent crown cover, and with trees which have the potential or have reached a minimum height of 2.0 m at maturity *in situ*" [MNRT, 2011]).
» Ensure that at least 50 percent of agroforestry plots are kept under crop or pasture production.

As the leads in the process of agroforestry policy development, the forest and agriculture sectors should establish an effective partnership and collaboration, rather than working in isolation.

Source: Msuya and Kideghesho, 2012

Traditional indigenous knowledge

Farmers possess wide-ranging indigenous systems beneficial to decision-making for sustainable management of agro-ecosystems. However, the current policy narrative in East Africa does not favour traditional knowledge and practices. Investment in policies that integrate indigenous knowledge and practices can be expected to reduce losses related to environmental degradation, recurrent natural disasters and climate change among these communities. The government can support indigenous knowledge by acknowledging indigenous systems of land use, supporting communities' empowerment and promoting participatory resource planning through resource mapping exercises. Actions should be considered, in preparing strategies for natural resources management and conservation, to give status to the knowledge and practices of traditional communities (e.g. biocultural protocols).

Policy entry points for a holistic approach: recommendations for different actors

In East Africa, government policies enabling agro-ecological practices are generally lacking. Some food production policies not only fail to support these approaches, but even promote practices that seem to contradict agro-ecological principles, resulting in severe negative impacts for farmers. An example is the support for inorganic fertilizer use in Kenya. Use of these fertilizers has grown since the country's independence in 1963, and many farmers believe that they cannot grow crops without them. Yet in the past two years, it has become evident that overuse of fertilizers is resulting in an increasing problem of acidic and non-responsive soils. In such instances, conservation agriculture and other measures to restore soil biodiversity could contribute to restoring soil health and preventing many soils from becoming non-productive.

This section recommends a number of actions that specific actors might take to encourage policy that recognizes farmers "not only as food producers, but also as providers of public goods" (Bianchi *et al.*, 2013).

Governments

Governments can take action to support agro-ecological approaches by developing supporting policies and strategies to support a general reorientation of agricultural policy towards holistic, whole-farm approaches, including greater support for farmer training, support for social organizations that encourage farmer-to-farmer learning, and development of incentive measures (e.g. insurance, participation in certification schemes) that assist farmers in making a transition to a more ecological form of farming. They should strengthen existing measures that facilitate the uptake and use in the agricultural sector of inputs that are the least damaging to the environment, and provide support for building and expanding the expertise that can develop whole-farm management systems appropriately, including support for agriculture research.

Specific approaches to ensure that policy addresses ecosystem services and ecological intensification in a flexible way include the following (derived in part from Bianchi *et al.*, 2013; Pe'er *et al.,* 2014; Reed *et al.,* 2014):

- involving stakeholders, including farmers, environment experts and scientists, in policy development;
- supporting training and education programmes for farmers and land managers on harnessing ecosystem services in agricultural production;
- boosting the capacity and quality of extension services through improved recruitment rates, in-service training and provision of tools for extension;
- supporting research for identifying measures that enhance ecological intensification and for providing information on values, risks and multidimensional benefits of such measures;
- encouraging flexible implementation of policy to account for local conditions and appropriate spatial scales;

» recognizing that farmers, applying holistic practices, provide public goods such as soil conservation or watershed services, and should be supported for their contribution;
» linking payments for ecosystem services to the value of the public goods provided by the farmers rather than the size of the cultivated area;
» providing incentives for cross-boundary collaboration in the provision of ecosystem services that need to be managed at catchment or wider spatial scales.

In many agricultural and agropastoral communities in East Africa, decision-making on land use and control over key political, economic and social factors of production are the province of men. Providing ways for women to participate in decision-making processes is critical.

Finally, although it is a sensitive issue, it is paramount that population growth in Africa be discussed in the context of food security. It is a well known prediction that by 2050, the world's population will be 9.7 billion, and reportedly a quarter of this will be in Africa. Bremner (2012) makes a case that investment in women and family planning is a necessary complement to agriculture and food policy solutions if future needs are to be met and pressure on soil, water and forest cover to be reduced.

The research community

Research on ecosystem services that underpin agricultural production (e.g. pest regulation, soil health, pollination) could provide a better understanding of measures that can be supported to enhance these services.

An effective and convincing way of assigning value to single or packaged ecosystem services remains an urgent need, if policymakers are to be convinced to enhance these through policy. In addition, as several reviews have underscored, policymakers and land managers alike will want to have some concept of the risk and uncertainty in attaining benefits from ecological intensification. An example of a long term study is as the farming system trial in operation since 1981 at the Rodale Institute in Pennsylvania, United States of America (Mirsky *et al.*, 2012) – it can give some interesting insights into stability of yields achieved through enhancement of ecosystem services under variable climatic conditions.

One of the key policy limitations and barriers to implementation that has been identified for functional agrobiodiversity, which may apply equally well to ecological intensification, is the limited information available in terms of yield performance, data on profitability and reduced input costs relative to conventional approaches. Positive reports of the potential of functional agrobiodiversity are regarded as "rarely underpinned by a rigorous economic and agronomic analysis" (Bianchi *et al.*, 2013). Improved monitoring and evaluation of appropriate indicators will be key to persuading farmers to adopt practices for enhancing functional agrobiodiversity. However, remaining ambiguity about financial and agronomic risks associated with implementation of alternative measures is still a challenge for large-scale adoption of such measures. The same challenges would apply to the upscaling and spread of ecological intensification practices, pointing to a need to promote research to close the knowledge gaps.

Farmers and farm communities, including extension agents and multipliers

Farmers and farm communities ultimately will know best how ecosystem services can be incorporated in farm practices and provide benefits to the farm and beyond. Policy measures to support ecosystem services will be most sustainable and effective when they pay for the ecosystem services that have the greatest value for civil society stakeholders. Farmers can contribute substantially to identification of the most valuable services and means of ensuring them by participating in training courses and demonstration activities on ecosystem services in agriculture and then engaging as stakeholders in the design and development of rural development and agri-environment initiatives. The involvement of farm communities can also increase the demand for initiatives that best account for local conditions and appropriate spatial scales.

Farmers can support such agro-ecological approaches by:

- respecting traditional practices as being a time-tested basis for low-input management of natural resources, and building on these with new understanding from agricultural research;
- being open and willing to take a whole-system approach to management that considers interactions among crops and areas of habitat on farm, over time as well as space;
- sharing their observations with neighbours and promoting farmer-to-farmer learning;
- using all resources at hand, including increased access to communication technology, to stay informed about approaches and inputs in holistic farming.

Other actors

The reconciliation and sustainable management of food production, biodiversity and ecosystem services is a constant, protracted and multi-scaled challenge. Given the urgency of this objective, the trends and the complexity of pressures and drivers at play, it may be valuable to consider how policy options and responses could function at lower jurisdictional levels, where relatively direct flows of benefits might be more easily recognized and tracked, and incentive mechanisms for their provisioning might be more directly implemented and sustained. Thus, at subnational and societal levels, actions that could be taken include:

- encouraging farmer organizations and cooperatives to co-manage ecosystem services that are delivered across landscapes rather than within individual farm boundaries (e.g. through landscape IPM initiatives), allowing specific targets groups (e.g. smallholders in marginal areas, young farmers, cooperating farmer groups) to profit from environmentally friendly practices or joint provision of landscape-scale benefits (Pe'er *et al.*, 2014);
- working with the private sector to incubate businesses that support ecological intensification (e.g. provision of organic inputs such as compost and cover crop seed mixtures, provision of knowledge and advice that support ecological over conventional inputs);
- working with private-sector food retailers to promote – for their own benefit and that of society – more resilient farming practices, ensuring less volatility of food supply;

» developing food-sector procurement policies that have multiple benefits, such as more nutritious foods for schools and hospitals, cultivated in ways that conserve biodiversity and make landscapes around urban centres more capable of controlling flooding and erosion.

REFERENCES

Achiando, G. 2012. *Effectiveness of communications systems and indigenous knowledge in adaptation to climate change by small holder farmers in Kilifi District*. MSc thesis, Egerton University, Kenya.

Akinwumi, G.S., Fariyike, T.A., Olufunmi, O.O., Olabode, I.A. & Adelaja, B.A. 2013. Influence of the rate and timing of mulching on the growth and yield of ginger (*Zingiber officinale* L.). *Acta Horticulturae,* 1007: 323-328.

Albrecht, A. & Kandji, S.T. 2003. Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems and Environment,* 99: 15–27. DOI: 10.1016/S0167-8809(03)00138-5.

Altieri, M.A. 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. *Agriculture, Ecosystems and Environment,* 93: 1–24.

Andrew, I.K.S., Storkey, J. & Sparkes, D.L. 2015. A review of the potential for competitive cereal cultivars as a tool in integrated weed management. *Weed Research,* 55: 239-248.

Appiah, M. & Pappinen, A. 2010. Farm forestry prospects among some local communities in Rachuonyo District, Kenya. *Small-Scale Forestry*, 9: 297-316. DOI: 10.1007/s11842-010-9117-z.

Apse, C. & Bryant, B. 2015. *Upper Tana-Nairobi Water Fund: a business case*. Nairobi, The Nature Conservancy.

Asfaw, S. 2008. *Global agrifood supply chain, EU food-safety standards and African small-scale producers – The case of high-value horticultural export from Kenya*. PhD thesis, University of Hannover, Germany.

Augustine, D.J. & McNaughton, S.J. 2004. Temporal asynchrony in soil nutrient dynamics and plant production in a semiarid ecosystem. *Ecosystems,* 7(30): 829–840.

Augustine, D.J., Veblen, K.E., Goheen, J.R., Riginos, C. & Young, T.P. 2011. Pathways for positive cattle–wildlife interactions in semi-arid rangelands. *In* N.J. Georgiadis, ed. *Conserving wildlife in African landscapes: Kenya's Ewaso ecosystem*, pp. 55–71. Washington, DC: Smithsonian Institution Scholarly Press.

AWF (African Wildlife Foundation). 2015. Land and habitat protection. Website (available at www.awf.org/habitat-protection). Accessed 19 March 2015.

Ayuke, F.O., Rao, M.R., Swift, M.J. & Opondo-Mbai, M.L. 2003. Impact of soil fertility management strategies on diversity and population of soil macrofauna in an agroecosystem. *East African Agricultural and Forestry Journal*, 69(2): 131-137.

Bàrberi, P. 2002. Weed management in organic agriculture: are we addressing the right issues? *Weed Research*, 42: 176-193.

Bàrberi, P. 2015. Functional biodiversity in organic systems: the way forward? *Sustainable Agriculture Research*, 4: 26-31.

Barrios, E. 2007. Soil biota, ecosystem services and land productivity. *Ecological Economics*, 64: 269–285.

Bastiaans, L., Paolini, R. & Baumann, D.T. 2008. Focus on ecological weed management: what is hindering adoption? Weed Research, 48: 481-491.

Bationo, A., Waswa, B., Okeyo, J.M., Maina, F. & Kihara, J., eds. 2011. *Innovations as key to the Green Revolution in Africa – exploring the scientific facts*, Vols. 1 & 2. Dordrecht, the Netherlands, Springer.

Bellon, M.R., Gotor, E. & Caracciolo, F. 2015. Conserving landraces and improving livelihoods: how to assess the success of on-farm conservation projects? *International Journal of Agricultural Sustainability*, 13(2): 167–182.

Berkes, F., Colding, J. & Folke, C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, 10(5): 1251–1262.

Biamah, E.K., Rockstrom, J. & Okwach, J. 2000. *Conservation tillage for dryland farming. Technological options and experiences in Eastern and Southern Africa*. RELMA Workshop Report Series. Nairobi, Swedish International Development Corporation (SIDA) Regional Land Management Unit (RELMA).

Bianchi, F., Mikos, V.,Brussaard, L., Delbaere, B., Pulleman, M. 2013. Opportunities and limitations for functional agrobiodiversity in the European context. Environmental Science & Policy 27. 223-231:228.

Borlaug, N.E. & Dowswell, C.R. 1994. The importance of agriculture and a stable adequate food supply to the well-being of human kind. *In* R.A. Goldberg, ed. *Research in domestic and international agribusiness management*, pp. 1-32. Greenwich, Connecticut, USA, JAI Press.

Bremner, J. 2012. Population and Food Security: Africa's Challenge. Policy Brief, Population Reference Bureau.

CBD. 2010. *Global Biodiversity Outlook 3* (available at www.cbd.int/gbo3). Montreal, Canada.

CBD. 2014. *Global Biodiversity Outlook 4* (available at www.cbd.int/gbo4). Montreal, Canada.

CBD. 2016a. Ecosystem approach (available at www.cbd.int/ecosystem). Accessed January 2016.

CBD. 2016b. National Biodiversity Strategies and Action Plans (NBSAPs). Website (available at www.cbd.int/nbsap/default.shtml). Accessed May 2016.

Chacon, J.C. & Gliessman, S.R. 1982. Use of the "non weed" concept in the traditional tropical agroecosystems in southeastern Mexico. *Agroecosystems*, 8: 1–11.

Chengole, J.M., Welimo, M., Belmin, R., Ng'ang'a, T. & Kamau, G. 2014. From a desired to a despised and later desired tree: the case of prosopis introduction and management in Marigat, Baringo County, Kenya. *In* B. Triomphe, B., Waters-Bayer, A., Klerkx, L., Schut, M., Cullen, B., Kamau, G. & LeBorgne, E., eds. *Innovation in smallholder farming in Africa: recent advances and recommendations*, pp. 76–79. Montpellier, France, French Agricultural Research Centre for International Development (CIRAD).

Cloutier, D.C., van der Weide, R.Y., Peruzzi, A. & Leblanc, M.L. 2007. Mechanical weed management. *In* Upadhyaya, M.K. & Blackshaw, R.E., eds. *Non-chemical weed management: principles, concepts and technology*, pp. 111-134. Wallingford, UK, CAB International.

Cook, S.M., Khan, Z.R. & Pickett, J.A. 2006. The use of push-pull strategies in integrated pest management. *Annual Review of Entomology,* 52(1): 375.

Cooper, T., Hart, K. & Baldock, D. 2009. *The Provision of Public Goods Through Agriculture in the European Union*, Report Prepared for DG Agriculture and Rural Development, Contract No 30-CE-0233091/00-28, Institute for European Environmental Policy: London.

Costanzo, A. & Bàrberi, P. 2014. Functional agrobiodiversity and agroecosystem services in sustainable wheat production – A review. *Agronomy for Sustainable Development,* 34: 327-348.

Critchley, W., Reij, C. & Seznec, A. 1992. *Water harvesting for plant production*, Vol. II, *Case studies and conclusions for sub-Saharan Africa*. World Bank Technical Paper No. 157. Africa Technical Department Series. Washington, DC, World Bank.

Critchley, W. & Siegert, K. 1991. *Water harvesting: a manual for the design and construction of water harvesting schemes for plant production*. Rome, FAO.

Dabasso, B.H. 2006. *Herder knowledge of landscape scale biodiversity monitoring in Marsabit Central, northern Kenya.* MSc thesis, Norwegian University of Life Sciences (NMBU), Oslo.

Dabasso, B.H., Oba, G., & Roba, H.G. 2012. Livestock-based knowledge of rangeland quality assessment and monitoring at landscape level among Borana herders of northern Kenya. *Pastoralism*, 2(1): 1-13.

Daily, G. 1997. Introduction: what are ecosystem services? *In* Daily, G., ed. *Nature's services: societal dependence on natural ecosystems.* Washington, DC, Island Press.

Daily Nation. 2014. Ministry must take lead in combating lethal maize pest. 29 November. (Available at www.nation.co.ke/business/seedsofgold/Ministry-must--lead-in-combating-lethal-maize-pest/-/2301238/2539026/-/uxh6ah/-/index.html).

Das, T.K. & Yaduraju, N.T. 2011. Effects of missing-row sowing supplemented with row spacing and nitrogen on weed competition and growth and yield of wheat. *Crop and Pasture Science*, 62: 48-57.

Davis, A.D. 2010. Cover-crop roller-crimper contributes to weed management in no-till soybean. *Weed Science*, 58: 300-309.

Davis, A.D., Taylor, E.C., Haramoto, E.C. & Renner, K.A. 2013. Annual postdispersal weed seed predation in contrasting field environments. *Weed Science,* 61: 296-302.

Dicks, L., Vaughan, M. & Lee-Mäder, E. (in press). Developing incentives for farmers to support pollinators: contrasting approaches from Europe and the United States. Earthscan

Doran, J.W. & Parkin, T.B. 1996. Quantitative indicators of soil quality: a minimum data set. *In* J.W. Doran & A.J. Jones, eds. *Methods for assessing soil quality*, pp. 25–37. SSSA Spec. Publ. 49. Madison, Wisconsin, USA, Soil Science Society of America (SSSA).

Duveskog, D. 2001. Water harvesting and soil moisture retention – A study guide for farmer field schools. Nairobi, Farm Level Applied Research Methods for East and Southern Africa (FARMESA).

Dyer, N., Omondi, S. & Wantsusi, M. 2008. *Securing pastoralism in East and West Africa: protecting and promoting livestock mobility*. Karamojong Cluster Desk Review: Livestock mobility in northeast Uganda, northwest Kenya, southwest Ethiopia and southern Sudan. London, International Institute for Environment and Development (IIED). (Available at http://pubs.iied.org/pdfs/G03036.pdf).

FAO. 2009 *Livestock keepers – Guardians of biodiversity*. FAO Animal Production and Health Paper No. 167. Rome.

FAO. 2010a. *An international consultation on integrated crop–livestock systems for development: the way forward for sustainable production intensification*. Integrated Crop Management, Vol. 13. FAO, Rome.

FAO. 2010b. *Global Forest Resources Assessment 2010: country report for Kenya.* Rome.

FAO. 2015 Agroforestry (available at www.fao.org/forestry/agroforestry). Accessed 1 March 2016.

FAO. 2016 Pollination (available at www.fao.org/pollination/background). Accessed 19 March 2016.

Fayo, G.D. 2011. *Coping with scarcity in northern Kenya: the role of pastoralist Borana Gada indigenous justice institutions in conflicts prevention and resolutions for range resources managements*. MA thesis, Erasmus University, The Hague, the Netherlands.

Fenner, M. & Thompson, K. 2005. *The ecology of seeds*. Cambridge, UK, Cambridge University Press.

Flintan, F. 2011. *Changing nature of gender roles in the drylands of the Horn and East Africa: implications for DRR programming.* Report for the Oxfam-led Regional Learning and Advocacy Programme for Vulnerable Dryland Communities (REGLAP) (available at http://reliefweb.int/sites/reliefweb.int/files/resources/F_R_479.pdf).

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D. & Zaks, D.P.M. 2011. Solutions for a cultivated planet. *Nature,* 478: 337–342.

Franzel, S. & Wambugu, C. 2007. The uptake of fodder shrubs among smallholders in East Africa: key elements that facilitate widespread adoption. *In* M.D. Hare & K. Wongpichet, eds. *Forages: a pathway to prosperity for smallholder farmers*, pp. 203-222. Proceedings of an International Symposium. Ubon Ratchathani, Thailand, Ubon Ratchathani University.

Gachene, C.K.K., Kathumo, V., Okello, J.J. & Ngigi, M. 2015. The disappearing forest: a case study of trends in land use and land cover change of the threatened lower Tana River forest complex, coastal Kenya. *In* Z. Khalif, C.K.K. Gachene, P. Gicheru, D.M. Mburu & C.G. Gakahu, eds. *Sustainable land management in dry lands of Kenya: improving land productivity through participatory research and technology transfer*, pp. 1-12. Nairobi, UNDP.

Gachene, C.K.K. & Wortmann, C.S. 2004. Green manure/cover crop technology in eastern and central Uganda: development and dissemination. *In* M. Eilitta, J. Mureithi & R. Derpsch, eds. *Manure/cover crop systems of smallholder farmers: experiences from tropical and subtropical regions,* pp. 219-236. Dordrecht, the Netherlands, Kluwer Academic Publishers.

Gallai, N., Salles, J.M., Settele, J. & Vaissière, B.E. 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*, 68: 810-821.

Garibaldi, L.A., Carvalheiro, L.G., Leonhardt, S.D., Aizen, M.A., Blaauw, B.R. & Isaacs, R. 2014. From research to action: enhancing crop yield through wild pollinators. Frontiers in Ecology and the Environment, 12:439-447.

Gatsby Charitable Foundation. 2005. The quiet revolution: push-pull technology and the African farmer. Gatsby Occasional Paper. London, UK (available at www.infonet-biovision.org/sites/default/files/613.gatsby_occasional_paper.pdf).

Geertsma, R., Wilschut, L.I. & Kauffman, S. 2010. *Review for the Green Water Credits Pilot Operation in Kenya*. Green Water Credits Report 8. ISRIC Report 2010/02. Wageningen, the Netherlands, International Soil Reference and Information Centre (ISRIC) - World Soil Information.

Gicheru, P.T. & Kimigo, J. 2011. Impact on soil quality of land-use change and continuous cultivation in Sasumua catchment, Kenya. *Pedologist,* Special Issue, 55(3): 326-331.

Godfray, H.C.J., Beddington, J.R., Crute, J.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M. & Toulmin, C. 2010. Food security: the challenge of feeding 9 billion people. *Science*, 327(5967): 812-818.

Gómez, R., Liebman, M. & Munkvold, G. 2014. Weed seed decay in conventional and diversified cropping systems. *Weed Research,* 54: 13-25.

Government of Kenya. 2012. National Policy for the Sustainable Development of Northern Kenya and other Arid Lands. Sessional Paper No. 8 of 2012. Nairobi.

Guerry, A. D., Polasky, S., Lubchenco, J., Chaplin-Kramer, R., Daily, G. C., Griffin, R. Ruckelshaus, M., Bateman, I.J., Duraiappah, A., Elmqvist, T., Feldman, M. W., Folke, C., Hoekstra, J., Kareiva, P.M., Keeler, B.L., Li, S., McKenzie, E., Ouyang, Z., Reyers, B., Ricketts, T.H., Rockström, J., Tallis, H. & Vira, B. 2015. Natural capital and ecosystem services informing decisions: From promise to practice. Proceedings of the National Academy of Sciences, 112(24), 7348-7355.

Hallo, B., Oba, G. & Guyo, H. 2011. Livestock based perceptions of range quality change at landscape level among Borana community of northern Kenya. *Animal Production Society of Kenya*, 78.

Harker, K.N., Clayton, G.W. & O'Donovan, J.T. 2005. Reducing agroecosystem vulnerability to weed invasion. *In* Inderjit, ed. *Invasive plants: ecological and agricultural aspects,* pp. 195-207. Basel, Switzerland, Birkhäuser Verlag.

Heller, J. 1996. *Physic nut:* Jatropha curcas *L*. Rome, International Plant Genetic Resources Institute (IPGRI) (available at www.bio-nica.info/biblioteca/Heller1996Jatropha.pdf).

Henson, S., Masakure, O. & Cranfield, J. 2011. Do fresh produce exporters in sub-Saharan Africa benefit from GlobalGAP certification? *World Development,* 9(3): 375-386.

Huho, J.M., Ngaira, J.K.W. & Ogindo, H.O. 2011. Living with drought: the case of the Maasai pastoralists of northern Kenya. *Educational Research*, 2(1): 779-789.

Hunt, C., Riungu, M. & Mathiu, M. 2011. *Constructed wetland for water treatment and recreation, Ngong River: a preliminary feasibility study*. Nairobi, Centre for Environmental Stewardship.

IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development). 2009. *Agriculture at a crossroads: global report.* Washington, DC, Island Press.

ICRAF (World Agroforestry Centre). 2013. *Strategy 2013-2022 - Transforming lives and landscapes with trees*. Nairobi (available at www.worldagroforestry.org/content/strategy-2013-2022).

Iiyama, M., Kariuki, P.C. & Maitima, J. 2007. Crop-livestock diversification patterns in relation to income and manure use: a case study from a Rift Valley community, Kenya. *African Journal of Agricultural Research,* 2(3): 58-66.

Imbahale, S.S., Githaiga, J.M., Chira, R.M. & Said M.Y. 2008. Resource utilization by large migratory herbivores of the Athi-Kapiti ecosystem. *African Journal of Ecology*, 46: 43–51.

Jama, B., Palm, C.A., Buresh, R.J., Niang, A., Gachengo, C., Nziguheba, G. & Amadalo, B. 2000. *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya: a review. *Agroforestry Systems*, 49: 201–221.

Jamnadass, R., Place, F., Torquebiau, E., Malézieux, E., Iiyama, M., Sileshi, G.W., Kehlenbeck, K., Masters, E., McMullin, S., Weber, J.C. & Dawson, I.K. 2013. *Agroforestry, food and nutritional security*. Nairobi, World Agroforestry Centre (ICRAF).

Kalinda, C., Muriuki, J., Mburu, D., Ngamau, K., Kihoro, J., Odour, A., Cherogony, K., Malesu, M., Chisha-Kasumu, E. & Vinya, R. 2015. Effect of tillage and leguminous trees on soil organic carbon and infiltration rates in the semiarid region of Kibwezi, eastern Kenya. *In* Z. Khalif, C.K.K. Gachene, P. Gicheru, D.M. Mburu & C.G. Gakahu, eds. *Sustainable land management in dry lands of Kenya: improving land productivity through participatory research and technology transfer*, pp. 143-160. Nairobi, UNDP.

Kanyanjua, S.M., Ireri, L., Wambua, S. & Nandwa, S.M., 2002. *Acidic soils in Kenya: constraints and remedial options*. KARI Technical Note No. 11. Nairobi, Kenya Agricultural Research Institute (KARI).

Karanja, N.K. & Kahindi, J.H.P., eds. 2002. *Challenges and imperatives for biological nitrogen fixation: research and applications in Africa for the 21st century*. Nairobi, John Philips Africa Ltd. Publishers.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F. & Schuman, G.E. 1997. Soil quality: a concept, definition and framework for evaluation. *Soil Science Society of America Journal*, 61: 4–10.

Karuma, A., Mtakwa, P., Amuri, N., Gachene, C.K. & Gicheru, P. 2015. Tillage and cropping effects on soil water dynamics and crop yields in Mwala District, Kenya. *In* Z. Khalif, C.K.K. Gachene, P. Gicheru, D.M. Mburu & C.G. Gakahu, eds. *Sustainable land management in dry lands of Kenya: improving land productivity through participatory research and technology transfer*, pp. 121-141. Nairobi, UNDP.

Kasina, M.J. 2012. Bees require protection for sustainable horticultural crops production in Kenya. *Julius-Kühn-Archiv*, 437: 167-172.

Kasina, M., Maingi, P., Mulwa, J., Karanja, T., Momanyi, G., Kyallo, G. & Matolo, N. 2014. *Bactrocera invadens* fruit fly population distribution within Kandara sub county, Murang'a County, Kenya. *The 8th Egerton University International Conference Proceedings*, pp. 136-141. Njoro, Kenya, 26-28 March 2014.

Kasina, M.J., Kraemer, M., Martius, C. & Wittmann, D. 2009a. Farmers' knowledge of bees and their natural history in Kakamega district, Kenya. *Journal of Apicultural Research*, 48(2): 126-133.

Kasina, M.J., Mburu, J., Kraemer, M. & Holm-Mueller, K. 2009b. Economic benefit of crop pollination by bees: a case of Kakamega small-holder farming in western Kenya. *Journal of Economic Entomology,* 102(2): 467–473.

Kent Wildlife Trust. 2016. Website (available at www.kentwildlifetrust.org.uk). Accessed May 2016.

Kermeliotis, T. 2013. Boy scares off lions with flashy invention. *CNN*, online edition, 26 February (available at http://edition.cnn.com/2013/02/26/tech/richard-turere-lion-lights). Accessed March 2016.

Khan, Z.R. & Pickett, J.A. 2001. Habitat management strategies for the control of cereal stemborers and striga in maize in Kenya. *Insect Science and its Application,* 21: 375-380.

Khan, Z.R., Midega, C.A., Amudavi, D.M., Hassanali, A. & Pickett, J.A. 2008. On-farm evaluation of the 'push–pull' technology for the control of stemborers and striga weed on maize in western Kenya. *Field Crops Research*, 106(3): 224-233.

Khan, Z.R., Midega, C.A.O., Pittchar, J.O., Murage, A.W., Birkett, M.A., Bruce, T.J.A. & Pickett, J.A. 2014. Achieving food security for one million sub-Saharan African poor through push–pull innovation by 2020. *Philosophical Transactions of the Royal Society B*, 369: 20120284. DOI: 10.1098/rstb.2012.0284369.

Kibet, S. &. Oyieke, H. 2009. *Possible integration of traditional knowledge, gender roles and beliefs in modern conservation*. A commissioned Study for the Research Programme on Sustainable Use of Dryland Biodiversity (RPSUD). Nairobi, National Museums of Kenya.

Kifuko-Koech, M., Pypers, P., Okalebo, J R., Othieno, C.O., Khan, Z.R., Pickett, J.A., Kipkoech, A.K. & Vanlauwe, B. 2012. The impact of *Desmodium* spp. and cutting regimes on the agronomic and economic performance of *Desmodium*–maize intercropping system in western Kenya. *Field Crops Research,* 137: 97–107.

Kitalyi, A., Wambugu, R.O.C. & Kimaro, D. 2013. *FAO characterisation of Global Heritage Agroforestry Systems in Tanzania and Kenya*. Dar es Salaam, United Republic of Tanzania, Agroforestry and Development Alternatives (AFOREDA).

Kong, C.H., Hu, F., Wang, P. & Wu, J.L. 2008. Effect of allelopathic rice varieties combined with cultural management options on paddy field weeds. *Pest Management Science,* 64: 276-282.

Kremen, C., Iles, A. & Bacon, C. 2012. Diversified farming systems: an agroecological, systems-based alternative to modern industrial agriculture. *Ecology and Society,* 17(4): 44.

Kristjanson, P., Neufeldt, H., Gassner, A., Mango, J., Kyazze, F.B., Desta, S., Sayula, G., Thiede, B., Förch, W., Thornton, P.K. & Coe, R. 2012. Are food insecure smallholder households making changes in their farming practices? Evidence from East Africa. *Food Security,* 4: 381-397.

KWTA (Kenya Water Towers Agency). 2015. *Strategic Plan 2016-2020*. Nairobi, Republic of Kenya.

Labrada, R. 2008. Allelopathy as a tool for weed management. *Allelopathy Journal,* 22: 283-287.

Lal, R. 2004. Is crop residue a waste? *Journal of Soil and Water Conservation*, 59: 136-139.

Lal, R. 2013. Intensive agriculture and the soil carbon pool. *Journal of Crop Improvement*, 27(6): 735-751. DOI: 10.1080/15427528.2013.845053.

Landis, D.A., Menalled, F.D.A., Costamagna, C. & Wilkinson, T.K. 2005. Manipulating plant resources to enhance beneficial arthropods in agricultural landscapes. *Weed Science,* 53: 902-908.

Lean, G. 2016, January 3. UK flooding: How a Yorkshire town worked with nature to stay dry. *Independent*. Retrieved from: www.independent.co.uk/news/uk/home-news/uk-flooding-how-a-yorkshire-flood-blackspot-worked-with-nature-to-stay-dry-a6794286.html

Légère, A., Stevenson, F.C. & Benoit, D.L. 2011. The selective memory of weed seedbanks after 18 years of conservation tillage. *Weed Science,* 59: 98-106.

Lehmann, J., Weigl, D., Droppelmann, K., Huwe, B. & Zech, W. 1998. Nutrient cycling in an agroforestry system with runoff irrigation in northern Kenya. *Agroforestry Systems,* 43: 49–70.

Lewis, W.J., van Lenternen, J.C., Phatak, S.C. & Tumlinson, J.H. 1997. A total system approach to sustainable pest management. *Proceedings of the National Academy of Sciences of the United States of America,* 94: 12243–12248.

Lewu, F.B. & Afolayan, A.J. 2009. Ethnomedicine in South Africa: the role of weedy species. *African Journal of Biotechnology,* 8: 929–934.

Li, S.S., Wei, S.H., Zuo, R.L., Wei, J.G. & Qiang, S. 2012. Changes in the weed seed bank over 9 consecutive years of rice-duck farming. *Crop Protection,* 37: 42–50.

Liebman, M. & Gallandt, E.R. 1997. Many little hammers: ecological management of crop-weed interactions. *In* L.E. Jackson, ed. *Ecology in agriculture,* pp. 291-343. San Diego, California, USA, Academic Press.

Lott, J.E., Ong, C.K. & Black, C.R. 2009. Understorey microclimate and crop performance in a *Grevillea robusta*-based agroforestry system in semi-arid Kenya. *Agricultural and Forest Meteorology*, 149: 1140–1151. DOI: 10.1016/j.agrformet.2009.02.002.

Lux, S.A., Copeland, R.S., White, I.M., Manrakhan, A. & Billah, M.K. 2003. A new invasive fruit fly species from the *Bactrocera dorsalis* (Hendel) group detected in East Africa. *Insect Science and its Application,* 23: 355–360.

MA (Millennium Ecosystem Assessment). 2005a. *Ecosystems and human well-being: synthesis*. Washington, DC, *Island Press*.

MA (Millennium Ecosystem Assessment). 2005b. *Living beyond our means: natural assets and human well-being*. Statement from the Millennium Ecosystem Assessment Board (available at www.millenniumassessment.org/en/BoardStatement.html).

Mahmood, R., Naseer, M., Shahid, A.A., Usmani, A. & Ali, A. 2014. Screening of indigenous weed extracts against *Fusarium solani* with an emphasis to soil fertility-related microbial activities. *Journal of Food, Agriculture and Environment,* 12: 958-962.

Mairura, F.S., Mugendi, D.N., Mwanje, J.I., Ramisch, J.J., Mbugua, P.K. & Chianu, J.N. 2008. Scientific evaluation of smallholder land use knowledge in central Kenya. *Land Degradation & Development*, 19(1): 77-90.

Mancilla-Leytón, J.M., Pino Mejías, R. & Vicente, A.M. 2012. Do goats preserve the forest? Evaluating the effects of grazing goats on combustible Mediterranean scrub. *Applied Vegetation Science*, 16(1): 63-73.

Martin, E.C. 1975. The use of bees for crop pollination. In *The hive and the honey bee*, pp. 579–614. Hamilton, Illinois, USA, Dadant & Sons.

Martins, D.J., Miller, S.E., Cords, M., Hirschauer, M.T. & Goodale, C.B. 2014. Observations on an irruption event of the moth *Achaea catocaloides* (Lepidoptera: Erebidae) at Kakamega Forest, Kenya. *Journal of East African Natural History*, 103(1): 31-38.

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

Mati, B.M. 2010. Agricultural water management delivers returns on investment in eastern and southern Africa: a regional synthesis. *In* B. Mati, ed. *Agricultural water management interventions delivers returns on investment in Africa – A compendium of 18 case studies from six countries in eastern and southern Africa*, p. 1-29. Saarbrücken, Germany, VDM Verlag.

Mati, B.M. 2012. *Runoff harvesting for crop production: practical solutions for dryland agriculture*. Training Manual 1. Bujumbura, Burundi, Nile Basin Initiative (NBI), Nile Equatorial Lakes Subsidiary Action Programme (NELSAP) Regional Agricultural and Trade Programme (RATP).

Maundu, P. & Morimoto, Y. 2008. Reconciling genetic resources and local knowledge conservation and livelihoods enhancement in research and development: experiences of Bioversity International in sub-Saharan Africa. *Biodiversity,* 9(1&2): 56–60.

Mbow, C., van Noordwijk, M., Prabhu, R. & Simons, T. 2014. Knowledge gaps and research needs concerning agroforestry's contribution to Sustainable Development Goals in Africa. *Current Opinion in Environmental Sustainability*, 6: 162–170. DOI: 10.1016/j.cosust.2013.11.030.

Mbuku, S., Kahi, A. & Kosgey, I.S. 2012: Indigenous knowledge and adaptation strategies of pastoralists to climate variability in northern Kenya. Poster submitted to Tropentag Conference 2012, Goettingen, Germany, 9–11 October (available at www.tropentag.de/2012/proceedings/node356.html).

Mekonnen, M.M. & Hoekstra, A.Y. 2014. Water conservation through trade: the case of Kenya. *Water International,* 39(4): 451-468.

MEWNR (Ministry of Environment, Water and Natural Resources, Kenya). 2014. *Forest Policy, 2014*. Nairobi.

Mihale, M.J., Deng, A.L., Selemani, H.O., Mugisha-Kamatenesi, M., Kidukuli, A.W. & Ogendo, J.O. 2009. Use of indigenous knowledge in the management of field and storage pests around Lake Victoria basin in Tanzania. *African Journal of Environmental Science and Technology*, 3(9): 251-259.

Miriti, J.M., Kironchi, G., Esilaba, A.O., Heng, L.K., Gachene, C.K.K. & Mwangi, D.M. 2012. Yield and water use efficiencies of maize and cowpea as affected by tillage and cropping systems in semi-arid eastern Kenya. *Agricultural Water Management*, 115(2012): 148-155.

Mirsky, S.B., Matthew R. Ryan, William S. Curran, John R. Teasdale, Jude Maul, John T. Spargo, Jeff Moyer, Alison M. Grantham, Donald Weber, Thomas R. Way, Camargo, G. 2012. Conservation tillage issues: Cover crop-based organic rotational no-till grain production in the mid-Atlantic region, USA. Renewable Agriculture and Food Systems 27, 31-40.

MNRT. 2011. Proposed National Definition of Forest for Tanzania. Ministry of Natural Resources and Tourism. Dar es Salaam, Tanzania.

Molden, D., Frenken, K., Barker, R., de Fraiture, C., Mati, B. Svendsen, M., Sadoff, C. & Finlayson, C. M. 2007. Trends in water and agricultural development. *In* D. Molden, ed. Water for food, water for life: a comprehensive assessment of water management in agriculture, pp. 57-89. London, Earthscan & Colombo, International Water Management Institute (IWMI).

Moonen, A.C. & Bàrberi, P. 2008. Functional biodiversity: an agroecosystem approach. *Agriculture, Ecosystems and Environment*, 127: 7-21.

Msuya, T.S. & Kideghesho, J.R. 2012. Mainstreaming agroforestry policy in Tanzania legal framework. *In* M.L. Kaonga, ed. *Agroforestry for biodiversity and ecosystem services - science and practice*, pp. 129-140. Rijeka, Croatia, InTech.

Muindi, E.M., Mrema, J.P., Semu, E., Mtakwa, P.W., Gachene, C.K.K. & Njogu, M.K. 2015. Phosphorus adsorption and its relation with soil properties in acid soils of western Kenya. *International Journal of Plant Science,* 4(3). DOI: 10.9734/IJPSS/2015/13037.

Mulumba, J.W., Nankya, R., Adokorach, J., Kiwuka, C., Fadda, C., De Santis, P. & Jarvis, D.I. 2012. A risk-minimizing argument for traditional crop varietal diversity use to reduce pest and disease damage in agricultural ecosystems of Uganda. *Agriculture, Ecosystems and Environment,* 157: 70–86.

Mureithi, J.G., Gachene, C.K.K. & Ojiem, J. 2003. The role of green manure legumes in smallholder farming systems in Kenya: the Legume Research Network Project. *Tropical and subtropical agroecosystems,* 1: 57-70.

Mureithi, J.G., Njune, M.N., Ali, R., Thorpe, W. & Mwatate, C.D. 1998. Adoption of forages by smallholder farmers in coastal lowlands. *Tropical Grasslands*, 32: 221–229.

Mureithi, M.S., Verdoodt, A., Gachene, C.K.K., Njoka, J.T., Wasonga, V.O., De Neve, S., Meyerhoff, E. & Van Ranst, E. 2014. Impact of enclosure management on soil properties and microbial biomass in a restored semi-arid rangeland, Kenya. *Journal of Arid Land*, DOI: 10.1007/s40333-014-0065-x.

Mutegi, J.K., Mugendi, D.N., Verchot, L.V. & Kung'u, J.B. 2008. Combining Napier grass with leguminous shrubs in contour hedgerows controls soil erosion without competing with crops. *Agroforestry Systems*, 74: 37–49. DOI: 10.1007/s10457-008-9152-3.

Muthuri, C.W., Ong, C.K., Black, C.R., Mati, B.M., Ngumi, V.W. & van Noordwijk, M. 2004. Modelling the effects of leafing phenology on growth and water use by selected agroforestry tree species in semi-arid Kenya. *Land Use and Water Resources Research*, 4: 1–11.

Muthuri, C.W., Ong, C.K., Black, C.R., Ngumi, V.W. & Mati, B.M. 2005. Tree and crop productivity in *Grevillea*, *Alnus* and *Paulownia*-based agroforestry systems in semi-arid Kenya. *Forest Ecology and Management*, 212: 23–39. DOI: 10.1016/j.foreco.2005.02.059.

Mwangi, D., Kasina, M., Nderitu, J., Hagen, M., Gikungu, M. & Kraemer, M. 2012. Diversity and abundance of native bees foraging on hedgerow plants in the Kakamega farmlands, western Kenya. *Journal of Apicultural Research,* 51(4): 298-305.

Mwangi, P.M. & Mathenge, P.W. 2014. Comparison of tithonia (*Tithonia diversifolia*) green manure, poultry manure and inorganic sources of nitrogen in the growth of kales (*Brassicae oleraceae*) in Nyeri county, Kenya. *African Journal of Food, Agriculture, Nutrition and Development*, 14(3).

Mwenda, G.M., Karanja, N., Boga, H., Kahindi, J., Muigai, A. & Odee, D. 2011. Abundance and diversity of legume nodulating rhizobia in soils of Embu District, Kenya. *Tropical and Subtropical Agroecosystems,* 13(1) (Special Issue - Conservation and sustainable management of belowground biodiversity in Kenyan agroecosystems).

Nandwa, S.M. & Bekunda, M.A. 1998. Research on nutrient flows and balances in east and southern Africa: state of the art. *Agriculture, Ecosystems & Environment*, 71: 5-19.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, Dr., Chan, K.M., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H. & Shaw, M. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment, 7, 4–11.

NEMA (National Environment Management Authority). 2012. *Wetland Monitoring and Assessment Strategy for Kenya*. Nairobi.

NEMA & UNDP (United Nations Development Programme). 2009. *Fourth National Report to the Conference of Parties to the Convention on Biological Diversity*. Nairobi, NEMA.

Ng'endo, M., Catacutan, D., Kung'u, J., Muriuki, J., Kariuki, J. & Mowo, J. 2013. The policy environment of conservation agriculture with trees (CAWT) in eastern Kenya: do small scale farmers benefit from existing policy incentives? *African Journal of Agricultural Research*, 8(23): 2924-2939. DOI: 10.5897/AJAR12.1882.

Ngowi, A.V.F., Mbise, T.J., Ijani, A.S.M., London, L. & Ajayi, O.C. 2007. Pesticides use by smallholder farmers in vegetable production in northern Tanzania. *Crop Protection (Guildford, Surrey)*, 26(11): 1617-1624. DOI: 10.1016/j.cropro.2007.01.008.

Njarui, D.M.G. & Mureithi, J.G. 2006. Enhancing maize and fodder productivity by use of legumes in semi-arid region of eastern Kenya. *In* J.G. Mureithi, C.K.K. Gachene, J.W. Wamuongo & M. Eilitta, eds. *Enhancing agricultural productivity in East Africa – Development and up-scaling of green manure legume technologies in Kenya,* pp. 203–234. Nairobi, Kenya Agricultural Research Institute (KARI).

Njoka-Njiru, E.N., Njarui, M.G., Abdulrazak, S.A. & Mureithi, J.G. 2006. Effect of intercropping herbaceous legumes with Napier grass on dry matter yield and nutritive value of the feedstuffs in semi-arid region of eastern Kenya. *Agricultura Tropica et Subtropica*, 39: 260–272.

Nori, M. & Davis, J. 2007. *Change of wind or wind of change? Climate change, adaptation and pastoralism.* Nairobi, International Union for Conservation of Nature (IUCN) East Africa Regional Office.

Nyamwamu, B., Shiundu, K. & Kibet, S. 2005. *Indigenous knowledge for thirteen-priority species for Tatro community, Yala*. Technical Report submitted to National Museums of Kenya. Nairobi.

Nyangena, W. & te Velde, D.W. 2012. *Managing the water–energy–land (WEL) nexus for inclusive and sustainable growth. A case study of flower production around Lake Naivasha.* Background paper for the European Report on Development 2011/2012.

Nziguheba, G. 2001. *Improving phosphorus availability and maize production through organic and inorganic amendments in phosphorus deficient soils in western Kenya.* PhD thesis, Katholieke Universiteit, Leuven, Belgium.

Oba, G. 1994. *The role of indigenous range management knowledge for desertification control in northern Kenya*. Linköping, Sweden, Environmental Policy and Society (EPOS).

Oba, G. 2009. *Harnessing pastoralists' indigenous range management knowledge for drought-resilient livelihood systems in the Horn of Africa*. Gland, Switzerland, International Union for Conservation of Nature (IUCN) World Initiative for Sustainable Pastoralism (WISP) & FAO (available at http://cmsdata.iucn.org/downloads/harnessing_pastoralists_indigenous_knowledge_review_2009_1.pdf).

Oba, G. & Lusigi, W.J. 1987. *An overview of drought strategies and land use in African pastoral systems.* Paper 23a. London, Overseas Development Network (ODI) Pastoral Development Network.

Obiero, C., Birech, R., Maling'a, J., Freyer, B., Ng'etich, K. & Lang'at, J. 2013. Performance and challenges of biofuel cropping systems in Kenyan smallholder farming systems: a case study on castor (*Ricinus communis* L.), jatropha (*Jatropha curcas* L.) and croton (*Croton megalocarpus* L.). *Australian Journal of Crop Science*, 7(7): 917.

O'Donovan, J.T., Harker, K.N., Turkington, T.K. & Clayton, G.W. 2013. Combining cultural practices with herbicides reduces wild oat (*Avena fatua*) seed in the soil seed bank and improves barley yield. *Weed Science*, 61: 328-333.

Ojiem, J.O. 2006. *Exploring socio-ecological niches for legumes in western Kenya smallholder farming systems.* PhD thesis, Wageningen University, the Netherlands.

Ouma, G., 2009. Intercropping and its application to banana production in East Africa: a review. *Journal of Plant Breeding and Crop Science*, 1: 13–15.

Oweis, T. & Hachum, A. 2006. Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. *Agricultural Water Management*, 80: 57-73.

Oweis, T., Prinz, P. & Hachum, A. 2001. *Water harvesting - Indigenous knowledge for the future of the drier environments.* Aleppo, Syria, International Centre for Agricultural Research in the Dry Areas (ICARDA).

Pe'er, G., Dicks, L.V., Visconti, P., Arlettaz, R., Báldi, A.,T. Benton,T.G., Collins, S., Dieterich, M., Gregory, R.D., Hartig, F., Henle, K., Hobson, P.R., Kleijn, D., Neumann, R.K., Robijns, T., Schmidt, J., Shwartz, A., W. J. Sutherland, Turbé, A., Wulf, F., Scott, A.V. 2014. EU agricultural reform fails on biodiversity. Science 344:6188. Supplementary Materials

Petersen, J. 2005. Competition between weeds and spring wheat for 15N-labelled nitrogen applied in pig slurry. *Weed Research,* 45: 103-113.

Picasso, V.D., Brummer, E.C., Liebman, M., Dixon, P.M. & Wilsey, B.J. 2008. Crop species diversity affects productivity and weed suppression in perennial polycultures under two management strategies. *Crop Science*, 48: 331-342.

Place, F., Roothaert, R., Maina, L., Franzel, S., Sinja, J. & Wanjiku, J. 2009. *The impact of fodder trees on milk production and income among smallholder dairy farmers in East Africa and the role of research.* ICRAF Occasional Paper No. 12. Nairobi, World Agroforestry Centre (ICRAF).

Polajnar, J., Eriksson, A., Lucchi, A., Anfora, G., Virant-Doberletc, M. & Mazzonia, V. 2014. Manipulating behaviour with substrate-borne vibrations – Potential for insect pest control. *Pest Management Science*, 71: 15–23.

Porensky, L.M., Franziska, S., Veblen, K.E., Treydte, A.C. & Young, T.P. 2013. Megaherbivores and cattle alter edge effects around ecosystem hotspots in an African savanna. *Journal of Arid Environments*, 96: 55–63.

Pretty, J., Toulmin, C. & Williams, S. 2011. Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, 9(1): 5-24. DOI: 10.3763/ijas.2010.0583

Prinz, D. 1996. Water harvesting: past and future. *In* L.S. Pereira, R.A. Feddes, J.R. Gilley & B. Lesaffre, eds. *Sustainability of irrigated agriculture*, pp. 135-144. Proceedings, NATO Advanced Research Workshop, Vimeiro, Portugal, 21-26 March 1994. Dordrecht, the Netherlands, Springer.

Quinones, M.A., Borlaug, N.E. & Dowswell, C.R. 1997. A fertilizer based green revolution for Africa. *In* R.J. Buresh, P.A. Sanchez & F. Calhoun, eds. *Replenishing soil fertility in Africa*, pp. 81-95. Madison Wisconsin, USA, Soil Science Society of America (SSSA).

Ramsar Convention Secretariat. 2011. The annotated Ramsar List: Kenya (available at www.ramsar.org/cda/en/ramsar-pubs-notes-anno-kenya/main/ramsar/1). Accessed January 2016.

Rao, K.P.C., Verchot, L.V. & Laarman, J. 2007. Adaptation to climate change through sustainable management and development of agroforestry systems. *Journal of SAT Agricultural Research*, 4: 1–30.

Rao, M.R. & Mathuva, M.N. 2000. Legumes for improving maize yields and income in semi-arid Kenya. *Agriculture, Ecosystems & Environment*, 78: 123–137.

Reed, M.S., Moxey, A., Prager, K., Hanley, N., Skates, J., Bonn, A., Evans, C., Glenk, K. & Thomson, K. 2014. Improving the link between payments and the provision of ecosystem services in agri-environment schemes. Ecosystem Services 9:44–53.

Reid, R.S. & Ellis, J. E. 1995. Impacts of pastoralists on woodlands in South Turkana, Kenya: livestock-mediated tree recruitment. *Ecological Applications*, 5(4): 978–992.

Republic of Kenya. 2010. Agricultural sector development strategy 2010-2020. Retrieved from: http://faolex.fao.org/docs/pdf/ken140935.pdf

Republic of Kenya. 2012. *Report of the high-level national dialogue on Kenya water towers, forests and green economy*. Nairobi.

Republic of Kenya. 2013. *National Water Master Plan 2030*. Nairobi, Ministry of Water and Irrigation.

Republic of Kenya. 2015. Fifth national report to the conference of parties to the Convention on Biological Diversity. Retrieved from: www.cbd.int/doc/world/ke/ke-nr-05-en.pdf

Riginos, C., Porensky, L.M., Veblen, K.E., Odadi, W.O., Sensenig, R.L., Kimuyu, D., Keesing, F., Wilkerson, M.L. & Young, T.P. 2012. Lessons on the relationship between livestock husbandry and biodiversity from the Kenya Long-Term Exclosure Experiment (KLEE). *Pastoralism: Research, Policy and Practice*, 2(1): 10.

Roba, G.M. 2013 *Indigenous institutions and knowledge in natural resources management in project pilot districts of Mbeere-North, Kyuso, Narok-North and Dadaab*. Final report on documentation of indigenous institutions. Nairobi, UNDP (available at www.slmkenya.org/sites/default/files/indigenous_knowledge_final.pdf).

Robinson, D.A., Hockley, N., Domina, E., Lebron, I., Scow, K.M., Reynolds, B., Emmett, B.A., Keith, A.M., de Jonge, L.W., Schjønning, P., Moldrup, P., Jones, S.B. & Tuller, M. 2011. Natural capital, ecosystem services, and soil change: why soil science must embrace an ecosystems approach. *Vadose Zone Journal*. DOI: 10.2136/vzj2011.0051

Robinson, D.A., Lebron, I., Reynolds, B. & Hockley, N. 2010. What are ecosystem services and natural capital, and how does this apply to soil science? In *1st International Conference and Expoloratory Workshop on Soil Architecture and Physico-Chemical Functions "CESAR"*, Tjele, Denmark, 30 November – 2 December 2010, pp. 325–330. Tjele, Denmark, Aarhus University & Aalborg University.

Robinson, D.A., Lebron, I. & Vereecken, H. 2009. On the definition of the natural capital of soils: a framework for description, evaluation and monitoring. *Soil Science Society of America Journal*, 73: 1904–1911.

Rutunga, V., Karanja, N.K. & Gachene, C.K.K. 2001. Decomposition rates of biomass obtained from six month – old *Tephrosia vogelii*, *Tithonia diversifolia* and natural fallow vegetation at Maseno, Kenya. *Biological Agriculture and Horticulture*, 19: 49-62.

Rutunga, V., Karanja, N.K. & Gachene, C.K.K. 2008. Six month-duration *Tephrosia vogelii* and *Tithonia diversifolia* planted fallows for improving maize production in Kenya. *Biotechnology, Agronomy, Society and Environment*, 12(3): 267-278.

Sangeetha C. & Baskar, P. 2015. Allelopathy in weed management: a critical review. *African Journal of Agricultural Research*, 10: 1004-1015.

Sanguankeo, P.P. & León, R.G. 2011. Weed management practices determine plant and arthropod diversity and seed predation in vineyards. *Weed Research*, 51: 404-412.

Shelukindo, H.B., Semu, E., Msanya, B.M., Singh, B.R. & Munishi, P.K.T. 2015. Soil organic carbon stocks of the Kitonga catchment forest reserve, Tanzania: variations with elevation. *In* R. Lal, B.R. Singh, D.L. Mwaseba, D. Kraybill, D.O. Hansen & L.O. Eik, eds. *Sustainable intensification to advance food security and enhance climate resilience in Africa*, pp. 315-327. Cham, Switzerland, Springer International Publishing.

Sinja, J., Karugia, J., Waithaka, M., Miano, D., Baltenweck, I., Franzel, S., Nyikal, R. & Romney, D. 2004. Adoption of fodder legumes technology through farmer-to-farmer extension approach. *Uganda Journal of Agricultural Sciences*, 9: 222–226.

Smalling, E.M.A. 1993. *An agroecological framework for integrated nutrient management with special reference to Kenya.* PhD thesis, Agricultural University, Wageningen, the Netherlands.

Smestad, B.T., Tiessen, H. & Buresh, R.J. 2002. Short fallows of *Tithonia diversifolia* and *Crotalaria grahamiana* for soil fertility improvement in western Kenya. *Agroforestry Systems*, 55: 181-194.

Stintzing, F.C., Kammerer, D., Schieber, A., Adama, H., Nacoulma, O.G. & Carle, R. 2004. Betacyanins and phenolic compounds from *Amaranthus spinosus* L. and *Boerhavia erecta* L. *Zeitschrift fur Naturforschung – Section C: A Journal of Biosciences*, 59: 1-8.

Swiderska, K., Reid, H., Song, Y., Li, J., Mutta, D., Ongugo, P., Pakia, M., Oros, R. & Barriga, S. 2011. *The role of traditional knowledge and crop varieties in adaptation to climate change and food security in SW China, Bolivian Andes and coastal Kenya*. Paper prepared for the United Nations University Institute for the Advanced Study of Sustainability (UNU-IAS) Workshop on Indigenous Peoples, Marginalised Populations and Climate Change: Vulnerability, Adaptation and Traditional Knowledge, Mexico, City, 19–21 July.

Tabu, I.M., Obura, R.K. & Swift, M.J. 2004. Macrofauna abundance and diversity in selected farmer perceived soil fertility niches in western Kenya. *In* A. Bationo, ed. *Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa,* pp. 487-499. Nairobi, Academy Science Publishers.

TEEB (The Economics of Ecosystems and Biodiversity). 2016. Agriculture & food. Website (available at www.teebweb.org/agriculture-and-food). Accessed 14 March 2016.

The Royal Society. 2009. *Reaping the benefits: science and the sustainable intensification of global agriculture*. London, UK.

Tiffen, M., Mortimore, M. & Gichuki, F. 1994. More people less erosion: environmental recovery in Kenya. Overseas Development Institute (ODI). Act Press, Nairobi.

Tittonell, P., van Wijk, M.T., Herrero, M., Rufino, M.C., de Ridder, N. & Giller, K.E. 2009. Beyond resource constraints: exploring the biophysical feasibility of options for the intensification of smallholder crop–livestock systems in Vihiga district, Kenya. *Agricultural Systems*, 101: 1–19.

UNEP (United Nations Environment Programme). 2008. *Indigenous knowledge in disaster management in Africa*. Nairobi (available at www.icsu.org/icsu-africa/news-centre/news/Appendix9IndigenousBookletUNEP.pdf).

Wairegi, L., van Asten, P., Giller, K. & Fairhurst, T. 2014. *Banana-coffee system cropping guide*. Nairobi, Africa Soil Health Consortium.

Wasonga, O., Opiyo, F., Nyangito, M. & Hülsebusch, C. 2012. *Adapting or coping? Analysis of pastoralists' responses to climatic stressors in Kenya's drylands*. Paper prepared for Tropentag Conference 2012, Goettingen, Germany, 9–11 October (available at www.tropentag.de/2012/abstracts/links/Wasonga_qBf96iL2.php).

Were, K., Ram, B. & Dick, O.B. 2015. Effects of land cover changes on soil organic and total nitrogen stocks in the eastern Mau forest reserve, Kenya. *In* R. Lal, B.R. Singh, D.L. Mwaseba, D. Kraybill, D.O. Hansen & L.O. Eik, eds. *Sustainable intensification to advance food security and enhance climate resilience in Africa*, pp. 113-133. Cham, Switzerland, Springer International Publishing.

Western, D., Groom, R. & Worden, J. 2009. The impact of subdivision and sedentarization of pastoral lands on wildlife in an African savanna ecosystem. *Biological Conservation*, 142(11): 2538-2546.

Willcox, M.L., Graz, B., Falquet, J., Sidibé, O., Forster, M. & Diallo, D. 2007. *Argemone mexicana* decoction for the treatment of uncomplicated falciparum malaria. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 101: 1190-1198.

Williams, M.M. II & Boydston, R.A. 2013. Crop seeding level: implications for weed management in sweet corn. *Weed Science*, 61: 437-442.

World Bank. 2010. *Reshaping Economic Geography*. World Development Report. Washington, DC, World Bank.

Yahya, M.F.Z.R., Ibrahim, M.S.A., Zawawi, W.M.A.W.M. & Hamid, U.M.A. 2014. Biofilm killing effects of *Chromolaena odorata* extracts against *Pseudomonas aeruginosa*. *Research Journal of Phytochemistry*, 8: 64-73.

Zwickle, S., Wilson, R. & Doohan, D. 2014. Identifying the challenges of promoting ecological weed management (EWM) in organic agroecosystems through the lens of behavioral decision making. *Agricultural & Human Values*, 31: 355-370.

ANNEX
MULTIDIMENSIONAL VALUATION OF ECOSYSTEM SERVICES IN AGRICULTURE

Lucas A. Garibaldi and
Nadine Azzu

Ecosystem services provide essential monetary and non-monetary benefits to humans. However, the value of these benefits (particularly those external to agriculture), measured in monetary terms, is not always included in agricultural and national accounting. Many ecosystem services are not traded in markets and do not have imputed monetary value, although good estimates of monetary value can be obtained for some of them by calculating the costs of replacing the service (for example, the costs of treating polluted water using artificial means). This is an issue for the conservation of the natural assets that provide ecosystem services because when natural assets do not have an assigned monetary value, the market indicates that it is more profitable to convert land to other uses (Pretty and Smith, 2004).

Work on quantification of the values of ecosystem services has recently been increasing relatively rapidly. An example of such an undertaking is The Economics of Ecosystems and Biodiversity (TEEB), a global initiative whose main objective is to mainstream the values of biodiversity and ecosystems into economic decision-making at all levels. It aims to do this through a structured approach to valuation that can help decision-makers recognize the range of benefits provided by biodiversity and ecosystem services, demonstrate their value in economic terms and capture these values in decision-making. The study "TEEB for Agriculture and Food" (TEEBAgriFood) (TEEB, 2016) aims to provide a comprehensive economic evaluation of the "eco-agri-food systems" complex. It demonstrates that the economic environment in which farmers operate is distorted by significant externalities, both negative and positive, and a lack of awareness of dependency on natural capital.

Convincing arguments have been made for the value in monetary terms of many ecosystem services. However, further understanding and documentation are needed for these values to enter into decision-making. Farmers regularly take stock of what they spend on external inputs and assess the benefits they obtain, but few have the means to do so for the more hidden costs and benefits of ecosystem services, and those that can do so usually have an incentive to consider only those costs and benefits that affect them. A region's wealth includes the financial, physical, natural, human and social assets that enhance development and sustainable rural livelihoods.

There are different ways to define and measure value, of which monetization is only one. It is not the only way to place value on ecosystem services, but it is often highly influential. For example, socioeconomic valuation of ecosystem services and biodiversity takes into account multiple dimensions and can quantify both trade-offs and synergies among them. Increasing the conservation area in a farm, for instance, could reduce short-term crop production, involving a trade-off between natural assets and financial assets in the short term (Garibaldi *et al.*, 2014). But increasing the conservation area could, and often does, increase production and sustainability as well, because conservation areas may favour, for example, pollinators, natural predators of pests and improved water availability. Identifying and quantifying synergies and trade-offs can help decision-makers to better assess the consequences of their interventions, resulting in more effective, efficient and supported decisions. For example, it can lead to the promotion of investments and the development of activities that strengthen synergies and reduce trade-offs (Nelson *et al.*, 2009).

The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES, 2013) notes that "in keeping with the general anthropocentric notion of 'nature's benefits to people', one might consider a benefit to be ecosystems' contribution to some aspect of people's good quality of life, where a benefit is a perceived thing or experience of value". In the definition provided by the IPBES Conceptual Framework, "value" is multidimensional and cannot be estimated properly by one variable only.

Valuations of single and multiple dimensions complement each other, and each has advantages and disadvantages. The one-dimension approach can be understood, for example, through the effects of an "environmentally friendly" practice on ecosystem services, in which different ecosystem services (e.g. crop yield, pollination, water purification) are valued in the same units, usually in monetary terms. The multidimensional approach can integrate different variables, in both monetary and non-monetary terms, in the same analysis. The one-dimension analysis is simpler to communicate but has more errors and assumptions because all the variables need to be translated into monetary terms.

Example: quantitative socioeconomic valuation

A practical example of a methodology for valuing ecosystem services is a protocol developed for a quantitative approach to socioeconomic valuation of pollinator-friendly practices. Essentially, valuation is always based on contrast; this protocol, for example, has been used to show the contrast between pollinator-friendly and pollinator-unfriendly practices. It is applicable at the farm level, but also the landscape level. This protocol goes beyond monetary terms of valuation to include non-monetary terms, by considering multiple dimensions such as the five livelihood assets (financial, human, natural, physical and social) proposed in the Sustainable Livelihoods Theoretical Framework.

In this protocol, the researcher first sets up an experimental design, by defining a contrast. Then, the multiple dimensions of the socioeconomic value are considered by defining at least three variables per asset (financial, human, natural, physical and social). For example, the human asset could be defined by number of households, educational level and dietary diversity. Data for these variables can be obtained from regular questionnaires implemented by government agencies, Geographic Information System (GIS) databases and questionnaires specially prepared for this purpose. Once all the information has been collected for the five assets, then a statistical analysis is performed (standard multivariate statistics).

The results will then support decision-making. In the case of pollination, for example, the protocol might indicate to decision-makers which type of asset (financial, human, natural, physical or social) should be strengthened in order to enhance pollinator-friendly practices in a region. It can also help to identify opportunities to enhance limiting factors. If no negative relation between natural assets and the economic revenue of producers is found, this could provide a solid argument for conservation, since it suggests that it is possible to enhance pollinators without losing economic benefits (i.e. there is no trade-off between natural and financial assets) or that pollination could even enhance the productivity of some crops (i.e. synergies between natural and financial assets may exist).

AUTHOR AFFILIATIONS

AZZU, Nadine	Global Project Manager (Biodiversity and Ecosystem Services) Plant Production and Protection Division Agriculture and Consumer Protection Department, FAO, Rome, Italy
BÀRBERI, Paolo	Institute of Life Sciences Scuola Superiore Sant'Anna (SSSA) Piazza Martiri della Libertà 33 56127 Pisa, Italy
BERNIS FONTENEAU, Agnès	Consultant, Biodiversity for Food and Agriculture FAO, Rome, Italy
COATES, David	Secretariat of the CBD Montréal, Canada
COLOZZA, David	Consultant, Ecosystem Services and Climate Change Adaptation Plant Production and Protection Division Agriculture and Consumer Protection Department, FAO, Rome, Italy
D'ANNOLFO, Raffaele	Independent Researcher Via A.Vespucci 66 00153 Rome, Italy
GACHENE, Charles K.K.	Department of Land Resource Management and Agricultural Technology College of Agriculture and Veterinary Sciences University of Nairobi P.O. Box 29053-00625, Nairobi, Kenya
GARIBALDI, Lucas A.	Instituto de Investigaciones en Recursos Naturales, Agroecología y Desarrollo Rural (IRNAD), Universidad Nacional de Río Negro (UNRN) and Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina
GBEHOUNOU, Gualbert	Weed Officer Plant Production and Protection Division Agriculture and Consumer Protection Department, FAO, Rome, Italy

GEMMILL-HERREN, Barbara	Consultant on Agroecology and Ecosystem Services World Agroforestry Centre, Nairobi, Kenya
GETZ ESCUDERO, Arthur	Consultant, Local and Regional Policy Measures for Ecological Intensification Plant Production and Protection Division Agriculture and Consumer Protection Department, FAO, Rome, Italy
GRAUB, Benjamin	Agriculture Officer - Ecological Intensification Plant Production and Protection Division Agriculture and Consumer Protection Department, FAO, Rome, Italy
KALUNDA NANTONGO, Pauline	Environmental Conservation Trust of Uganda P.O. Box 8986 Kampala, Uganda
KASINA, Muo	Centre Director National Sericulture Research Centre Kenya Agricultural and Livestock Research Organization P.O. Box 7816 code 01000, Thika, Kenya
KIBET, Staline	Land Resource Management and Agricultural Technology Department College of Agriculture and Veterinary Sciences University of Nairobi, Kenya
MANCINI, Francesca	Pest and Pesticide Management Specialist Plant Production and Protection Division Agriculture and Consumer Protection Department, FAO, Rome, Italy
MATI, Bancy	Water Research and Resource Center Jomo Kenyatta University of Agriculture and Technology P.O. Box 62000-00200, Nairobi, Kenya
OTINGA, Abigael	University of Eldoret School of Agriculture and Biotechnology P.O. Box 1125-30100, Eldoret, Kenya
SIMIYU, WATTIMAH Stella	Independent Biodiversity Consultant P.O. Box 442300-00100 Ndemi Road, Nairobi, Kenya

This Technical Guidance Document addresses the need for mainstreaming biodiversity and ecosystem services into agriculture, at the national level. More specifically, it is aimed to assist countries in developing and implementing their National Biodiversity Strategy and Action Plans (NBSAPs), to consider ecosystem services – and opportunities for their management – in agricultural production systems. Through an EU-funded project on "Capacity-building related to multilateral agreements (MEAs) in ACP countries (Phase 2)", this document focuses on the East Africa region, and provides concrete examples and cases primarily from Kenya. The intention is that this document provides practical guidance to countries for building institutional capacity for synergistic implementation of MEAs, and identifying opportunities for managing biodiversity and ecosystem services to reduce the use of chemical inputs. It considers issues at the technical, institutional and policy levels. This publication is a result of technical papers prepared by experts on specific topics related to biodiversity and ecosystem services in agriculture but also on social and cross-cutting dimensions such as indigenous and traditional knowledge.




An initiative of the African, Caribbean and Pacific Group of States funded by the European Union

BIODIVERSITY & ECOSYSTEM SERVICES IN AGRICULTURAL PRODUCTION SYSTEMS

Food and Agriculture Organization of the United Nations
Viale delle Terme di Caracalla,
00153 Rome, Italy
www.fao.org

ISBN 978-92-5-109215-6
9 789251 092156
I5603E/1/04.16