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ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT WORKING PAPER

ENVIRONMENT CLIMATE CHANGE [ENERGY] MONITORING AND ASSESSMENT

Good Environmental Practices in Bioenergy Feedstock Production

Making Bioenergy Work for Climate and Food Security

BEFSCI

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Good Environmental Practices in Bioenergy Feedstock Production

Making Bioenergy Work for Climate and Food Security

Edited by Andrea Rossi

BEFSCI
Bioenergy and Food Security Criteria and Indicators

Bioenergy and Food Security Criteria and Indicators project
Food and Agriculture Organization of the United Nations (FAO)

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FOREWORD

The global demand for modern bioenergy, and especially liquid biofuels, is rapidly growing, driven mainly by climate change mitigation policies and increasing oil prices. This creates both opportunities and risks for developing countries.

On the one hand, modern bioenergy development can boost both agricultural and rural development by raising agricultural productivity, creating new employment and income-generating opportunities, and improving access to modern energy services in rural areas. On the other hand, if not properly managed, modern bioenergy development can trigger a number of negative environmental and socio-economic impacts, for instance by putting pressure on key resources such as land and water.

The environmental and socio-economic sustainability of modern bioenergy has been highly debated over the past few years. One of the most controversial issues that has dominated this debate is the relationship between bioenergy and food security.

In order to shed light on this complex issue and help policy-makers understand and manage the risks and opportunities for food security associated with various bioenergy development pathways, the Bioenergy and Food Security (BEFS) project of the Food and Agriculture Organization (FAO) of the United Nations developed an Analytical Framework and a toolbox, which are being implemented in several countries.

Building on this work, FAO's Bioenergy and Food Security Criteria and Indicators (BEFSCI) project has developed a set of criteria, indicators, good practices and policy options on sustainable bioenergy development that foster rural development and food security. BEFSCI aims to inform the development of national frameworks aimed at preventing the risk of negative impacts – and increasing the opportunities – of bioenergy development on food security, and help developing countries monitor and respond to the impacts of bioenergy development on food security.

In order to ensure that modern bioenergy development is sustainable and that it safeguards food security, a number of good practices can be implemented throughout the bioenergy supply chain.

Drawing from FAO's work on good practices in agriculture and forestry, the BEFSCI project has compiled a set of good environmental practices that bioenergy feedstock producers can adopt in order to minimize the risk of negative environmental impacts from their operations and to ensure that modern bioenergy delivers on its climate change mitigation potential. These practices can improve the efficiency and sustainability in the use of land, water and agricultural inputs for bioenergy production, thus reducing the potential competition with food production.

Although the focus of this report is on bioenergy, the practices described in it are relevant for any agricultural and forestry production, regardless of the use of the feedstocks.

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INTRODUCTION

Building on FAO's work on good practices in agriculture and forestry, the BEFSCI project (see box below) has compiled a set of good environmental practices that can be implemented by bioenergy feedstock producers in order to minimize the risk of negative environmental impacts from their operations, and to ensure that modern bioenergy contributes to climate change mitigation.

These practices can improve both the efficiency and sustainability in the use of land, water and agricultural inputs for bioenergy production, with positive environmental and socio-economic effects, including a reduction in the potential competition with food production. These practices can also minimize the impacts of bioenergy feedstock production on biodiversity and ecosystems, which provide a range of goods and services that are key for food security.

The good practices compiled in this report are divided into three main groups. The first group is comprised of agricultural management approaches (namely Ecosystem Approach, Conservation Agriculture and Organic Agriculture), which provide comprehensive and holistic frameworks and principles of sustainable agriculture. The second group consists of integrated, sustainable agricultural and forestry management systems, namely Agroforestry, Integrated Food-Energy Systems, and Multiple Cropping Systems and Crop Rotation. The third and last group includes a broad range of field-level agricultural and forestry practices that can be implemented on the ground by bioenergy feedstock producers, such as No- or Minimum Tillage, Integrated Pest Management, and Integrated Plant Nutrient Management.

For each good practice, a detailed description of the key features is provided, followed by a discussion of the potential environmental and socio-economic benefits associated with its implementation, as well as of the related challenges.

For each good practice, two practical examples of implementation in the production of key bioenergy feedstocks (such as sugar cane, maize, soybean and palm oil) in different regions of the world are provided.

An overview of the main potential direct benefits associated with the approaches, systems and practices described in this report is provided in table 1.

BOX 1. FAO'S BIOENERGY AND FOOD SECURITY CRITERIA AND INDICATORS (BEFSCI) PROJECT

Building on the Bioenergy and Food Security (BEFS) Analytical Framework, the BEFSCI project has developed a set of criteria, indicators, good practices and policy options on sustainable bioenergy production that foster rural development and food security, in order to:

- inform the development of national frameworks aimed at preventing the risk of negative impacts – and increasing the opportunities – of bioenergy developments on food security, and
- help developing countries monitor and respond to the impacts of bioenergy developments on food security and its various dimensions and subdimensions.

Table 1

MAIN POTENTIAL DIRECT BENEFITS	SUSTAINABLE AGRICULTURAL MANAGEMENT APPROACHES	Conservation Agriculture	The Ecosystem Approach and Sustainable Crop Production Intensification, Agro-ecology and Eco-agriculture	Organic Agriculture	SUSTAINABLE INTEGRATED AGRICULTURAL AND FORESTRY MANAGEMENT SYSTEMS	Agroforestry Integrated Food-Energy Systems Multiple Cropping Systems and Crop Rotation	SUSTAINABLE FIELD-LEVEL AGRICULTURAL AND FORESTRY PRACTICES	Alternatives to Slash-and-Burn	Community-Based Forest Management	Conservation and Sustainable use of Plant Genetic Resources and Seeds	Forest Buffer Zone	Integrated Pest Management (IPM)	Integrated Plant Nutrient Management (IPNM)	No- or Minimum Tillage	Pollination Management	Precision Agriculture	Rainwater Harvesting and Management	Rehabilitation of Degraded Lands	Soil Cover	Sustainable Forest Harvest	Sustainable Irrigation	Wild Biodiversity Management at Farm Level
ENVIRONMENTAL																						
Soil quality		√		√		√		√			√	√	√	√		√	√	√	√	√	√	√
Water availability and quality		√	√	√		√		√	√		√	√	√	√		√	√	√	√	√	√	√
Biodiversity			√	√		√		√	√	√	√	√			√			√		√		√
Agrobiodiversity		√	√	√		√				√		√			√				√			√
Climate change mitigation		√	√	√		√		√					√	√		√		√		√		
SOCIO-ECONOMIC																						
Productivity/Income		√	√	√		√		√	√	√	√	√	√	√	√	√	√	√	√	√		√
Availability of inputs		√	√			√																√
Access to energy						√		√	√		√								√	√		√

Please note that this table includes only the main potential direct benefits of the approaches, systems and practices described in the report. These and other potential benefits may or may not materialize depending on local conditions and circumstances.

CHAPTER 1

SUSTAINABLE AGRICULTURAL MANAGEMENT APPROACHES

INTRODUCTION

This first chapter provides an overview of the main sustainable agricultural management approaches, namely:

- Conservation agriculture;
- The Ecosystem Approach and Sustainable Crop Production Intensification, Agro-ecology and Eco-agriculture, and
- Organic Agriculture.

These approaches comprise a number of sustainable agriculture principles that can be implemented through the field-level practices discussed in the third chapter of this report.

The key features of the aforementioned agricultural management approaches, and the associated potential benefits and challenges, are described in the sections below. In addition, examples of the implementation of these approaches in bioenergy feedstock production in different regions of the world are provided.

The implementation of the agricultural management approaches described in this chapter can lead to a number of environmental and socio-economic benefits, including on soil quality, water availability and quality, biodiversity, agrobiodiversity, climate change mitigation, productivity/income and availability of inputs.

At the same time, these approaches present some challenges that limit their adoption, including in terms of input and labour requirements, land tenure, access to finance, awareness, education and research and development, and policies and institutions.

1.1 CONSERVATION AGRICULTURE

Maizura Ismail

Key features

In the past, conventional agricultural practices such as tilling the land, removing residues and keeping the field "clean" were believed to be associated with increased soil fertility. Over time, however, these practices may result in a reduction of soil organic matter, destroying soil structure, harming soil biota and exposing soil to erosion medium. These may lead to land degradation, and subsequent reduction in soil fertility, crop productivity and farm profitability.

In response to this, Conservation agriculture has been promoted as a set of principles and practices that may contribute to sustainable production intensification. Conservation agriculture refers to "an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security, while preserving and enhancing the resource base and the environment" (FAO, Conservation agriculture web site[1]). This is mainly achieved through three interlinked and mutually reinforcing principles, namely:

continuous no- or minimal mechanical soil disturbance;

permanent organic-matter soil cover, especially by crop residues and cover crops, and

diversified crop rotations in the case of annual crops, or plant associations in case of perennial crops, including legumes (Friedrich *et al.* 2009).

Based on natural biological processes above and below ground, Conservation agriculture aims to achieve acceptable profits through high and sustained agricultural production, while at the same time saving resources and conserving the environment. Under this approach, interventions such as mechanical tillage are reduced to an absolute minimum or avoided, and agrochemicals such as pesticides and mineral or organic nutrients are applied optimally and in ways and quantities that do not interfere with, or disrupt, the biological processes.

Continuous no- or minimal mechanical soil disturbance[2]

Tillage, or physical loosening of the soil, is used to: prepare seedbed for planting; control weed; increase water infiltration and aeration, and incorporate organic matter into lower soil layers. However, tillage may negatively impact the productive capacity of land in the long run.

In a no-till system as Conservation agriculture, crops are grown without mechanical seedbed preparation by directly inserting them with special equipment into the soil. The equipment penetrates the soil cover, opens a seeding slot and places the seed into that slot, with size of the slot and the associated movement of soil kept at the absolute minimum.

1 http://www.fao.org/ag/ca/

2 For a detailed description of *No- or Minimum Tillage*, see section 3.7.

Land preparation for seeding or planting under no-tillage involves slashing or rolling the weeds, previous crop residues or cover crops; or spraying herbicides for weed control, and seeding directly through the mulch (Maltsoglou and Khwaja 2010).

Permanent organic-matter soil cover, especially by crop residues and cover crops[3]

According to the Conservation agriculture manual by the International Institute of Rural Reconstruction (IIRR) and the African Conservation Tillage (ACT) (2005), farmers can ensure permanent cover for the soil by cultivating cover crops, which are crops cultivated specifically for soil improvement purposes and thus not harvested, or by maintaining a layer of residue cover on the field. These methods may be applied simultaneously.

Cover crops may be planted during the season, intercropped with the main crop to cover soil areas not covered by the crop itself, or planted after the harvest to cover the whole field. In the case of the latter, the cover crop may be allowed to grow throughout the cropping season, it may be slashed and left on the soil surface as mulch, or plowed down as green manure (IIRR and ACT 2005). Cover crops should be: compatible with the main crops; easy to establish; suitable for local conditions; competitive compared to weeds; able to either fix nitrogen or concentrate phosphorus; resistant to local pest and climate conditions, and able to produce sufficient seeds for next plantings (Bunch 2003).

Crop residues may be used as cover as well. They include: organic material left over in the fields from the previous harvesting; cover crops sown the previous season and left in the fields after slashing or herbicide application; leaves and branches trimmed from trees in and outside the cropping area; and other mulches of grasses, shrubs, weeds, litter, husks and other organic waste materials (Shaxson and Barber 2003).

Diversified crop rotations in the case of annual crops, or plant associations in case of perennial crops[4]

To avoid pest and pathogen build-up, declining fertility, biodiversity loss and soil degradation brought about by monoculture, farmers under Conservation agriculture attain soil fertilization and pest control through crop rotation in the case of annual crops, or intercropping of associated plants in the case of perennial crops.

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3 For a detailed description of *Soil Cover*, see section 3.12.
4 For a detailed description of *Multiple Cropping Systems and Crop Rotation*, see section 2.3.

Potential benefits[5]

Soil quality

The no-till practice improves soil structuring processes and retains topsoil from loss through erosion, while the maintenance of soil cover protects and encourages regeneration of soil. Last, but not least, crop rotation or intercropping increase soil fertility and provide pest protection to the crops to ensure farm profitability and sustainability. On land being first opened for agricultural use, the simultaneous application of Conservation agriculture principles may allow the soil to retain the soil's original desirable characteristics and mimic the forest floor conditions, (Kassam *et al*. 2009).

Water availability and quality

Soil with high organic matter content may hold more water compared to regular soil. Reversing the loss of organic matter through Conservation agriculture may improve soil porosity, thus prolonging the availability of plant-available soil water in times of drought (Kassam *et al.* 2009). The high water infiltration in soils under Conservation agriculture may also lead to reduced surface runoff and soil erosion, improving surface water quality and enhancing groundwater resources (Maltsoglou and Khwaja 2010).

Agrobiodiversity

Agrobiodiversity under Conservation agriculture systems tends to increase (Hendrix *et al.* 1986; Jackson *et al*. 2003; Lindwall and Sonntag 2010). In the absence of mechanical soil tillage the biodiversity in the soil is increasing from a bacterial dominated population under tillage to a much wider variety including fungi and macrofauna. A foodweb is established, including the surface areas under the residue mulch cover. The relatively stable environment in a mulch-covered not tilled soil facilitates also the growth of beneficial organism populations which are one explanation for the reduced pest and disease problems under fully established Conservation agriculture. Above ground biodiversity is also facilitated by the diverse crop rotations, including grain legumes, which would then also facilitate pollinator populations.

Climate change mitigation

The United States Department of Agriculture (USDA 2008) performed a study to estimate the Soil organic carbon (C) sequestration with Conservation agriculture in the southeastern USA. The results of the study show that the value of total soil C sequestrated with Conservation agriculture can be relatively high (from 0.4 to 1.0 Mg C/ha/yr depending on management and soil conditions). Conservation tillage, increased cropping

5 While all three Conservation agriculture practices are beneficial to the farm, their combination allows for simultaneous soil conservation and regeneration. The specific benefits of each Conservation agriculture practice are discussed in the sections on these practices within the third chapter of this report.

system complexity, cover cropping, animal manure application, optimum fertilization, and rotation of crops with pastures are effective strategies to enhance soil organic C sequestration.

Productivity/income

Conservation agriculture allows for: a reduction of production costs; reduction of time and labour, particularly at times of peak demand such as land preparation and planting, and reduction of costs of investment and maintenance of machinery in mechanized systems (Maltsoglou and Khwaja 2010).

With regard to time/labour requirements, conservation practices such as no- or minimum tillage and cover cropping may enable certain tasks to be completed in a shorter time than the conventional method. For example, cover crops suppressing weeds or no-till planting reduce the size of the task, while two operations such as opening up the land and planting may be performed simultaneously (Bishop-Sambrook *et al.* 2004). Thanks to these features, the adoption of Conservation agriculture may be particularly beneficial for small-scale farms facing acute labour shortages, as certain Conservation agriculture practices such as no- or reduced tilling may enable farmers to grow more food with less work (IIRR and ACT 2005).

In addition to reducing production costs, Conservation agriculture may lead to a yield increase, by helping farmers reduce a number of risks often associated with conventional agriculture, such as: declining soil fertility; stunted or restricted root growth due to development of hardpan; plant vulnerability to drought due to soil's low capacity to retain water, and loss of topsoil to erosion and runoff (IIRR and ACT 2005).

Through the implementation of Conservation agriculture practices, farmers may also get a deeper understanding of cropping systems and improve their overall farm management (Friedrich *et al.* 2008). This may have positive effects on their productivity and thus on their income.

Availability of inputs

Synthetic pesticides and mineral fertilizers use tend to decline in Conservation agriculture when compared to conventional tillage-based farming systems, allowing the achievement of a new balance between the organisms of the farm-ecosystem, insect pests and beneficial organisms, crops and weeds (Friedrich *et al.* 2008). The application of Conservation agriculture practices may: reduce weed, insect pest and disease incidence through biological means; raise agro-ecological diversity; favour biological nitrogen fixation; and result in higher and more stable yields accompanied by lowered costs of production (Kassam *et al.* 2009).

Challenges

Pest issues

No-till farming may be facilitated by the use of herbicides, especially in the transitional phase from conventional to conservation agriculture, before farm's biological equilibrium is achieved, and particularly when farmers rely on herbicide as the only weed management strategy applied (Friedrich 2005; Thiombiano and Meshack 2009). But this may be overcome once the Conservation agriculture environment stabilizes and farmers learn to use rotations and cover crops to manage weeds.

Input and labour requirements

In order to minimize mechanical soil disturbance, farmers practising Conservation agriculture need direct seeding implements for planting through the permanent soil cover. However, farmers – especially smallholders – may have limited access to implements and inputs due, among other things, to: the relatively high costs of implements and herbicides, and the lack of support from machinery dealers who may not wish to promote Conservation agriculture as it may reduce machinery sales, particularly of large tractors (APCAEM 2007; Thiombiano and Meshack 2009).

At the same time, farmers may be reluctant to invest in an implement that they are not familiar with, due to the associated learning curve, which could outweigh the labour – and time-saving benefits of such implement (Bishop-Sambrook *et al.* 2004).

Competing use of residues

In the beginning, farmers may not feel able to sufficiently provide soil cover due to: high decomposition rate of biomass; competing use of residue including as livestock feed, huts and/or fence material, and fuel for cooking; and traditional arrangements such as grazing rights of farmer's fields after harvest (Ashburn *et al.* 2002; Thiombiano and Meshack 2009). Specific measures need to be in place for Conservation agriculture, including inclusion of shrubs or trees in the production system; reaching agreements with livestock owners on grazing rights, and growing special plots of fodder and fuelwood (IIRR and ACT 2005).

Land tenure

The adoption of Conservation agriculture requires an initial capital and time investment for specialized planting equipment and training for management of the new farming system (Maltsoglou and Khwaja 2010). Under uncertain land tenure, farmers may not have an incentive to bear these costs, as the benefits of Conservation agriculture practices would be felt especially in the medium and long term, when farmers might no longer have access to the same land (Thiombiano and Meshack 2009).

Awareness, education, and research and development

In most countries, Conservation agriculture is a relatively unknown concept and there is limited awareness among producers of this approach and its benefits. As it is a knowledge-intensive, complex system to learn and implement, particularly site specific aspects, it cannot be reduced to a simple standard technology. (Kassam *et al.* 2009).

Switching from conventional agriculture to Conservation agriculture also involves a fundamental change of mindset. In order for farmers to move away from traditional behaviour or practices, they must be aware of the problem. Lack of knowledge regarding alternative farming systems, appropriate implements and affordable inputs, such as cover crop seeds and chemicals is often seen as a major constraint for the development of Conservation agriculture in Africa (Ashburn *et al*. 2002). Radical changes to the extension services are also needed in order for farmers to see their farms as a business rather than merely as a way to feed their families (IIRR and ACT 2005).

Policies and institutions

The main factors limiting the adoption of Conservation agriculture on a large scale include: limited level of awareness among policy-makers of the benefits of this approach; lack of research programmes for scaling up Conservation agriculture practices, and insufficient extension services and NGOs capacities (Thiombiano and Meshack 2009).

Examples in bioenergy feedstock production

Region: Southern Africa
Country: Zambia
Crop/Feedstock: Maize (*Zea mays)*

The COMACO Model: Increasing smallholder productivity through Conservation agriculture in the Luangwa Valley, Zambia[6]

The main source of income for the communities in the Luangwa Valley, a mixed woodland landscape dotted with smallholder farms, is farming. The main food crops are maize (*Zea mays*) and sorghum (*Sorghum bicolor*), but the increase in cultivation of cash crops, such as cotton (*Gossypium sp.*) and tobacco (*Nicotiana tabacum*), left some farmers' families less able to meet their own food requirements. Monoculture of crops and the local practice of burning crop residues depleted soil nutrients, and in the case of crop residues burning, also contributed to soil erosion. As a result, farmers were forced to deforest the adjacent national forest and national park to cultivate new land. Subsistence farmers also hunted illegally and exchange the meat for food, while poor families generated income to buy food by selling charcoal they make from trees from the forests.

In 2002, the Community Markets for Conservation (COMACO), a joint initiative of the Wildlife Conservation Society and the World Food Programme (WFP), initiated a community programme in the Luangwa Valley to improve smallholder productivity through the implementation of a number of Conservation agriculture practices, and to help preserve biodiversity.

Among other things, the COMACO project provided training to farmers on sustainable farming technologies and improved land use practices. In particular, COMACO trained farmers on: no-tillage farming; the production and application of home-made fertilizers (to help save on fertilizer costs), and how to cover the area between rows with the previous year's crop residues instead of burning them to suppress weed growth and increase soil moisture

The COMACO project also promoted, among farmers, the introduction of crops that require little pesticides and produce food without extensive labour inputs, such as paddy rice; and groundnuts (*Arachis hypogaea*), which can provide an additional source of food and income and, as nitrogen fixers, are ideal for crop rotation.

Smallholder farmers trained on Conservation agriculture practices were organized into producer groups. Products under the COMACO project were processed, packaged and marketed as "added value" environmentally friendly products under the brand "It's Wild!", with profits channelled back to the producer groups. In order to remain within the producers group, farmers must comply with community land use plans and continue to

6 The information included in this section was either adapted or excerpted from: Ecoagriculture Partners (undated).

implement production practices that promote wildlife and watershed conservation.

Thanks to this project, local smallholder farmers learned new methods of cultivation, enabling them to diversify their crop production and to increase their productivity in a sustainable way. In addition, COMACO helped farmers gain access to new markets, thus providing them with new income sources, with positive effects on their food security. These positive effects were confirmed by a survey conducted in 2006, which found a better food security status among the smallholder farmers who had been involved in the COMACO project.

Region: Central America
Country: Honduras
Crop/Feedstock: Maize (*Zea mays*); sorghum (*Sorghum bicolor*); fuelwood

Quesungal system: Conservation agriculture with an agroforestry component in Lempira, Honduras[7]

In Lempira, Honduras, the farmers have replaced the traditional slash-and-burn system with the Quesungual system, which is Conservation agriculture with an agroforestry component. Mainly practised by smallholder farmers (1-3 hectares), the Quesungual system includes: naturally regenerated and pruned trees, shrubs and traditional agroforestry components, such as high-value timber and fruit trees; and subsistence crops, such as maize (*Zea mays*), beans and sorghum (*Sorghum bicolour*). The major production system of the region is subsistence agriculture, characterized by its low productivity. Maize is the first crop, intercropped with (both) sorghum and beans.

Prior to sowing, vegetation is cleared by hand or herbicide. Still in the dry season, the trees and shrubs are pruned at a height of 1.5 to 2 metres, in order to eliminate branches and regrowth, and provide light for the future crop. The pruned material was then used as soil surface cover. The branches and trunks, which can be used as fuelwood and poles, were removed from the plot.

Farmers usually use no-tillage for crop sowing or minimum tillage in very specific situations. Before sowing the second crop (often beans) the field is cleared a second time but trees and shrubs are not necessarily pollarded. Mineral fertilizers are expensive and thus only used when maize and sorghum are both grown as first crop. Only once during the cropping season, weeds are cleared either manually or by using a herbicide. The crops are harvested in the traditional way.

An economic analysis of this transition showed that during the first two years maize and sorghum yields are about equal to those obtained with the traditional slash-and-burn system. From the third year, however, their yields increase, in addition to which the plot provides the farmer with fuelwood and posts, which give an extra value to the production.

Because of the increased production of maize, the quantity of stover increased

7 The information included in this section was either adapted or excerpted from: FAO (2001).

as well; this can be sold as livestock fodder. Additionally, from the first year onwards the farmer can rent out the land for livestock grazing, because of the increased biomass production. Usually this is done for two months. The application of the Quesungual system not only meets the household subsistence needs for fruit, timber, fuelwood and grains, but generates a surplus, which generates an extra income when sold in the market

Among the benefits farmers found in applying Conservation agriculture practices within the Quesungual system, include: improved soil moisture conservation, which permits a good development of the crop, even in very bad conditions; less soil erosion; reduced disease incidence in the bean crop due to the mulch; production of fuelwood and fruits from the trees and shrubs; production of timber after about seven years for construction or to be sold; increase in soil fertility and increased efficiency of fertilizers applied; increased agricultural production compared to traditionally managed plots; increased longevity of plots compared to the slash-and-burn system, and reduced requirement for labour in the establishment and maintenance of the system.

The disadvantages include: equal or slightly lower grain production during the first year compared to the traditional system; higher incidence of slugs in the bean crop during the first years; difficulty in achieving balance in soil cover so as to not impede the germination of the seeds, and incidence of diseases during periods of high rainfall due to combination of shading and higher humidity.

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1.2 THE ECOSYSTEM APPROACH AND SUSTAINABLE CROP PRODUCTION INTENSIFICATION, AGRO-ECOLOGY AND ECO-AGRICULTURE

Romina Cavatassi, Maizura Ismail, Marco Colangeli[8]

Key features

Introduced by the so-called "Green revolution", modern agriculture is characterized by the use of high yielding varieties, irrigation, fertilizers and pesticides. The green revolution signed a profound paradigm shift as a result of both technological progress and changing human needs (FAO 2011; FAO 2010a; FAO 2010b. However, the gains in agriculture came often at the cost of degrading natural resources and ecosystems. The need to rethink and reshape agricultural approaches within a sustainable framework, whereby food security would represent the top priority, is thus at the forefront of the international agenda.

Agriculture is the main economic sector of many developing countries and represents the source of livelihood for 75 percent of the poor in these countries. It contributes to food security not only as a direct source of food, but also indirectly through the income it generates (FAO 2010a). Given that farmers represent the largest group of natural resources managers on earth (FAO 2009) and that the answer to food security could only rely on the agricultural sector, agriculture is called upon to respond to the main challenges the world is facing today: feeding a growing population with changing dietary habits, whilst preserving the natural resource base and contributing to both climate change mitigation and adaptation. In addition, agriculture is expected to meet the growing demand for biomass for feed, fibre and biofuel production.

A number of different agricultural frameworks and approaches have emerged and evolved over the last few decades to address the sustainable use of natural resources and ecosystems in the context of agricultural development. All these frameworks, while emphasizing different aspects of the environment and of human knowledge to preserve, assert substantially that in order to be able to continue and/or increase production in the long term, agriculture must respect the natural ecosystem in which it operates.

FAO has recently defined one of the most holistic and comprehensive of these approaches: "The Sustainable Crop Production Intensification (SCPI) or Save and Grow Approach". SCPI represents a new paradigm shift consisting of an Ecosystem Approach applied to sustainable intensification of crop production. The Ecosystem Approach, developed under the Convention on Biological Diversity (CBD) and endorsed by FAO, is defined as "a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way" (CBD 2000); thus considering not only the biological processes and their interactions, but also the social and economic aspects involved.

8 Marco Colangeli is the author of the second example.

A similar approach, but with a focus on the agro-ecosystem rather than on the ecosystem as a whole, is agro-ecology[9]. Agro-ecology emphasizes the importance of preserving agricultural biodiversity and the biological processes associated with agricultural systems. It is a convergence of the two scientific disciplines of agronomy and ecology, aiming at the holistic study of agro-ecosystems, including both human and environmental elements (FAO 2007; Altieri 2007). For its practitioners, agro-ecology is defined as the application of ecological concepts and principles to the design and management of sustainable agro-ecosystems (FAO 2007). The ultimate goal of agro-ecology is to integrate components so that overall biological efficiency is improved, biodiversity is preserved, and the agro-ecosystem productivity and self-sustaining capacity is maintained (Altieri and Nicholls 2005).

Eco-agriculture is based on similar principles, but is conceived at the landscape level[10]. Eco-agriculture emphasizes the importance of wild biodiversity and of human interactions at landscape level. More in detail, it refers to the “integrated conservation-agriculture landscape where biodiversity conservation is an explicit objective of agriculture and rural development” (Scherr and McNeely 2007). Eco-agriculture aims to achieve improved livelihoods, conservation of biodiversity (genetic resources, ecosystem services and wild flora and fauna) and sustainable production simultaneously, at a landscape level. Eco-agriculture relies on resource management strategies that focus on production and conservation areas. In production areas, the aim is to achieve a sustainable increase in agricultural output whilst reducing costs in ways that enhance the habitat quality and ecosystem services. In conservation areas, natural habitats are expanded and/or protected in ways that provide benefits for farmers and communities in the surrounding areas.

Sustainable Crop Production Intensification based on the Ecosystem Approach represents a more holistic framework[11]. It is conceived at the level of the ecosystem as a whole, and it aims to provide an adequate answer to the dual challenge of feeding the world whilst protecting the environment. It requires the application of sustainable agricultural management practices and production systems, considering the economic, social and institutional aspects involved in addressing the challenge (FAO 2011).

For SCPI to be effective, the ecosystems approach needs to be applied throughout the food value chain in order to increase efficiencies and strengthen the global food system. Under SCPI, farm management is based on biological processes, integration of a various range of plant species, and appropriate use of external inputs including fertilizers and pesticides (FAO 2011).

In practice, SCPI entails the implementation of most of the so-called: “Sustainable Land Management[12] (SLM)” practices identified by the UN Rio Summit in 1992 and that

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9 For further information on agro-ecology and its features, see: Altieri and Nicholls (2005); Altieri (2007); and FAO (2007).

10 For further information on Eco-agriculture and its features, see: Sherr and McNeely (2007); and Sherr *et al.* (2008).

11 For further information on Sustainable Crop Production Intensification (SCPI), see: FAO (2011).

12 SLM practices are categorized under four main principles linked to the improvement of: a) water

are described in this report. Provided that there is no single blueprint for an ecosystem approach to crop production intensification, a range of farming practices and technologies, often location specific, have been developed. Among others, SCPI recommends a number of practices described in this report:

- Maintaining healthy soil to enhance crop nutrition.
- Cultivating a wide range of species and varieties in associations, rotations and sequences.
- Using well adapted, high-yielding varieties and good quality seeds.
- Efficient water management.
- Favouring multicropping, crop rotation, agroforestry and crop-livestock integration.
- Adopting the Integrated Pest Management approach.
- Using Precision agriculture and Conservation agriculture to enhance efficiency of farm operations.
- Institutional support at national and local levels.
- Strengthening extension services.
- Mobilizing social capital.
- Recognizing the critical role of women in agriculture.

The following sections address the main potential benefits and challenges related to SCPI under the Ecosystem Approach. Most of these also apply to agro-ecology and eco-agriculture, keeping in mind that the level to which theses approaches apply is different: ecosystem for SCPI; agro-ecosystem for agro-ecology; and landscape for eco-agriculture. When there are differences in terms of potential benefits and challenges among these approaches, these are explicitly indicated. Likewise, when a benefit or a challenge applies only to one of these approaches, this is explicitly mentioned.

Potential benefits

Water availability and quality

SCPI through its recommended practices may limit soil erosion and water loss, as well as achieve potential ecosystem benefits related to its hydrological functions. Practices such as soil cover and minimum tillage, as well as application of crop rotation and multiple cropping systems may help farmers retain more water in their soil. Moreover using drought tolerant varieties may also reduce a farm's water requirements. Reduced need for irrigation will also decrease the risks of salinization. On the other hand, practices such as contour farming and terracing may reduce soil erosion and maintain the quality of water resources. Precision irrigation, although knowledge intensive, is claimed to provide

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management on rainfed and irrigated land; b) soil fertility; c) plant management: plant material and control of weeds, pest and diseases, and d) microclimate. For further information on SLM, see: Liniger *et al.* (2011).

an answer to farmers through reliable and flexible water availability, thus representing a major platform for sustainable intensification. Lastly, SCPI suggests that, in the future, fertigation technology (i.e. use of liquid fertilizers), deficit irrigation and wastewater-reuse will be better integrated within irrigation systems improving their efficiency whilst reducing the costs (FAO 2011).

Biodiversity

Intensive and unsustainable use of pesticides and fertilizers has been linked to habitat pollution and degradation, and to a consequent decline in biodiversity. Conversely, an agricultural system which pays attention to the ecosystem functions and the natural environment, where the use of external inputs is sustainably managed and the IPM approach is adopted, guarantees a higher level of biodiversity.

Agro-ecology suggests some specific strategies to exploit complementarities and synergies from farms with high biodiversity including the use of field margins, vegetation corridors and arthropod diversity (Altieri and Nicholls 2005). Similarly, one of the main objectives of eco-agriculture is to ensure that agricultural activities are compatible with the natural functions of ecosystems. As a matter of fact, four of its strategies directly benefit biodiversity in the surrounding area, namely: modifying farming systems to mimic the ecological structure and function of natural ecosystems; reducing or reversing conversion of natural areas by increasing farm productivity; creating biodiversity reserves that benefit local farming communities, and developing habitat networks in non-farmed areas of agricultural landscapes.

Agrobiodiversity

SCPI, through its Ecosystem Approach and the associated land management practices, pays particular attention to the ecosystem structure, functioning and diversity. Yet at the same time it utilizes adaptive approaches in order to anticipate and adapt to changes and respond to stressful events.

Adopting the Ecosystem Approach to achieve SCPI implies developing new varieties and expanding the available portfolio of crops and varieties to be adaptable to different ecosystems, soil and climate conditions. More in particular, the required varieties will need to be adapted to less favoured areas and production systems and help improve the provision of ecosystem services. Moreover, given that SCPI requires a more efficient and targeted use of external inputs, plants will need to prove higher productivity and increased efficiency in the use of nutrients and water, in addition to greater resistance to insect pests and diseases and higher resilience to drought and other stressful climatic conditions. As a consequence, the agrobiodiversity associated with the agricultural system is extremely important (FAO 2011).

Agrobiodiversity and soil biota and nutrients are also cornerstones of agro-ecology and eco-agriculture. In particular, agro-ecology specifically suggests that soil fertility should be maintained through a combination of worm composting with crop residues, constant incorporation of organic matter into the soil, intercropping with nitrogen-fixing legumes and pasturing animals on crop residues, and use of manure as fertilizer (Rosset *et al.* 2011). Similarly, eco-agriculture landscapes are designed to house a high degree of agrobiodiversity. Eco-agriculture encourages biodiversity proliferation in the agricultural landscape by providing a conducive environment through the adoption of practices such as: reducing the use of agrochemicals; maintaining hedgerows, windbreaks or natural habitat adjacent to agricultural fields; maintaining habitat patches that are spatially and temporally heterogeneous; maintaining habitat connectedness on a landscape level; implementing water, soil and biodiversity friendly resource management systems, and maintaining critical ecological processes and biodiversity composition (Buck *et al.* 2004).

Climate change mitigation

SCPI could play an important role in climate change mitigation through increased carbon sequestration in sustainably managed soils and reduction of emissions owing to more efficient use of fertilizer and irrigation (FAO 2011). A useful list of SLM practices, most of which are part of SCPI as well as of the other approaches described above, has been reviewed and analysed by Branca *et al*. (2011) in terms of trade-offs between climate change mitigation and food security or poverty reduction. Many SLM practices can simultaneously achieve both adaptation and mitigation goals, especially those that increase soil organic carbon and that represent an *ex ante* approach to climate changes that can reduce the need for costly *ex post* coping measures (FAO 2009; Branca *et al.* 2011). If payments for these carbon mitigation services were available, this could also provide large flows of funds to help promote SLM activities particularly in Africa.

Productivity/income

The core principle of SCPI is to increase productivity and production whilst maintaining or reducing the use of external inputs. In economic terms, this translates into higher profits determined by higher returns given the same or even lower costs. Moreover the system would also reduce the risks associated to production and stabilizes yields over the long term. Last but not least, given the increased adaptive capacity of the ecosystem, vulnerability to pests and diseases as well as to climatic and other stresses or shocks is reduced.

Similarly, agro-ecology and eco-agriculture imply benefits translated into economic returns from agriculture. Eco-agriculture explicitly stresses, in addition to the increased efficiency of input use, also the synergies between inputs; the substitution of natural capital for financial capital; more efficient spatial organization; economies of scale through farmer collaboration and benefits to farming from wild species or revegetation (Buck *et al.* 2004).

Availability of inputs

Through species and genetic diversification of the ecosystem, as well as enhanced soil biota, the availability of inputs can be increased. Farmers may be able to use residues from one component as input for another, receive nutritional and pest management contributions through legume-based intercropping, and fight pest outbreaks through agrobiodiversity.

Pest control

Pest management strategies addressed through an ecosystem approach represent an integral part of SCPI. Integrated Pest Management (IPM) has become the world's leading holistic strategy for plant protection. Based on ecological principles, the concept of ecosystems and the goal of sustaining ecosystem functions, the Integrated Pest Management (IPM) approach is founded on the idea that the first and most fundamental line of defence against pests and diseases in agriculture is a healthy agro-ecosystem, in which the biological processes that underpin production are protected, encouraged and enhanced (FAO, 2011). In other words, IPM involves the scientific application of ecosystem principles to the management of pest populations in order to avoid their build up to damage levels. A more diversified and resilient ecosystem with improved agricultural management can help avoid indigenous pest outbreaks, respond better to pest invasions and reduce risks from pesticides to both human health and the environment (FAO 2011).

Farmers development and stakeholder participation

A key part of implementing the SCPI through the Ecosystem Approach is an equitable decision- making process that includes all the relevant stakeholders. This requires putting social capital and participatory approaches at the basis of agricultural management, decentralizing management to the lowest appropriate level; considering all relevant scientific, indigenous and local actors and the information they can bring, and including all relevant sectors of society and scientific disciplines (Pound 2008).

Likewise, agro-ecology requires an increased participation of farmers in agricultural management as it combines scientific inquiry with indigenous and community-based knowledge and experimentation, emphasizing technology and innovations that are knowledge-intensive, low cost and readily adaptable by small and medium-scale producers. These methods may enhance social equity, sustainability and agricultural productivity over the long term (PANNA 2009). Given that both approaches require capacity building at local level, all stakeholders involved would also have the chance of increasing their know-how and the farming technologies they adopt.

Despite all the potential benefits related to the adoption of the Ecosystem Approach for sustainable intensification of agricultural production or of the other approaches, the adoption level of the practices through these approaches is not always very high and this is certainly due not only to the required capacity and adoption costs but also to a number of other challenges and costs that shifting to a new agricultural approach involves. The costs and challenges involved would obviously need to be considered within the specific context at stake, particularly for those farming regions or marginal areas that present special difficulties to the introduction of some components of SCPI or of the other approaches. The following section provides a description of the main challenges and costs of adoption.

Challenges

First and foremost, the Ecosystem Approach, as well as the other approaches, is knowledge-intensive. It requires capacity building, an implementation process that takes into account the local and specific context in which it is applied and a collaborative network to facilitate the learning process and the social exchange of information between farmers and scientists (Warner 2007). This implies a number of difficulties and costs as better described below.

Land tenure

Under uncertain land tenure, farmers implementing the practices associated with the approaches described above might not be able to retain land access long enough to reap the benefits of the required investments (McCarthy *et al.* 2011). According to the literature, a minimum of ten years may be necessary before any significant achievements can been realized in cases where the environment is severely degraded and restoration is required before gains can be expected (Ryden 2008). Moreover, without security of tenure, farmers may not be inclined to invest on the land and may choose to use their resources for other investments that yield better returns in the short term.

Adoption and production costs

One of the main challenges and difficulties in adopting the Ecosystem Approach through SCPI or either one of the above mentioned approaches is the cost associated with their implementation. McCarthy *et al.* (2011) identified five main types of costs:

- *Investment costs*, which include the cost of learning the new practices and of acquiring the necessary equipment, machinery, materials, and labour force.
- *Maintenance costs*, which refer to recurrent expenses for the purchase of seeds and fertilizers, hired labour, maintaining the equipment, and paying back the obtained credits.
- *Opportunity costs*, which are the costs associated with the allocation of own factors of production into the adoption of a certain practice rather than to other uses.
- *Transaction costs*, which include the costs associated with collecting and processing the information for the adoption of the new technology, the costs of negotiation when adopting one; a certain practice might allow participating in some sort of payment for environmental service scheme, and monitoring and enforcement costs when the adoption is at a larger scale and involves the community level.
- *Risk costs*, which are associated with the uncertainty surrounding the actual materialization of the potential benefits of the adopted practices and to the yield variability during early stages of adoption. This is particularly true in areas where insurance mechanisms and access to credit are limited.

Access to finance and insurance mechanisms

Another barrier to the implementation of the practices associated with the approaches described above is the difficulty of accessing credit and to get insured against the production and market risks. The inability of local financial institutions to offer credit not to mention longer-term loans, coupled with farmers' lack of collaterals, hinder the adoption of SCPI. In this regard, insurance mechanisms and facilitating access to credit, particularly for smallholders, would encourage farmers to adopt sustainable production systems that are potentially more productive and more profitable, but involve, at the same time, greater financial risks (FAO 2011).

Access to market

To be profitable, SCPI requires a dynamic and efficient market for inputs and services as well as for the final produce. Whether farmers and particularly smallholders adopt the ecosystem approach through the SCPI, or one of the other approaches, would largely depend on their ability to access the market and grasp the benefits associated with the sale of their produce. Yet access to both input and output markets has proven difficult for many smallholders, who remain at the margins of the agricultural economy (Cavatassi *et al.* 2010), and with the smallest farmers often unable to enter formal markets (McCullogh *et al.* 2008). In those cases, the challenge is to create comparative advantages for smallholders or to reduce the transaction costs associated with purchasing from large numbers of farmers producing small quantities. To forge links to high-value markets, small farmers need to be organized in groups and institutions in order to reduce transaction costs and they need to be given access to equitable market prices and necessary information on market requirements (FAO 2011; Cavatassi *et al.* 2010; McCullogh *et al.* 2008; Shepherd 2007; Winters *et al*. 2005).

Particularly important within the issue of market access, is accessing crop varieties that are suited to different climatic conditions, agronomic practices and farmers' needs. A successful application of the ecosystem approach within the SCPI framework requires availability, access and utilization of good quality seeds of the right varieties to the farmers through an effective seed multiplication and delivery system (FAO 2010a, FAO 2011). This would require the involvement of both public and private sectors, with local seed enterprises producing certified seed and marketing it to farmers where possible (FAO 2011). The achievement of SCPI would thus depend also on effective regulation of the seed sector including a comprehensive strategy aimed at improving the links between formal and informal seed sectors.

Investments in agriculture and infrastructure

The agricultural sector, particularly in developing countries, necessitates substantial and sustained investments in human, natural, financial and social capital in order to achieve SCPI. Investments to improve the transport infrastructure would significantly improve farmers' access to supplies of fertilizers, seeds and other inputs. In addition, investment in processing, storage and cold chain facilities are needed in order to help farmers obtain more value from their production. Modern information and communication technologies would also facilitate small farmers' participation in SCPI (FAO 2011).

Policies and institutions

The adoption of the approaches described above and the implementation of the associated practices require an enabling environment that includes institutional, policy and legal frameworks.

Some of the main reasons for the limited rate of adoption of these approaches include: inappropriate national and local political agendas; lack of operational capacity; unclear demarcation of responsibilities; lack of good governance and lack of or costly enforcement of enabling regulations (Liniger *et al.* 2011).

In order for farmers to implement the practices described in this section, the benefits must outweigh the costs. When the economic system reflects costs appropriately - including the high environmental cost of unsustainable practices – the choice will ease the adoption of SCPI. Policies aimed at putting a price on these negative environmental externalities and rewarding, at the same time, the positive externalities associated with good agricultural practices, are required in order to incentivise farmers to implement these practices.

In formulating programmes and strategies for the adoption of SCPI policy-makers are advised to consider the development of the agricultural sector as a whole. There is a risk, for example, that policies that aims at achieving economies of scale through value chain development and consolidation of land holdings may exclude smallholders, or reduce their access to productive resources.

FAO, in its latest publication on this matter (FAO 2011), suggests governments to improve coordination and communication across all subsectors of agriculture, from production to processing and marketing. In this regard farmers' organizations and cooperatives, women and a strong social capital, represent key assets for the successful adoption and implementation of the Ecosystem Approach.

Finally, international instruments, conventions, and treaties relevant to SCPI or to other sustainable production approaches may need to be harmonized and further improved. This will require collaboration between international organizations concerned with rural development and natural resources as well as governments, civil society organizations and farmer associations (FAO 2011).

Examples in bioenergy feedstock production

Region: East Africa
Country: Uganda
Crop/Feedstock: Maize (*Zea mays*); cassava (*Manihot esculenta*); sugar cane (*Saccharum officinarum*); sweet potato (*Ipomoea batatas*)

Poverty eradication in the Iganga district, Uganda: maize, cassava, sugar cane, millet, and sweet potatoes productivity increase through Ecosystem Approach-based practices[13]

The Iganga district is one of the most densely populated districts of Uganda, with around 200 people per km^2. Farmers combine perennial tree crops with rainfed annual crops within a mosaic of tropical forest remnants and encroaching on savannah shrubs and grasslands. The most important crops are maize, cassava, sugar cane and sweet potatoes.

Since the 1970s, most natural forests, wetlands and woodlands have been cleared due to unsustainable harvest levels of fuelwood and timber, and in order to make room for agriculture and human settlements. As a result, wild species have declined, swamp soils have dried up, becoming sterile, and fuelwood and other forest products have become increasingly scarce.

In 1997, the NGO *Africa 2000 Network* started a three-year project aimed at improving the sustainability of farming in the area through an Ecosystem Approach. In order to meet this goal, the project focused its efforts on: increasing the diversity of native crops; introducing organic soil management methods such as compost production, mulching and fallow techniques, and introducing Integrated Pest Management (IPM) and agroforestry practices. In addition, improved cookstoves, capable of reducing fuelwood consumption by 50-75 percent as well as improving safety in the kitchen, were introduced through the project.

Since 1997, more than 20 000 farmers have benefited from this project. Promotion of an increased diversity of indigenous crop varieties has contributed both to maintaining local agrobiodiversity and to increasing food security. After three years from the beginning of the project, 99 percent of the participating farmers reported an increase in the productivity of maize, cassava, millet, sugar cane and sweet potatoes; 89 percent of farmers reported an increase in income, and 61 percent of households reported a reduction in the time spent collecting fuelwood as a result of the improved efficiency of cookstoves.

13 The information included in this section was either adapted or excerpted from: FAO (2003).

Region: Australia/Oceania
Country: Australia
Crop/Feedstock: Sugar cane (*Saccharum officinarum*)

Ecosystem Approach-based practices to improve soil health and reduce yield decline of sugar cane in Queensland, Australia[14]

Yield decline of sugar cane (*Saccharum officinarum*) is a widespread problem throughout the Australian sugar industry. It results from loss of productive capacity of soil under long-term sugar-cane monoculture, due to lack of rotations, excessive tillage of the soil at planting and soil compaction from the use of heavy machinery during harvesting. In 1993, in Queensland, northern New South Wales and in Western Australia, a multidisciplinary research programme, known as the Sugar Yield Decline Joint Venture, was established among concerned institutes to develop solutions to revive a viable, productive and sustainable sugar-cane industry. The aim of the programme was to identify viable alternatives to the conventional monoculture and high-input system through ecosystem approach-based practices.

Crop rotation was the first Ecosystem Approach-based practice to be introduced. Trials were established at five sites in Queensland on land which had been under cane monoculture for at least 20 years, incorporating three different breaks, varying from 9 to 42 months, and using as alternative crops soybean (*Glycine max*), peanut (*Arachis hypogaea*), and maize (*Zea mays*).

In order to increase soil nutrients, another Ecosystem Approach-based practice was adopted: organic amendments. Sugar-cane cultivation produces waste material and by-products that were returned at the rate of 10-15 tonnes (dry weight)/ha of cane trash to the soil surface after each harvest.

In order to reduce the bulk density of the topsoil, minimum tillage techniques were implemented as well during the programme. There is a traditional belief that tillage of the soil between sugar-cane cropping cycles has beneficial effects in terms of controlling root diseases and pests. This may be true with some root feeding pests such as the canegrub (mainly genus *Antitrogus, Dermolepida, Lepidiota* and *Rhopaea)* However, the deployment of biopesticide products, such as those containing the fungus *Metarhizium anisopliae* (a natural biological control agent of the canegrub), were found to be more effective in a minimum tillage scenario.

The adoption of the aforementioned Ecosystem Approach-based practices under the Sugar Yield Decline Joint Venture in Queensland led to a 33 percent increase in average sugar-cane yields.

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14 The information included in this section was either adapted or excerpted from: FAO (2003).

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1.3 ORGANIC AGRICULTURE

Maizura Ismail

Key features

Environmental and health concerns regarding the dependency on synthetic inputs, such as fertilizers and pesticides in crop production and antibiotics in the livestock sector, have stimulated interest in more sustainable approaches to food production, including Organic Agriculture.

The FAO/WHO Codex Alimentarius Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (2007) define Organic Agriculture as "a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity". Organic agriculture, where possible, emphasizes the use of cultural, biological and mechanical management practices in preference to the use of off-farm inputs.

The FAO/WHO Codex Alimentarius Guidelines further stated that "an organic production system is designed to:

- enhance biological diversity within the whole system;
- increase soil biological activity;
- maintain long-term soil fertility;
- recycle wastes of plant and animal origin in order to return nutrients to the land, thus minimizing the use of non-renewable resources;
- rely on renewable resources in locally organized agricultural systems;
- promote the healthy use of soil, water and air as well as minimize all forms of pollution thereto that may result from agricultural practices;
- handle agricultural products with emphasis on careful processing methods in order to maintain the organic integrity and vital qualities of the product at all stages, and
- become established on any existing farm through a period of conversion, the appropriate length of which is determined by site-specific factors such as the history of the land, and type of crops and livestock to be produced".

In most countries and especially for the purpose of export, claims of Organic and the higher premium it entails have to be based on inspection and certification of compliance, with specific production and processing methods as required by organic standards.

With regard to crops grown specifically for bioenergy production, organic certification is not relevant, due to the designated use of these crops and the consequent lack of a price premium. However, most of the principles discussed in this section and their implementation through the field-level good practices described in the third chapter of this report, are important for these crops as well, as they can enhance the sustainability of their production.

Potential benefits

Soil quality

Building and maintaining soil fertility through natural processes, with particular focus on organic matter content, biological activity and soil erosion, is central to organic farming practices, which do not allow for the use of synthetic pesticides and fertilizers (Scialabba and Hattam 2002). A long-term study of two comparable adjacent farms (one organic and one conventional) in Spokane, Washington, United States, found that the organically-farmed soil had significantly higher organic matter content, thicker topsoil depth, higher polysaccharide content (for soil aggregation), lower modulus of rupture (less hardened surface) and less soil erosion (Reganold *et al.* 1987). Similar results were found in other studies such as for the case of the “DOK” long-term experiment in Switzerland, where organically managed soils exhibited greater biological activity and soil aggregate stability than the conventionally managed soils (Mäder *et al.* 2002).

Soil with higher organic matter content provides more nutrients for plant uptake and habitat for soil organisms. It also binds soil particles, which improve the water holding capacity of soil (Bot and Benites 2005). No- or minimum tillage, the use of plant residues and the avoidance of synthetic fertilizers and pesticides may lead to an increase in earthworm population, which is vital for the aeration, aggregation and stabilization of soil (Darlington 2009). This may also contribute to an increase in soil water retention and infiltration capacity, reduce the risk of erosion, and maintain topsoil thickness and the productive capacity of land (Reginold *et al. 1987*).

Water availability and quality

Organic agriculture does not rely on a number of conventional farming practices that may lead to negative impacts on water quality such as excessive application of mineral N-fertilizers, lack of soil cover and water contamination from synthetic pesticides. Increased biomass in organically managed soils decreases irrigation water requirements. In addition, earthworm burrowing may increase porosity and drainage, preventing occurrence of waterlogging; it may also increase soil aeration and water retention, which are vital for roots development and incorporation of organic matter (McGarry 2006).

Biodiversity

In an organic system, wild species such as bees, earthworms, predators and parasitoids perform a variety of ecological services such as pollination, maintenance of soil fertility and pest control (Scialabba and Hattam 2002). These wild species can replace soil fertility management and pest control based on synthetic agrochemicals. The use of local landraces and the large associated biodiversity in organic farming systems have the potential to act as a hedge against future environmental changes, including climate change, and the emergence of new pests or the resurgence of old ones, therefore enhancing the resilience of agro-ecosystems (Vandermmer *et al.* 1998).

Agrobiodiversity

Organic farms tend to be mixed farms, integrating animal husbandry and crop production, and using landraces, various cropping systems and rotations (Scialabba and Hattam 2002). This wealth of diverse production processes and final products enhances the resilience of organic farming systems to price fluctuations and disruptive changes of input and output prices.

At the same time, organic practices, such as crop rotations, strip-cropping, green manuring, organic fertilization, no- or minimum tillage and avoidance of chemical pesticides and herbicides, may create suitable conditions for soil fauna and flora, as well as root symbioses, nutrient cycling, soil forming and conditioning (Scialabba 2000). The increase in biological activity and biodiversity, both above and below ground, is likely to provide a positive contribution towards attracting birds and larger animals, thus further increasing the biodiversity in the farm (Reganold *et al.* 1987).

In addition to enhancement of ecological food webs, organic farms usually maintain hedgerows, vegetative buffer strips, riparian corridors, buffer zones and other landscape features that provide shelter to predators, pollinators and other biodiversity beneficial to agricultural production.

Therefore, by design, organic farms show higher agrobiodiversity and overall biodiversity than conventional farms, as confirmed in a number of studies (e.g. Mäder *et al.* 2002; Pacini *et al*. 2003).

Climate change mitigation

FAO (2009) conducted a literature review to evaluate the opportunities and constraints of carbon accounting for organic agriculture management in developed and developing countries. The study concluded that there is scientific evidence that organic agriculture can sequester more carbon than conventional agricultural practices or inhibit the carbon release. In particular, the author estimated that organic agriculture has the potential of sequestering an average of 200 to 400 kg C per hectare per year for all croplands. All available studies showed higher carbon stocks in organic systems as compared to conventionally farmed sites.

Overall, organic systems have demonstrated to compensate for GHG emissions through enhanced soil carbon sequestration and being almost carbon neutral (Scialabba and Müller-Lindenlauf 2010).

Productivity/income

Although prices of organic products vary, an FAO/International Trade Centre/Technical Centre for Agricultural And Rural Cooperation (FAO/ITC/CTA 2001) study on fresh certified organic fruit and vegetables markets in developed countries suggests that the price premium generally ranges between 20 and 40 percent above conventional prices, with higher peaks in some cases. In a study on the adoption of organic agriculture among small farmers in Latin America and the Caribbean by the International Fund for Agricultural

Development (IFAD), farmers were able to receive higher prices for certified organic products, with the premium over the price of conventional products ranging from a minimum of 22.2 percent paid to banana producers in the Dominican Republic in 2002 to 150 percent paid to cacao producers in Costa Rica in 2001 (IFAD 2004).

Generally, labour costs in organic farms are higher, due either to higher wage costs or labour needs. However, despite higher labour inputs, production costs are lower in both developed and developing countries, making organic farms economically more profitable than conventional farming (Nemes 2009).

Human health and safety

Besides containing less nitrates and pesticides residues, organic plant products contain more dry matter, vitamin C, carotenoids, phenolic compounds, exogenous indispensable amino acids, reducing and total sugars, iron, magnesium and phosphorus compared to conventional plant products (Rembiałkowska 2009). The five-year Quality Low Input Food project, funded by the European Commission to compare impacts of conventional and organic food production, showed that on top of containing higher levels of nutritionally desirable compounds, organic food also has lower levels of nutritionally undesirable compounds such as heavy metals, mycotoxins, pesticide residues and glyco-alkaloids (Leifert 2009). A review of the USDA's pesticide data programme, the California Department of Pesticide Regulation's marketplace surveillance programme and a private residue-testing programme showed that pesticide residues are more likely to be found, and at higher levels, in samples of conventional food compared to organic food (Winter and Davis 2006).

In addition, if managed improperly, the application of synthetic pesticides and fertilizers may present occupational health and safety risks to workers. A study on agricultural workers and their families in Iowa and North Carolina, United States, found that occurrence of prostate cancer was statistically significant among pesticide applicators compared to the general population, while a non-significant elevation of lip cancer was also observed among them (Alavanja *et al.* 2005). By avoiding the application of these products, workers' health and safety can be improved.

Challenges

Input and labour requirements

Organic agriculture methods of production tend to be more labour intensive compared to conventional agriculture. In organic farms, farmers usually have to implement alternative manual techniques for pest removal, soil additions and conservation due to limited use of synthetic chemical inputs (Santos and Escalante 2010). Additional activities include: cover cropping to replace fertilizers; waste composting and green manuring; hand weeding and pest removal, and crop rotation.

Land Tenure

Insecure land tenure may act as a deterrent for farmers implementing land conservation measures as the returns may only be obtained in the medium and long run (IFAD 2004). Land tenants may also need to seek permission from the landowners before implementing land conservation measures.

Adoption costs

Conversion to organic production may put pressure on the farm finances initially as it may lead to a decline in output and farm income during the conversion phase, as well as to an increase in costs due to the investment and labour requirements, as well as the additional certification requirements (Firth *et al.* 2004; IFAD 2004). The profitability of conversion is very dependent on the farm's initial financial position, the rate of conversion, and the premium secured from resulting organic products. The type of relationship established between the farmers or farmers' organizations and buyers also plays a key role in determining the price margins, with better premiums secured when long-term relationships are established (IFAD 2004).

Access to finance

When farmers shift from conventional to organic production, they may need some financial support, especially during the initial period, when in addition to having to bear additional costs they need to get certified without being able to obtain premium prices (IFAD 2004). Some financial institutions also do not recognize the added value of organic farming, and therefore might be less willing to provide credit for organic cultivation, which involves higher labour and certification costs.

Awareness, education, and research and development

One of the major reasons farmers are reluctant to convert from conventional to organic agriculture is the lack of data and knowledge on the transition process and its implications. Without clear information on the physical and financial costs involved and on the economics of organic farms, farmers may be reluctant to invest in a complex process that involves changes in the production system, as well as innovations and restructuring in the farm systems (Firth *et al.* 2004).

Consumer confidence

The potential weakening of organic standards, either due to the allowance of non-organic ingredients in food labelled as Organic or to the watering down of Organic standards' requirements, as well as occurrence of unpunished fraud cases may lead to consumer cynicism and loss of confidence in organic markets (Martin 2007; Tschang 2007; Sønderskov and Daugbjerg 2010). A consumer survey of organic markets by FAO/ITC/CTA (2001) found that in most developed markets, consumers express distrust of the authenticity of certified organic imports and prefer domestic organic products.

Policies and institutions

Organic farming is no longer limited only to the developed world, as it is commercially practised in 160 countries, representing 37.2 million hectares and a market of US$54.9 billion in 2009 (Willer and Kilcher 2011). According to some studies (e.g. Badgley *et al.* 2007), organic methods could produce enough food on a global per capita basis to sustain the current human population, and potentially an even larger population, without increasing the agricultural land base, and while reducing the detrimental environmental impacts of conventional agriculture.

The main challenge is how to promote and optimize this potential for the benefit of food security and the health of global ecosystems. In order to unlock this potential, in industrialized countries funds should be provided to support the transition phase and to compensate for decreased yields until soil fertility is restored; in developing countries, more and better agro-ecological knowledge generation and dissemination would be required.

In some countries, there may be a lack of support from agricultural departments, research institutions and extension services in generating knowledge, and research and development in organic agriculture when compared to conventional agriculture. In addition, governmental subsidies for synthetic fertilizers and pesticides may make conversion to organic agriculture less attractive, especially if no corresponding incentives are provided for organic inputs.

Lack of harmonization among standards

Organic standards are not currently harmonized internationally, with several differences among the standards, as well as in their interpretation. In particular, differences exist in defining terms and specificity of the standards (Sawyer *et al.* 2008). According to Sawyer *et al.* (2008), the lack of harmonization among organic standards may inhibit the international movement of organic products, affecting trade either by manifesting effects equivalent to an import ban (when the importing country does not recognize the exporter's standards) or to a tariff (through an increase in the costs of exporting products resulting from conformation to the importer's different standards).

Examples in bioenergy feedstock production

Region: South America
Country: Brazil
Crop/Feedstock: Soybean (*Glycine max*)

Certified organic soybean production in Capanema, south of Brazil[15]

Soy cultivation is the most important source of income for the farmers of the small town of Capanema in south Brazil. In 1986, a group of local farmers decided to eliminate synthetic inputs from their soy production. Since then, in collaboration with the organic supply company Gebana Brasil, more than 250 farmers have started producing organic ingredients for brands such as Demeter and BioSuisse, as well as other organic products both for export and for the local market.

Contracts were stipulated between Gebana Brasil and local farmers. Under these contracts, the company provides advice on organic cultivation methods, organizes and finances seeds, fertilizers and biological pest control, while farmers provide organic soy under specific terms and conditions. During each winter, the contracts are renewed, further developments are discussed, and requirements for seeds and other means of production are identified.

In September/October, organic soy seeds are delivered to the farmers and production data is collected for certification. Farmers start sowing in October/November and harvest in March/April. Throughout this time, organic experts from the company constantly work alongside farmers to advise on organic production of soy and other crops, such as manioc (*Manihot esculenta*), wheat (*Triticum sp.*), maize (*Zea mays*), bananas (*Musa spp.*) and pineapples (*Ananas comosus*), as well as on other issues such as financing.

In terms of labour requirements, most of the work consists of weeding, which is usually carried out by workers who are family members and neighbours. Harvesting is usually done by hand. If it is done with hired combined harvesters, the machineries need to be totally clean to avoid possible contamination with genetically modified soy.

Gebana Brasil pays between 40 percent and 100 percent above the local market price for organic soybeans. To avoid dependency on soy, farmers are encouraged to cultivate other crops for consumption or sale on the local market, as well as for export, through the company itself.

15 The information included in this section was either adapted or excerpted from the web site of the company Gebana Brasil: http://www.gebana.com/htm/gebana_brasil_e.htm.

Region: South Asia
Country: India
Crop/Feedstock: Sugar cane (*Saccharum officinarum*)

Organic sugar-cane production in the San Javier region, province of Misiones, Argentina[16]

The San Javier region, located in the province of Misiones in the northeast of Argentina, has a particularly high share of small organic producers. San Javier, with its 600 small scale farmers, was responsible for the cultivation of approximately 1 500 ha of certified organic sugar cane in 2001, and represented 37 percent of the total number of certified organic producers in Argentina.

The development of organic sugar-cane production by smallholder farmers in the San Javier region was strongly supported by the provincial government of Misiones. In early 1996, following the bankruptcy of the private firm owning the mills due to the competition with imports from neighbouring countries, the Institute for the Promotion of Agriculture and Industry (IFAI) - which is the development arm of the Misiones government - took over the management of the sugar-cane processing facilities.

IFAI started to promote the conversion to organic production in 1997 as part of an effort to recover the mill and transfer it back to private producers. The production of organic sugar cane made it possible to maintain the mill and the crop output. By 2000, IFAI was supporting the production of 3 450 tons of organic sugar, most of which was exported to European countries. In addition to managing the mill, IFAI also provided extension services for farmers.

As this example shows, organic farming can be a viable option for sugar-cane production, including in the context of small scale production for export markets.

16 The information included in this section was either adapted or excerpted from: IFAD (2004).

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CHAPTER 2

SUSTAINABLE INTEGRATED AGRICULTURAL AND FORESTRY MANAGEMENT SYSTEMS

INTRODUCTION

This chapter provides an overview of three sustainable integrated agricultural and forestry management systems, namely:

- Agroforestry;
- Integrated Food-Energy Systems (IFES), and
- Multiple Cropping Systems and Crop Rotation.

These agricultural (including livestock) and forestry management systems allow for the integrated production of food, feed, fuels and/or fibre, thus reducing the potential competition between the respective markets.

The key features of the aforementioned management systems, and the associated potential benefits and challenges, are described in the sections below. In addition, examples of applications of these systems in bioenergy feedstock production in different regions of the world are provided.

The implementation of the integrated agricultural and forestry management systems described in this chapter can lead to a number of environmental and socio-economic benefits on: soil quality, water availability and quality, agrobiodiversity, climate change mitigation, productivity/income, and access to energy (in the case of IFES).

At the same time, these management systems present some challenges that limit their adoption, including in terms of input and labour requirements, access to finance, awareness, education and research and development, and policies and institutions.

2.1 AGROFORESTRY

Maizura Ismail, Marco Colangeli

Key features

Agroforestry refers to "land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals on the same land management unit[17]" (FAO 1993).

Agroforestry, which has been an integral part of many traditional farming systems for a long time, includes both crop and/or animal farms that have trees incorporated into or maintained in them, as well as existing forested areas that are managed for both wood and non-wood forest products (Beetz 2002; Schroth and Sinclair 2003). In agroforestry systems, a broad range of products may be produced, including food, feed, fuels, fibre and building materials.

Agroforestry can either be by spatial arrangement, i.e. intercropping of trees and crops; or by temporal sequence, i.e. trees included in crop rotations. Although agroforestry systems are extremely heterogeneous, some common characteristics can be identified (Nair 1993):

- deliberate integration of trees with crops or animals;
- inclusion of more than one species and production of two or more outputs, and
- significant economic and/or ecological interaction between woody and non-woody species.

Nair (1993) classified agroforestry systems depending on whether the integrated species are woody perennials, herbaceous plants or animals (see figure 1). They comprise:

- trees-crops combination – agrisilvicultural systems;
- trees-animals/pasture combination – silvopastoral systems, and
- trees-crops-pasture/animals combination – agrosilvopastoral systems.

Other criteria for the classification of agroforestry systems include predominant land use and type of tree cover (Schroth and Sinclair 2003). Considering the different components, spatial/temporal mixtures and technologies used, there are a number of variations in agroforestry systems (see figure 1), making further classification difficult.
The most widespread agroforestry systems are:

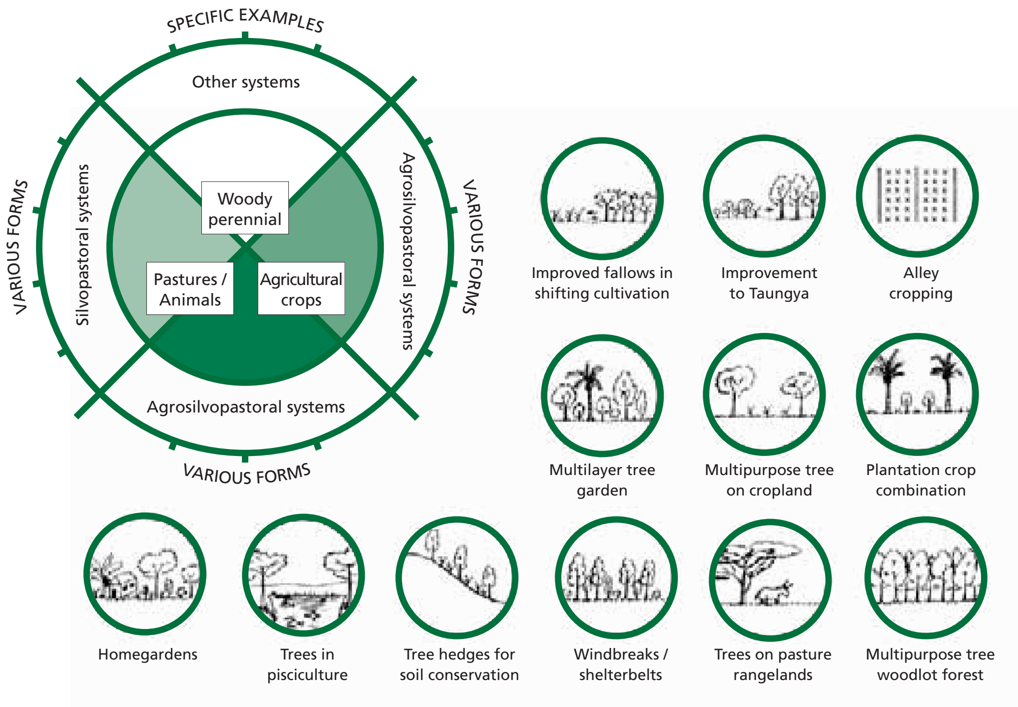
- Livestock in plantations: combining crop and animal farming, in which the livestock forages on the leaves of trees and grass in the plantation, and the trees benefit from the additional manure as fertilizer;

17 The tree component may also provide the environmental services that improve soil quality, soil water infiltration, soil nutrient recycling and microclimate for better crop and animal growth, on top of reducing erosion and providing shelter.

- Windbreaks, shelterbelts and hedgerows: planting of tree species of specific heights in between crops and around the farm to give shelter to crops and animals, as well as mark farm boundaries;
- Multi-layer tree garden: cultivating crops of different heights in a multistorey arrangement under a tree canopy to maximize land use potential;
- Improved Taungya: Taungya literally translates to "hill cultivation" in Burmese and is locally understood as shifting cultivation, in which annual agricultural crops are grown along with forest species during the early years of forestry plantation establishment, before trees grow too tall and the canopy blocks the sunlight;
- Multipurpose tree woodlot forest: trees and shrubs that are deliberately maintained and managed for more than one economic or ecological service, or production functions.

Figure 1

Classification of agroforestry systems based on the type of components – top left; and major agroforestry systems



Source: Adapted from Nair (1985 and 1993)

Various types of bioenergy and bioenergy feedstocks can be produced under these systems, including fuelwood, both first and second-generation liquid biofuels, and biogas (under silvopastoral and agrosilvopastoral systems).

Potential benefits

Soil quality

Agroforestry may contribute towards soil fertility by increasing nitrogen input through nitrogen-fixing trees; and by increasing soil organic matter though additional production and decomposition of litter and pruning. In agroforestry systems, improvement of soil physical conditions and soil microbiological activities are possible thanks to year-round presence of root exudates and decaying root cells (Bot and Benites 2005; Nair 2007). Agroforestry may also positively affect soil quality through rehabilitation of waterlogged areas; greater uptake and utilization of nutrients from deeper layers of soils by deep-rooted trees; prevention of land degradation caused by erosion and advancing deserts, and rehabilitation of degraded land. Silvopastoral and agrosilvopastoral systems have been found to be particularly beneficial in terms of soil enhancement (Amézquita *et al.* 2008).

As different agroforestry components reach different heights and mature at different points in time, most systems are unsuitable for mechanization and manual harvesting is required. This may reduce the risks of adverse impacts on soil quality caused by soil compaction (Tarigan 2002).

Water availability and quality

Through the effects on soil quality described above, agroforestry may also affect water availability and quality. In particular, as soil physical conditions and microbial activities improve in agroforestry systems, soil water infiltration can increase, leading to an increase in water availability for plant root uptake. By reducing erosion, agroforestry can also improve water quality in waterways of surrounding areas.

Biodiversity

Areas set aside as forest/riparian buffer-zones, shelterbelts and windbreaks can play a key role in maintaining plant and animal biodiversity by: acting as a buffer to protected areas; protecting them from the direct effects of more intensive agriculture and human settlements; creating corridors that enable movement of animals from one protected area to another, and increasing the overall connectivity of natural habitats (Bichier 2006).

In Krui (Sumatera, Indonesia), for instance, resin-producing agroforests are home to 92 bird species, 46 species of mammals, including 17 species that are protected by Indonesian law, and also have primate populations comparable to those observed in natural forests (92 observed bird species). In addition, the establishment of these resin-producing agroforests protected the area from logging, and acted as buffer for the neighbouring national park (Colchester *et al.* 2005).

Agrobiodiversity

Agroforestry adds plant and animal biodiversity to farm landscapes through the inclusion of tree species, thus increasing farms' resilience. A review of scientific studies on this issue by Cotter and Tirado (2008) concluded that diversity in agricultural landscape, as well as in the wild, “provide a natural insurance policy against major ecosystem changes” and are “crucial in highly variable environments and those under rapid human-induced climate change”.

Agroforestry may also lead to an increase in the number of populations of predator species that protect crop plants from pest outbreaks and pollinator species important for ensuring harvests of important crops (Nair 2007).

Climate change mitigation

Agroforestry systems show a high carbon sequestration potential. Although this potential varies depending on the type of agroforestry system considered, as well as on local soil and environmental conditions, all agroforestry systems can sequester more carbon as compared to sole agricultural land use systems (Yadava 2010).

In India, the average sequestration potential in agroforestry, over 96 million ha of land, was estimated to be around 25 tons of carbon per hectare (t C ha^{-1}), while in China it was estimated at 6-15 t C ha^{-1} over 75.9 million hectares (Yadava 2010).

Silvopastoral systems have been found to have a particularly high potential for carbon sequestration (Amézquita *et al.* 2008). In different studies carried out in Latin America, total carbon in silvopastoral systems was found to vary between 68-204 t/ha, with most carbon stored in the soil, while annual carbon increments varied between 1.8 to 5.2 t/ha.

Productivity/income

Despite lower economies of scale compared to monoculture systems, agroforestry may increase farm income through diversification of farm products from trees. Boffa (1999) listed 24 different species of multipurpose trees maintained or cultivated in agroforestry systems that have between four and nine tree parts with multiple end-uses. Silvopasture, in particular, integrate trees, livestock, and forage into a single system on one site. A study on Argentina’s silvopastoral systems, for instance, estimated that silvopasture yields an annual income per hectare higher than alternative agricultural, cattle-ranching or forestry systems when these are evaluated singularly (Esquivel *et al.* 2004).

Agroforestry may also increase profitability by making more efficient use of labour and other resources (Gold *et al.* 2004). For example, in a farm located in Kenya’s Central Province, dairy cattle milk production doubled thanks to the use of high protein feed from calliandra (*Calliandra calothyrsus*) and mulberry trees (*Morus alba*) planted on-farm as a frame for bean (*Vigna spp.*) production (Pye-Smith 2010). In addition, farm income increased thanks to the sale of fodder tree seeds.

Access to energy

Agroforestry may increase access to energy mainly in two ways: by generating fuelwood and/or biogas; and by increasing farm income, thus helping farmers to get access to more and better fuels, equipment and energy services. The same farm in Kenya mentioned above generates a constant harvest of fuelwood from calliandra and mulberry hedges, and another farmer in the same area was able to purchase a solar system to power his house, thanks to the income generated from the sale of milk, fodder seeds and livestock on his agroforestry operation (Pye-Smith 2010).

Challenges

Pest issues

The issue of livestock internal parasites is aggravated by the shading effect of tree crops in silvopastoral and agrosilvospastoral systems, which favours parasite egg survival and persistence. External parasites, especially the tick *Boophilus microplus*, have also shown higher incidence in conditions of tree canopy cover if compared to similar grazing systems without a tree layer (CIRAD 1993). Tick infestations affect the productivity of dairy cows, leading to a decrease in both milk quantity and quality (Jonsson *et al.*1998).

Input and labour requirements

The lack of adequate planting materials and seeds is often identified as a key constraint to the wider adoption of agroforestry innovations (Franzel *et al*. 2006). Local multiplication of forest species could be limited, and thus efforts are often necessary to establish effective, sustainable, and community-based systems to produce enough seedlings.

Agroforestry systems also require diversity in inputs and labour requirements as different species have different growing seasons and nutrient and pest management requirements. This can lead to an increase in production costs and labour requirements. In a study on silvopastoral systems in Colombia, Costa Rica and Nicaragua, for instance, the adoption of these systems was found to be associated with an increase in the need of day-workers ranging from 34 to 106 percent (Mosquera-Losada *et al.* 2005).

Land tenure

Insecure land tenure, combined with other factors such as land fragmentation, poor extension services, limited technical knowledge, and lack of available planting materials, could discourage farmers from adopting agroforestry systems (Neupane and Thapa 2001). Land tenants may also not have the option to include tree components into their farms as it could affect land tenure status (Bot and Benites 2005). For example, in certain customary rights systems in Burkina Faso, Indonesia and Kenya, planting a tree gives the planter rights over the land on which it is planted; while in Tanzania, planting permanent trees without permission on someone else's land could be construed as a "misbehaviour" and constitute grounds for eviction (Fortmann 1985).

According to Fortmann (1985), adoption of agroforestry practices may be discouraged in cases where there are uncertainties in relation to:

- the rights to own, lend, mortgage and inherit the tree;
- the rights to own and inherit the land on which the tree is grown;
- the rights to harvest or gather tree products;
- the rights to use the tree and the shaded land underneath the tree;
- the rights to remove part of, or the entire, tree;
- the rights to compensation for improving land and land value due to planting of trees, and
- the rights of women in relation to all of the above.

Access to finance

Farmers may not have access to sufficient resources to invest in the establishment of agroforestry systems. In a study on the economics of silvopastoral systems' adoption in northeastern Argentina, for instance, access to finance at the moment of the establishment of - or conversion to - a silvopastoral system was identified as the main challenge for the majority of farmers, who had been able to adopt this system only thanks to a government cost-share programme. The study concluded that it is unlikely that new farmers, particularly small farmers with limited resources, will adopt agroforestry systems without some form of incentives.

Access to market

Agroforestry products may face marketing problems due to the lack of established marketing institutions, market information, and grade or quality standards (Gold *et al.* 2004). Better markets for agroforestry products may be developed by improving the structure, conduct, and performance of agroforestry tree product markets, as well as by improving access to markets by low-income producers (Denning 2001). This may require the development of innovative marketing methods, marketing capacity building, and processing to add value to products. According to Van Noordwijk (2006), improvement in farmers' marketing skills may be as important as technical changes in the production stages of agroforestry.

Awareness, education, and research and development

Agroforestry systems are complex, requiring interdisciplinary expertise and understanding, as well as knowledge of specific species. In an agroforestry system, the tree, crop, and animal species inherently interact with each other and have to be selected carefully to avoid negative impacts on crop production due to competition for light, water and nutrients; allelopathic effects, and occurrence of pests and diseases (Bot and Benites 2005).

Improvement of agroforestry research and teaching in higher education institutions and basic education institutions for farmers may lead to graduates and farmers being better equipped to develop, disseminate, and implement sustainable agroforestry and natural resource management practices (Denning 2001). Focus should also be given to extentionists' education. In a study on agroforestry policy and implementation in Nepal, for instance, the lack of understanding on agroforestry was one of the main reasons identified for the extension workers' failure to deliver appropriate technology to farmers (Regmi 2003).

Policies and institutions

Agriculture and forestry are often dealt with separately at both research and policy levels, and as part of different production systems at the field level. Government policy and investment/grant schemes are focused on established disciplines of conventional agriculture or forestry, and therefore may be unable to provide sufficient guidance and support for the development of agroforestry programmes (Nair 1993; Doyle 2002). For example, a study on agroforestry policy and implementation in Nepal shows that although agroforestry is acknowledged in the Agricultural Perspective Plan and the Master plan for the Forestry Sector, forestry officials are mostly focused on accomplishing forestry targets on government owned forestland (Regmi 2003).

In the United States, federal and/or state regulations, such as government-imposed restrictions on farming or forestry operations, prohibition of animal grazing, and transfer payments for pure agricultural crops, may discourage farmers from adopting agroforestry practices (Garrett 1997).

Examples in bioenergy feedstock production

Region: South East Asia
Country: Malaysia
Crop/Feedstock: Oil palm (*Elaeis guineensis*)

Income diversification through integration of oil palm and livestock production in Malaysia

During the 1980s, the Malaysian Department of Veterinary Services established the Ruminant/Tree Crop Integration project, with the aim of integrating livestock cultivation into oil palm and rubber plantations, in order to optimize land resource use, and diversify and increase farm-based income for small-scale farmers (VSD 2004). Under this project, the input for livestock rearing is kept low by implementing rotational cattle grazing on natural vegetation and undergrowth, supplemented by palm oil leaves in the case of forage shortage (Chin 1998). At the same time, manure from livestock is used as fertilizer in the plantations.

At a cattle stocking rate of one head every 4 hectares, farmers' income increased on average by RM 160 (US$42.09)/hectare/year (ha/y); in addition, farmers were less affected by the fluctuation in the price of the main crops (Faridah 2001). The integration of livestock in palm oil plantations was also found to benefit farmers by: reducing labour cost/ha/yr by half and weeding costs by 30-50 percent; increasing oil palm fresh fruit bunch (FFB) yield by 6-30 percent; decreasing the use of chemical fertilizers, and improving soil structure through the addition of organic matter to the soil (Faridah 2001).

Although mostly used in the manufacture of food and body care products, a growing share of palm oil is also being used to produce biodiesel. Some palm oil mills utilize the empty fruit bunch (EFB) as feedstock for boilers, while other palm oil mills have started harvesting biogas from the palm oil mills effluent (POME) for heat and electricity generation (Chong and Zaharudin 1988). Integrated plantations can further optimize their production by utilizing livestock manure to produce biogas.

The Malaysian Palm Oil Board (MPOB), in collaboration with smallholders, has carried out integrated farming trials with other plants as well in the first few years of oil palm growth, such as yellow sugar cane, banana and pineapple. As reported by Faridah (2001), during these trials, oil palm and two ratoons of yellow sugar cane yielded a net profit of RM 11731 (US$3 086) per hectare; oil palm combined with two harvests of banana yielded a net profit of RM 16 644.20 (US$4 379) per hectare; and oil palm one harvest of pineapple yielded a net profit of RM 3 469.86 (US$1 121) per hectare.

Region: South America
Country: Colombia
Crop/Feedstock: Sugar cane (*Saccharum officinarum*); animal dung (biogas - methane)

Highly integrated food- and energy-producing farm in Santander, Colombia[18]

The Tosoly Farm, which is located in Santander, Colombia, is a highly integrated, highly complex farm that produces food and energy for family consumption, as well as for sale in a crop/livestock-based system.

The 7 ha farm is divided into many sections and production areas, including: a natural forest; Arabica shade grown coffee under "Guamo" trees (*Inga hayesii* Benth); sugar cane; permanent plantations of forage trees, including mulberry (*Morus alba*) and tithonia (*Tithonia diversifolia*); and plantations of forage plants, such as new cocoyam (*Xanthosoma Sagittifolium*) and water spinach (*Ipomoea aquatic*). Approximately 2 ha of the farm is used for other low level uses including citrus and bamboo, pasture, fish ponds, roads, and buildings (Preston and Rodríguez 2009*; Bogdanski et al.*, 2010).

Basically, the cropping is based on sugar cane (feed for pigs, food and energy), coffee and cocoa (food and energy), and multipurpose trees. The livestock and fuel components are chosen for their capacity to utilize the crops and by-products produced on the farm.

After extracting the juice used as sweetener and fed to the pigs, the sugar-cane bagasse is used as the goat and cattle pen lining to absorb excreta, as well as a fuel source for a gasifier. The gasifier provides combustible gas for an internal combustion engine linked to an electric generator. The sugar- cane tops, including the growing point and some whole stalk, are the main feed for the cattle and goats.

For protein, the goats consume the leaves, fine stems, and bark of forage trees. The residual stems are then used as another source of fuel in the gasifier. The cows are kept for the production of milk, meat and manure. Transportation of forage and sugar cane are done using a horse. Other than that, the farm also keeps hens and ducks that are kept in semi-confinement systems and live on foraging for eggs and meat. Rabbits that forage for food are kept for their meat.

All high moisture wastes are recycled through plug-flow, tubular plastic (Polyethylene) biodigesters. Pig and human excreta are the feedstock for four biodigesters. Wastewater from coffee pulping, washing of dishes and clothes go to a fifth biodigester. Effluents from all biodigesters are combined and recycled to the crops as fertilizer. Periodically, goat and cattle manure is recycled to the crops as fertilizer and a source of organic matter.

Most of the energy on the farm is produced by gasification of the sugar-cane bagasse and the stems from the mulberry and tithonia forages. There are also 800 W of installed capacity of photovoltaic panels that are estimated to yield 8 KWh daily. The eight

18 Unless otherwise stated, the information included in this section was either adapted or excerpted from: Bogdanski *et al.* (2010).

biodigesters produce 6 m^3 daily of biogas, two thirds of which are converted to electricity (6 KWh/day) using it as fuel in the same IC motor-generator attached to the gasifier. The remainder is employed for cooking. Low grade heat energy, produced by the solar water heater and the wood stove, is not included in the energy balance.

After deducting the electricity required to power the farm machinery and for household use, the farm has the potential to export a surplus of 104 KWh daily, which at the current price of electricity (US$0.20/KWh), would yield an annual return of US$7 600. The gasifier produces 4.4 tonnes of biochar yearly, which is returned to the soil, with a significant carbon sequestration potential. The house and machinery combined use 11 KWh/day of electricity. The farm produces ten times this amount, mostly through the gasifier, with 8.0 KWh/day generated by the solar panels and 6.0 KWh/day from the biodigester. Therefore, 104 KWh/d may be sold to the grid for around US$20 per day, or US$7 558 per year.

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2.2 INTEGRATED FOOD-ENERGY SYSTEMS (IFES)[19]

Anne Bogdanski, Maizura Ismail

Key features

Simultaneous production of food and energy, carried out under Integrated Food-Energy Systems (IFES), may reduce the impacts and competition arising from bioenergy production on food security.

Sachs and Silk (1991) referred to IFES as farming systems that are designed to integrate, intensify, and thus increase the simultaneous production of food and energy. Generally, simultaneous production of food and energy can be realized in two ways:
Type 1 IFES: production of feedstock for food and for energy on the same land, through multiple-cropping patterns or agroforestry systems.

Type 2 IFES: adoption of renewable energy technologies that allow maximum utilization of all by-products, and encourages recycling and economic utilization of residues.

Type 1 IFES

Type 1 IFES combines the production of both food and energy feedstock on the same land unit, maximizing land use efficiency. This can either be through mixed production systems with different crops and animals, such as in multiple-cropping systems for food, feed and energy feedstock cultivation, or by combining trees with annual crop or animal production, such as in agroforestry systems.

Type 2 IFES

Type 2 IFES aims to fully utilize all by-products or residues in an agricultural production system. This can be achieved through the inclusion of renewable energy technologies such as anaerobic digestion or gasification, which produce energy and soil amendments at the same time. Ideally, Type 2 IFES builds on Type 1 and maximizes synergies between the production of different crops and/or animals.
The core characteristics of Type 2 IFES are:

- High productivity: the cultivation of high-biomass crops should be the first step in establishing IFES, which means basing the production on plants with high photosynthetic efficiencies.
- Optimal use of biomass, based on the idea that nothing is considered "waste": by-products or leftovers from one process become the starting point for another in cycles that mimic natural ecosystems.
- When appropriate, crop and animal integration: bioenergy production can reduce the environmental footprint of livestock through the multiple use of animal feed

19 Unless otherwise stated, the information included in this section was either adapted or excerpted from: Bogdanski *et al.* (2010).

crops. Given that about one third of the existing arable land worldwide is used for growing crops to be fed to livestock rather than humans, there is potential for this to also co-produce bioenergy without significantly reducing the amount of livestock supported.

- Linking food and energy production: anaerobic digestion uses crop and/or animal residues to produce both energy and bioslurry, which can serve as an excellent soil amendment, or fish feed. Gasification uses dry residues from crop production to produce energy and biochar, a carbon-rich soil amendment. The cycle closes when such by-products feed into the next round of crop and animal production.

Potential benefits

Climate change mitigation

IFES contributes to climate change mitigation in several ways, depending on the type of crops or animals and the management practices used. When crop and livestock residues are turned into biogas, the release of the greenhouse gas (GHG) methane is considerably reduced, as done in Type 2 IFES. When IFES reduces pressure on land use through intercropping (Type 1) or through the use of residues (Type 2), GHG emissions that would have occurred from new land conversion are omitted. Croezen *et al.* (2008) found that the more systematic use of by-products could amount to a reduction of 10 to 25 percent of land needed to produce liquid biofuels. Subsequently, by-products used in Type 2 IFES also affect indirect land-use change (ILUC). When bioenergy crops generate feed as by-products and feed production elsewhere can be avoided, the indirect land-use change is smaller.

Productivity/income

Through the production of energy on farm and the full use of by-products, IFES provides the option to replace fossil fuels with renewable energies for household activities or productive uses. Also, fossil-fuel based inputs such as fertilizers and pesticides can be fully or, at least, partially replaced by organic inputs which will lead to considerable household savings. Surplus food, feed, energy or organic inputs can be sold and generate extra income.

Access to energy

Through IFES, smallholders and local communities in remote rural areas may improve their access to modern bioenergy through production of biogas, wood pellets, or vegetable oils and/or other sources of renewable energy. This may help improve farms' productivity through fuel or electricity powered equipment, irrigation, and transportation. In addition, this may lead to improved food storage and preparation. Improved access to energy through locally produced biomass may have positive effects on sanitation, health services, education and communication.

Challenges

Input and labour requirements

IFES requires significant manual inputs as the combination of multiple crops and/or animals on the same land offers less scope for specialization and mechanization.

Competition in residue use

Agricultural residues are also being used as soil conditioner, organic fertilizer, building material, erosion protection, feed for livestock and poultry, livestock bedding, raw material for board and paper manufacturing, mushroom cultivation, and as a component for traditional foods preparation (Saono and Sastrapradja 1983). Diverting residue from these traditional uses for use as bioenergy feedstock could detract from the farm's ability to maintain soil quality, and household food security.

Access to finance

Some IFES, particularly those that require renewable energy technologies or those that include slow-growing perennial crops such as trees, require some financial investments and long-term planning. These factors, combined with a long payback period and limited access to financing services, could make IFES unaffordable for small-scale farmers.

Awareness, education, and research and development

Depending on the level of complexity, scale, and configuration of an IFES farm, the farmer may need to be knowledgeable in cash crops, vegetable and fruit production, animal husbandry, aquaculture, grassland management, forestry, carpentry and construction. The farmer may also need to have the technical knowledge needed to set up and maintain equipment such as digesters, gasifiers and generators. Even when the technologies needed to implement an IFES are reliable and economical, experience has shown that new technology can be rejected or abandoned if it is unfamiliar to those who may use it.

Policies and institutions

Because of the cross-sectoral nature of IFES and sectoral nature of national policy and legal frameworks, practitioners often miss out on incentives such as grants and subsidies. Some government support, for example, subsidized chemical fertilizers and subsidized fossil fuels act as a disincentive for the application of sustainable agricultural and energy practices such as IFES.

Examples in bioenergy feedstock production

Region: East Africa
Country: Malawi
Crop/Feedstock: Pigeon pea (*Cajanus cajan*); sorghum (*Sorghum spp.*); maize (*Zea mays*)

Type 1 IFES: Intercropping food, feed and fuel

The "pigeon pea" IFES model in Malawi is an intercropping model between staple foods (mainly maize (*Zea mays*), sorghums (*Sorghum spp*.), millets (genus *Eleusine*, *Panicum*, *Pennisetum*) and pigeon peas (*Cajanus cajan*), a nitrogen fixing double purpose plant, which delivers protein-rich vegetables for human consumption, fodder for animals, and woody plant material for cooking. It shows the successful integration of crops which deliver both food and energy for basic household needs, hence food and feed provision and access to energy.

In contrast to "improved" varieties that yield more crop but as little biomass as 80 g per stem, one stem of local pigeon pea varieties can weigh over 800 g. Depending on the variety, the stove technology and the type of meal, one local plant can provide enough energy for a family of five to cook 1-2 meals per day. The average need for cooking fuel on a 3-stone-fire is 3-4 kg/day. On an improved stove like a simple clay stove it reduces to 1.5-2 kg/day.

A former GTZ programme on Integrated Food Security in Mulanje promoted pigeon peas among farmers with an average landholding size of less than 0.4 hectare, and many families use pigeon peas now as cooking fuel for 3-8 months per year. If complemented by other agricultural residues such as sorghum stalks and maize combs, some manage to cook with their home-grown fuel throughout the entire year using a simple cooking stove, thus omitting the need to collect fuelwood in the nearby forest reserve. Some families claim that they have not bought or collected any firewood in the last five years.

Region: Southeast Asia
Country: Viet Nam
Crop/Feedstock: Animal manure (for biogas production)

Type 2 IFES: Biogas Programme in Viet Nam

Following the socio-economic reform or "Doi Moi" in 1986 and the resulting land redistributed to peasant households, the Vietnamese Gardener's Association (VACVINA) was mandated with the responsibility to promote low-capital, high-efficiency, small-scale integrated farm management systems, in which vegetables and fruit production, fish ponds and livestock are closely integrated with biogas production (Pham 2010).

In VACVINA households, some products from the garden are used to feed the fish, while the fish pond provides water, mud and slime to irrigate and fertilize the garden. Fish waste is given to animals as feed and animal manure is used as fertilizer for plant and food for fish, as well as for biogas production. Meat, milk, fish and vegetable from the garden are used for household consumption and the surplus sold on the local market. Biogas digesters using animal manure as input generate enough daily fuel for cooking and lighting, and the resultant slurry used as a fertilizer to improve soil quality for vegetable production. Latrines can also be added to the system to enable human waste to be used for energy.

As a financial incentive to purchase a biogas digester, VACVINA offers an early-bird discount which reduces the original price by up to 30 percent. On top of this, a household saves on firewood and synthetic fertilizer, breaking even after ten years. The biogas produced displaces the use of firewood estimated at 2 500 kg per household per year for which families spend between US$5 and US$10 per month. The application of the organic fertilizer reduces the application of synthetic fertilizers by about 50 percent.

Apart from these financial benefits, the farmers' standard of living increases significantly. Long hours formerly needed to collect firewood can be saved, and respiratory and eye diseases related to smoke decrease significantly. The unpleasant odour of unhygienic pig and manure operations, and the pollution of nearby waterways, vanishes, which does not only serve the farmer but also the environment.

At the same time, integrated agricultural practices increase the capacity to adapt to climate change by increasing farmers' resilience by making him/her more self-sufficient in terms energy and agricultural inputs, and through income diversification (e.g. if they sell the compost generated through biogas production, or the biogas itself).

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2.3 MULTIPLE CROPPING SYSTEMS AND CROP ROTATION

Maizura Ismail

Key features

Over time, continuous intensive monoculture cropping systems may lead to pest and pathogen build-up, declining soil fertility, loss of biodiversity and ultimately, land and natural resource degradation. Before the introduction of synthetic fertilizers and pesticides, farmers used to maintain nitrogen supply in the soil for crop uptake by cultivating nitrogen fixing crops, and pests were often controlled biologically by changing or diversifying the crops cultivated on the farm. This was generally achieved through application of multiple cropping systems and crop rotation.

Multiple cropping systems

"Multiple cropping systems" is a general term to describe cultivation and management of two or more crops on the same field in the same year. The main objective of multiple cropping systems is crop intensification in the space and/or time dimensions.

There are two main types of multiple cropping systems:

- Time-dependent form, or sequential cropping – farmers grow and manage two or more crops in sequence on the same field in the same year. The second crop is planted after the first crop has been harvested, and crop intensification is only in the time dimension.
- Space-dependent form, or intercropping – farmers grow and manage two or more crops simultaneously on the same field in the same year. More than one crop is cultivated on the farm at any one time, and crop intensification is in both time and space dimensions (Kassam, *et al.* 1993).

Sequential cropping

Sequential cropping is further distinguished into subcategories, which are:

- Double (triple, and so on) cropping – growing two different crops on the same land, in the same year, one after another, while a triple cropping system involves cultivating a third crop.
- Ratoon cropping – re-growing a second crop from the stubble of the first crop that has been left after the harvest. Not all crops can grow from ratoon. Examples of ratoon crops include sugar cane, sorghum, rice and papaya.
- Relay cropping – growing two or more crops in the same field, in which a part of the lifecycle of the crops overlaps. For example, when the second crop is cultivated after the first crop has reached its reproductive stage but before its harvest. Some references also categorize relay cropping under intercropping.

Intercropping

Intercropping's more common subcategories are:

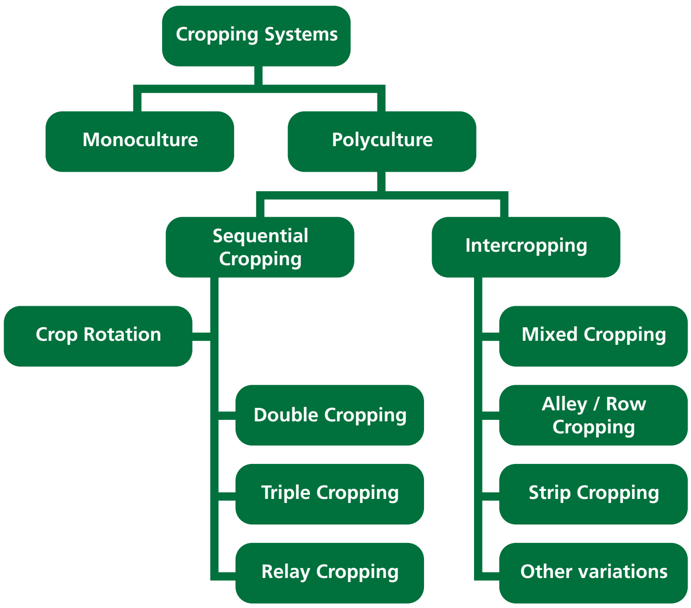
- mixed intercropping – growing two or more crops simultaneously without distinct row arrangement, also known as random cropping;
- alley/row intercropping – growing two or more crops simultaneously where one or more crops are planted in rows, and
- strip intercropping – growing two or more crops simultaneously in wide enough strips to allow independent cultivation but narrow enough to permit crop interaction.

Other variations of intercropping include multilevel intercropping, where crops of different heights are intercropped for optimum use of sunlight, and intercropping of crops with different depth of root penetration (Nair 1993).

A graphical representation of all these different systems is provided below.

Figure 2

Multiple Cropping Systems and Crop Rotation



Crop rotation

Crop rotation is the practice of cultivating a variety of crops in succession on the same plot of land to break the build-up process of pests and pathogens, as well as reduce pressure on declining soil properties by giving the soil time to rebuild and improve.

Simply put, to apply crop rotation the farm is divided into separate fields depending on field types that may be suitable for certain groups of crops. A diversified crop mix and sequence is planned and implemented, in a two- to six-year rotation, depending on the rotation goals and farmers' production and market requirements. Performance of fields is monitored to ensure proper planning and implementation of cropping for the next rotation (Mohler 2009b).

During each rotation, farmers can cultivate one crop per field or, after considering the benefits and requirements of each crop, apply other cropping patterns such as intercropping, mixed cropping and undersowing (Sharma 2001; Johnson and Toensmeier 2009). Some crop rotation also includes a fallow period when the land is allowed to rest for one to six years before it is cultivated again.

The key for successful rotation is cultivating succeeding crops that are of a different genus, species, subspecies or varieties than the previous crops, with different seeding time, pest issues, soil enrichment benefits and nutritional needs, while at all time ensuring food security and profitability for farmers. The rotation could be cyclical, in which the same sequence of crops is repeated indefinitely, or non-cyclical, in which the sequence of crops varies irregularly to meet the evolving business and management goals of the farmer (Mohler 2009a).

Crop rotation is one of the main principles of major farming systems including Organic Agriculture, Conservation agriculture, Integrated Pest Management and Integrated Plant Nutrient Management.

Although the practice of crop rotation overlaps with sequence-based multiple cropping systems, it is not entirely similar. Where multiple cropping systems take place in one year, the duration of crop rotation takes longer, with effective arrangement allowing for two to six years before the same crop is repeated (Mohler 2009b). Multiple cropping systems and crop rotation also differ in their main objectives, between crop intensification for the former, and soil conservation and pest control for the latter. However, in application, crop rotation does share many of its benefits and challenges with multiple cropping systems.

Potential benefits

Soil quality

Monoculture cropping may put pressure on soil as each crop has specific nutritional needs and extended cultivation may lead to leaching of the minerals and nutrients from the soil, leading to reduction in yields and/or increase in costs of chemical fertilizers. Rotating and diversifying the crops grown on a piece of land gives the soil time to improve, especially in cases involving crops that have the potential to enrich soil, such as nitrogen-fixing legumes.

The growing of different crops, such as maize, wheat, barley and millet, also conserve soil due to their different root systems which extract nutrients available at different layers of the soil (Verma 1998; Peel 1998). It is also important to consider that while crop rotation and diversification may increase soil organic material, both crops and crop residues have allelopathic effects that inhibit or promote growth of subsequent crops, pests or soil organisms (Scialabba and Williamson 2004).

Soil quality can also be improved through crop rotation and diversification through a diverse source of organic matter from the crop selection that balances out the humus building and nitrogen enriching effect of residues. Residues with low carbon-to-nitrogen (C:N) ratios, such as residues from legumes, decompose quickly and release relatively large amounts of nitrogen but contribute very little humus. Conversely, residues with high C:N ratios, such as from cornstalks, break down more slowly and increase humus content, but release relatively fewer readily available nutrients. “Diversity ensures sufficient organic C and N for humus formation and produces a pool of potentially available nutrients that can become mobilized according to crop demand” (MOSES 2009). According to MOSES (2009), diverse residue sources may also sustain efficient and diversified microbial community, as bacteria are associated with high nitrogen materials, while fungi increase in high carbon soil, both of which may carry out important functions for crop production.

Crop rotations and diversification that promote an increase in organic matter and microbial activity may increase aggregate stability (SQI 1996). A study in Colorado involving corn, sugar beet, and barley planted in succeeding years resulted in an increased soil aggregate stability from 67 to 76 percent when three years of alfalfa were added to the rotation (Peel 1998). Increased aggregate stability reduces the tendency of the soil to puddle or crust, improving soil pores and the rate of water infiltration, increasing water and nutrients available for plant uptake, and may also reduce wind erosion.

Inclusion of certain species such as alfalfa and sweet clover can be used to dry up saline seeps and other wet areas, preventing accumulation of salts on the surface and allowing re-cropping to a cash crop such as wheat (Peel 1998). Adding a second crop, as well as inclusion of cover crops in rotation, and reduction of soil preparation due to ratooning may reduce the amount of time soil is exposed to medium, thus reducing soil erosion.

Water availability and quality

As presented above, increased aggregate stability of the soil may improve the rate of water infiltration and, thus, increase water availability for plant uptake. Similar to effects of different root systems in rotated crops such as maize, wheat, barley and millets on nutrients extraction at different layers of the soil, crop rotation and diversification may also lead to greater overall efficiency in soil water utilization at different layers of soil (Verma 1998; and Peel 1998).

Agrobiodiversity

Diverse residue sources sustain an efficient microbial community as bacteria are associated with high nitrogen materials, while the abundance of fungi increases in relation to high carbon materials (MOSES 2009). Both fungi and bacteria carry out important functions related to water dynamics, nutrient cycling and disease suppression. These include:

- decomposing simple carbon compounds in soil organic matter into forms useful to

other soil organisms in the soil food web;
- decomposing pesticides, pollutants and hard-to-decompose compounds like chitin and cellulose;
- fixing nitrogen from atmosphere;
- increasing accumulation of humic-acid rich organic matter that is resistant to degradation;
- solubolizing phosphorus and making available soil nutrients like phosphorus, nitrogen, micronutrients and perhaps water to plants, and
- trapping and parasitizing on disease-causing nematode and insects (Ingrams 2000).

Climate change mitigation

FAO (2004) has implemented several collaborative programmes to assist developing countries in the adoption of land-management practices that reverse the current land degradation, desertification and reduce inadequate land use. Most of the research and case studies on soil carbon sequestration have been conducted in temperate zones, and in order to assess the potential of drylands four agrosystems in Argentina, India, Kenya and Nigeria were reviewed. The results displayed that in a scenario of multiple cropping systems and crop rotations, the effects of these practices on carbon sequestration are remarkable. On average, conventional monoculture systems did not store carbon; rather, carbon emissions ranging from 0.01 to 0.3 tonnes/ha/year (t/ha/y) were recorded. In the case of crop rotations, instead, there is a consistent tendency towards carbon sequestration. The values relative to carbon storage ranged between 0.1 and 0.9 t/ha/y in the four locations surveyed, thus, the benefits of these practices in terms if compared to traditional monoculture are evident.

Productivity/income

Multiple cropping can be defined as intensive farming systems that have the potential to generate increased income as from an increase in both number of crops and yield (FAO 1983). In addition, crop rotation allows the cultivation of more than one crop, enabling the farmers to spread the risk of fluctuating prices, spreading labour needs more evenly during the year (Bot and Benités 2001). The crop diversity may also reduce the economic risks due to climate and/or market shocks and fluctuation. In the case of a crop failure, the second crop will provide a buffer against income shocks.

Through biological control of pests and pathogens, as well as nitrogen enrichment of soil by cultivation of legumes and pulses by rotating crops, farmers may reduce their reliance on chemical pests and nutrient inputs.

In an area with highly varied microenvironments differing in characteristics such as soil, water, temperature, altitude, slope, and fertility, genetic diversity may allow farmers to exploit the full range of the land, especially for resource-poor farmers operating under low-input conditions in marginal lands (Worede *et al.* 2000).

Availability of inputs

As different crops have different requirements, multiple cropping systems may allow for more efficient use of farm resources, such as land, fertilizers, pesticides, equipment, labour, moisture, sunlight and other means of production (FAO 1983). As mentioned above, nitrogen-fixing crops may contribute to soil enrichment and crop diversity may provide pest control services, thus reducing the need for synthetic inputs. The systems also spread out labour needs throughout the year as crop management and harvesting periods may differ from one crop to another.

Most pests and disease-causing organisms are host specific and extended cultivation of host plants allows for a build-up of pests and population of pathogens. The technique of using crop rotation for disease management is to cut off food supply to pests and pathogens by ceasing cultivation of host plants and by growing non-host plants until the pests and pathogens in the soil die or their population is reduced to a negligible level (McGrath 2009). Crop rotation also reduces the reliance on chemical fertilizers and improves soil quality in cases where soil enriching crops, such as nitrogen-fixing legumes, are included in the rotation.

Also, crops growing in soils receiving organic matter from a diverse source have been shown to be less attractive to some insect pests, as a result of a more nutritionally-balanced growth medium (MOSES 2009).

Dietary diversity

Crop rotation and diversification have proven to improve malnutrition by including crops of minor economic value but high micronutrient and protein content in the rotation, enriching household diets and health, and promoting a diverse local food supply that is accessible to poor households (Scialabba 2007).

Challenges

Input and labour requirements

Depending on the existing conditions, such as labour availability and skills, equipments, contracts and field types, farmers may face difficulties when incorporating new crops into the farm. Rotating and diversifying crops may entail additional investment, which may increase production costs. Farmers may also have existing agreements to produce certain amounts of certain crops.

Opportunity and production costs

Despite the benefits to soil fertility, some crops are less profitable than others. Rotation may reduce the area used for production of the main cash crop, which may result in the loss of economies of scale and increases the average cost of production, thus reducing the farm's competitiveness. Farmers may be pressured to cultivate cash crops in a monoculture system as they may offer better market opportunities and prices compared to soil building crops such as legumes, especially when farm land is scarce.

However, the profitability of rotation systems tends to be higher than that of monocropping systems in the long term, thanks to higher yields and lower production costs. Under monocropping systems, these costs tend to increase over time, due for example to the emergence of pest and disease problems.

Awareness, education, and research and development

Under the multiple cropping systems and crop rotation, the number of crops (and crop families) grown can be large, creating a huge number of potential crop sequences from which to choose. The knowledge required to design effective rotation systems and the complexity of managing these systems may represent a significant challenge to small-scale farmers and extension workers. Decisions need to be based, among others, on:

- the specific crops' nutritional and pest management requirements;
- the specific crops' water requirement, and
- potential allelopathic effects.

Examples in bioenergy feedstock production

Region: South East Asia
Country: Thailand
Crop/Feedstock: Cassava (*Manihot esculenta*)

Cassava-legumes intercropping for food and feed in the Mahasarakham province in northeast Thailand[20]

Farmers in the Mahasarakham province in northeast Thailand, the biggest cassava (*Manihot esculenta*) producing region in the country, have successfully developed a food-feed system based on cassava-cowpea strip intercropping, using legumes such as cowpea (*Vigna unguiculata*), peanut (*Arachis hypogaea*), and mungbean (*Vigna radiata*).

Intercropping of cassava increases efficiency as the crop does not efficiently use the available light, water and nutrients during its early growth stages, due to its slow initial development. Legumes make a suitable short-duration second crop as they also improve soil fertility through nitrogen fixation and incorporation of crop residues, as well as by providing fodder through grazing or cut and mixed with dry cereals for stall feeding.

The farmers of the Mahasarakham province, which is one of the poorest areas of Thailand, benefit from intercropping through: reduced income vulnerability, due to the instability of the rainfed farming system, poor soil quality and fluctuation in market demand and price for the major crops such as cassava, and through additional food from edible seeds of cowpea, peanut and mungbean. Cowpea fodder is especially good for lactating cows, maintaining milk yields of 5 litres/cow/day, and all three legumes are drought tolerant (as cassava) and are suitable to the climate of northeast Thailand.

The intercropping practised by dairy farmers in Mahasarakham province shows that, although cassava yields tend to decrease with intercropping, due to competition for light, water and nutrients, the land use efficiency and overall farm income tend to increase with the introduction of the second crop (e.g. cowpea, peanut and mungbean), especially when edible seeds are used for food and crop residues are used as fodder. It was estimated that, in the Mahasarakham province, land use efficiency is on average 72-76 percent higher under cassava-cowpea intercropping than under cassava monoculture, with the former system providing net returns of THB 6 367-10 835 (US$140.61- 239.28) as of 2001; land-use efficiency was found to be 30-98 percent higher under cassava-peanut intercropping than under cassava monoculture, with net returns of THB 3 431-11 950 (US$75.77-263.91) in 2001. Finally, a 66-97 percent higher land-use efficiency was estimated for cassava-mungbean intercropping compared to cassava monoculture.

20 The information included in this section was either adapted or excerpted from: Polthanee at al. (2001).

Region: Central Asia
Country: Kyrgyzstan
Crop/Feedstock: Fuelwood

Poplar-Lucerne intercropping for timber, fuelwood and feed production in the Chui Valley, Kyrgyzstan[21]

In the Chui Valley, which is the main crop production area in Kyrgyzstan, around 90 percent of the cultivated land is irrigated for wheat (*Triticum sp.*), maize (*Zea mays*), sugar beet, lucerne (*Beta vulgaris*) and vegetables. Of this, approximately one third (ca. 320 000 ha) is degraded due to loss of fertility, salinization and waterlogging, mainly as a result of the collapse of the drainage system introduced during soviet times.

On a plot of 5 ha on a degraded plain in this area, a farmer planted two local poplar species - *Populus alba* and *Populus nigra* – and a hybrid from Kazakhstan (*Populus pyramidalis*), in order to obtain from this rapid growth trees both timber and fuelwood, which were both in short supply in the area[22]. The trees were planted in rows about 5 metres wide, separated by 10-15 metre strips planted with lucerne (*Medicago sativa*) and a grass (*Bromus inermis*), both for use as feed.

Through this intercropping system, the farmer in question could obtain both fuelwood and feed. On poplar plantations, slow-growing/sick trees, as well as pruned branches, are used as fuelwood – which can amount to 20-30 m^3 per hectare. With regard to feed, lucerne and grass were either cut-and-carry for feed or livestock was allowed to graze the plot.

In addition, the poplar trees, which are known for their tolerance to waterlogging and salinity, provided biodrainage, contributing to lowering the water table and reducing salinity. Desalinization of the soil takes on average ten years, when it re-becomes suitable for irrigated cereal cropping.

In addition to obtaining both fuelwood and feed, through the intercropping system described above, the farmer in question was thus able to rehabilitate the land, which can now be used again to grow wheat, maize and sugar beet as before.

A recent assessment has shown that there is growing interest in the system by farmers in the region. In addition, in the lower Yanvan Valley of Tajikistan, a similar biodrainage system has been described, using poplar and mulberry trees. In this case, wheat was intercropped with the trees.

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21 The information included in this section was either adapted or excerpted from: WOCAT (2007).
22 Poplar trees are used for commercial heat and power production, especially in northern Europe, and also show a high potential for second-generation liquid biofuel production.

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CHAPTER 3

SUSTAINABLE FIELD-LEVEL AGRICULTURAL AND FORESTRY PRACTICES

INTRODUCTION

The third and last chapter of the report provides an overview of 15 sustainable field-level agricultural and forestry practices. Some of these practices (i.e. Community-Based Forest Management, Forest Buffer Zone, and Sustainable Forest Harvest) are specific to the forestry sector, which is an important source of feedstocks for both traditional bioenergy and advanced biofuels.

The key features of the aforementioned field-level practices, and the associated potential benefits and challenges, are described in the sections below. In addition, examples of the implementation of these practices in bioenergy feedstock production in different regions of the world are provided.

The implementation of the sustainable field-level agricultural and forestry practices described in this chapter can result in multiple environmental and socio-economic benefits on: soil quality, water availability and quality, biodiversity, agrobiodiversity, climate change mitigation, productivity/income, availability of inputs, and access to energy.

At the same time, these management systems present a number of challenges that limit their adoption, including in terms of pest issues, input and labour requirements, land tenure, production costs, access to finance, access to market, awareness, education and research and development, and policies and institutions.

3.1 ALTERNATIVES TO SLASH-AND-BURN

Amir Kassam, Maizura Ismail, Marco Colangeli[23]

Key features

Traditionally, many farmers in tropical areas of Asia, Africa and South America used to practise "slash-and-burn" under shifting cultivation, a system which was once widespread in temperate zones as well (Pretty 2002). Slash-and-burn, also known as swidden agriculture or rotational farming, is part of the shifting cultivation method, in which the use of land rotates from a forested or wooded area, to clearing of the area for agricultural purposes, to a short period of cultivation, followed by a long period of fallow when forest, "bush" vegetation and soil recover. After a certain period when the exhausted land has recovered, farmers repeat the cycle and clear the area again for production. To prepare the land, farmers usually cut the forest or woodland vegetation, let the residues dry, and then burn them during the dry season. Crops, usually subsistence staple crops such as maize, cassava and rice, are then planted on the ashes, taking advantage of the nutrient available from the burning of vegetation, as well as of reduced pests from the fire.

Under certain conditions with low population pressure and long fallow periods, slash-and-burn may be an economical and practical means of land preparation that also results in reduced soil acidity due to ashes, short-term increase in nutrients supply to crops, and temporary eradication of pests and diseases in the fields due to heat from the fire (Denich *et al.* 2004). However, combined with climate change, land degradation and population growth, the growing demand for forest products and fertile agricultural lands has led to shortening the fallow periods, thus not allowing the bush fallow land to adequately recover, and leading to increased clearing of the forest margins, even beyond the logged-over forest areas (Sadio 2009). Slash-and-burn also leads to further environmental degradation by removing large quantities of nutrients from the system through leaching and soil erosion, as well as endangering land and forest resources, biodiversity and upland water resources.

Potential alternatives and improvements to slash-and-burn are land clearing methods that do not use fire, but rather land restoration methods and cultivation practices that contribute to soil nutrient maintenance, pest management and sustainable livelihoods. These alternatives include:

- Slash-and-mulch;
- Improved fallow, and
- Conservation agriculture.

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23 Marco Colangeli is the author of the examples.

Slash-and-mulch

Slash-and-mulch agriculture consists of clearing forest vegetation by slashing and then planting the crops in the resulting mulch (Thurston 1994). As an alternative to slash-and-burn, this system uses the decomposing mulch as a source of nutrients, and as a soil cover to protect the land from erosion and weed infestation. Slash-and-mulch should be part of a Conservation agriculture[24] (CA) approach, because the maintenance of a mulch cover requires that the soil disturbance is minimized by not tilling, and that residues from crops and green manure cover crops are used as a source of organic matter to replenish the mulch as it decomposes and is incorporated in the soil by macrofauna such as earthworms and termites (FAO 2008).

Improved fallow

During traditional fallow, land is left uncultivated and is generally used for grazing or left to return to natural vegetation to restore topsoil fertility. During improved fallow, land is planted and managed with fast growing species specifically selected for their fertility enhancement properties during a short-duration fallow period (Hall *et al.* 2006). The species selected are usually leguminous trees, shrubs and herbaceous cover crops that rapidly replenish the topsoil in one or at most two growing seasons, enabling farmers to shorten the fallow period without exhausting the land (Amadalo *et al.* 2003). At the same time, improved fallow often provides farmers with other benefits, including the diversification of food, fuelwood and fodder production.

Farms may optimize benefits from improved fallow by ensuring that the improved fallow plants have enough time to grow and accumulate large quantities of biomass and nutrients in the field. At the end of the fallow period, the trees, shrubs or herbaceous legumes are cut down and the biomass (leaves, twigs, branches) is incorporated into the soil while the land is being prepared for the next crop. This practice should be replaced by using the biomass for mulching without disturbing the soil as is done in CA systems (Friedrich *et al.* 2009). The plants that are part of the improved fallow create conditions that are unfavourable to most problematic weeds, making the subsequent establishment of crops easier than if the area had to be cleared of undesirable weeds (Elevitch and Wilkinson 2000).

Conservation agriculture

In slash-and-burn agriculture, there is minimum soil disturbance and this feature should be maintained in combination with mulch cover and introducing deep-rooted legumes and high biomass species into the rotation, so that the improved alternative systems can be managed as CA systems with all the productivity, economic and environmental benefits that CA can offer if properly managed (Friedrich *et al.* 2009; Kassam *et al.* 2009 and 2011; FAO 2011).

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24 For a description of *Conservation agriculture*, see section 1.1.

Potential benefits

Soil quality

A zero-burning system of land clearing such as slash-and-mulch may result in better soil fertility than traditional slash-and-burn. and inclusion of other species in the improved fallow system may restore farmland's topsoil fertility[25].

Integration of different types of species with a different biomass composition may also enable farmers to benefit in terms of added nutrient, as well as organic carbon content, both in the short term and in the long term.

Mulches used in slash-and-much systems may also protect the seedlings from the impact of rain, hail, and wind, thus increasing rate of germination, while at the same time enhancing the activities of beneficial microbiological activity (Thurston 1994). The trees and shrubs integrated into the improved fallow systems also fill the space in the farms, thereby impeding the establishment of undesirable weeds, as several invasive and problematic weeds thrive in open, sunny conditions on vacant land (Elevitch and Wilkinson 2000).

Benefits related to soil quality from CA-based slash-and-mulch cropping systems as an alternative to bush-fallow rotation in sub-Saharan Africa include improved soil organic matter and soil structure, improved infiltration and drainage, reduced runoff and erosion, improved soil moisture storage and availability leading to longer growing period and reduced risk of drought failure (see below) and climate change mitigation (Thierfelder and Wall 2010a and 2010b; Thierfelder and Nyagumba 2011). Trees in CA-based agroforestry systems can facilitate nutrient cycling, capturing plant nutrients from deeper soil profile and concentrating them in the topsoil in organic forms. Such CA systems with nitrogen fixing trees, like Faidherbia (*Faidherbia albida*), as alternatives for sustainable food security have been elaborated by Garrity *et al.* (2010) and Bayala *et al.* (2011).

Water availability and quality

The major advantage of slash-and-mulch systems is the mulch itself. The removal of biomass residue by burning increases water evaporation, thus reducing water use efficiency on the farm and water productivity. Mulches may: decrease soil moisture evaporation and lower soil temperature; increase infiltration rate and improve water absorption, thus reducing water loss through erosion and leaching; reduce rain splashing, which is a dissemination channel for numerous bacterial and fungal pathogens, and suppress weeds, thus reducing competition between crops and weed for water (Thurston 1994). Further, with CA-based slash-and-mulch practices, there is further improvement in crop water availability because of minimum soil disturbance and increased soil organic matter as well as improved soil structure, moisture holding capacity and rooting volume. In addition, reduced erosion

25 Experiments conducted in Gabon revealed that incorporation of biomass pruned from trees and shrubs restored Ferralsol fertility to a reasonable agronomic level within one year and maintained nutrients availability under continuous cropping, tripling crop yield compared to traditional slash-and-burn systems (Sadio 2009).

and runoff, combined with higher effective rainfall, may lead to an increased recharge of aquifers and groundwater, and to an improvement in water quality due to the reduction in runoff and in sediment and agrochemical loading (Friedrich *et al.* 2009).

Biodiversity

Intentional fire during slash-and-burn often gets out of control. Fire may burn through the understory of nearby forests, killing small trees, vines and shrubs, which then collapse and spilling firewood and kindling to the ground, as well as opening the forest overhead, and thus exposing it to intense tropical sun (Lindsey 2004). This may heat the forest floor, pushing fire danger even higher. It may also cause smoke hanging over the forest, which leads to suppressed rainfall, increasing forest's vulnerability to El Niño-driven droughts (Lindsey 2004). In addition, fire and heat destroy soil inhabiting biodiversity as including natural enemies of pests.

Climate change mitigation

Forest fires that often follow improper use of fire for land clearing emit large amounts of greenhouse gases. For example, the Indonesian forest fires in 1997-1998 released more than 700 million metric tonnes of CO_2 into the atmosphere, making Indonesia one of the largest emitters of greenhouse gases in that period (Herawati *et al.* 2006).

Palm *et al.* (1999) showed that alternatives to slash-and-burn can store significant amounts of carbon in the form of both above- and below-ground biomass. Indeed, improved fallow may store up to 8.5 tons of carbon per hectare per year (t C/ha/y), and agroforestry systems can store up to 9.3 t C/ha/y. Relative soil carbon values (0-20cm depth) for land-use systems compared to undisturbed forests were measured as follows (Palm *et al.* 1999): agroforestry systems 80-100 percent; pastures 80 percent; long-term crop/fallow 90-100 percent; short-term crop/fallow 65 percent; and degraded grasslands 50 percent or less.

CA-based alternatives can reduce all crop production sources of GHG emissions because of reduced fossil fuel and fertilizer use. Improved drainage also reduces N_2O and CH_4 emissions. Also there is greater carbon sequestration ((Kassam *et al*. 2009; Baig and Gamache 2009; Lindwall and Sonntag 2010; Corsi *et al.* 2011).

Productivity/income

As use of fertilizer to increase yields requires cash, poor farmers and farmers without access to fertilizer market may face difficulty in obtaining it. For farmers not using mineral fertilizers, improved fallow may increase yields while requiring about the same land and labour inputs for the farmers' main cropping strategy (Kwesinga *et al.* 2005). Adoption of improved fallow with non-legume and legume crops, including pulses such as pigeon pea (*Cajanus cajan*), green gram (*Vigna radiata*) or lablab bean (*Dolicos lablab*)[26], may

26 In a study on Zimbabwe, improved fallow was found to increase the income available to households for discretionary spending, with the biggest increase in the least resource endowed households, making the technology suitable for efforts to increase well-being of poor households (Mudhara and Hildebrand 2002).

also increase the income of farmers by introducing additional primary and secondary products into the production system This has been reported for locations in the rusha region in Tanzania by Owenya *et al*. (2011) in which pigeon pea and lablab in the cropping systems provided a basis for increased biomass for mulching and for livestock production. Such CA-based alternatives provided greater income because of reduced input costs and improved output and factor productivity (efficiency) (FAO 2011).

Access to energy

By introducing woody plants in improved fallow, or by integrating trees within CA-based cropping systems, farmers can harvest fuelwood, as well as timber and edible seeds at the end of the fallow period, or on an ongoing basis. In cases where perennial oil crops such as castor bean (*Ricinus communis*) and jatropha (*Jatropha curcas*) are integrated into the alternative cropping system, these can serve as biofuel feedstocks.

Human health and safety

Forest fires as a result of slash-and-burn have been reported to have consequences on human health and safety. For instance, the 1997-98 Indonesian peat forest fire, half of which was due to slash-and-burn activities according to WWF estimates, caused an estimated 20 million people in Indonesia to suffer respiratory problems; 19 800-48 100 premature deaths; elderly individuals to suffer serious deterioration in overall health, and an increase in traffic accidents due to thick smoke impairing visibility (Harrison *et al.* 2009). Some of these effects were felt in neighbouring countries as well (Agus and Manikmas 2003). On the other hand, CA-based slash-and-mulch alternatives with legume crops in the rotations and associations can improve human nutrition and health.

Challenges

Pest issues

An issue that has been raised in relation to alternatives to slash-and-burn is that unburned plant residues could promote the breeding of pests and diseases. With regard to this issue, research and continuous assistance is needed in order to assess any potential risks and identify the best alternatives for farmers (Ayarza and Welchez 2004). For example, with CA-based alternatives, new agro-ecosystem equilibrium is established in which there are a greater number of natural enemies of pests. Also, increased crop diversification, improved plant health and mulch and cover crops within CA-based alternatives can lead to decreased problems from insect pest, pathogens and weeds (FAO 2011).

Input and labour requirements

For smallholders, moving from slash-and-burn to a more permanent cropping system can mean a loss of services from forests, in addition to loss of products such as wood, fruit, other food and medicines, as well as the added task of supporting high production inputs that permanent cropping requires (Sadio 2009). Another major problem of use of mulches is that large quantities of material are often needed and, unless crop residues are produced *in situ*, material has to be brought in from outside the field (Thurston 1994). However, in CA-based alternatives, mulch cover can be developed over time as biomass production increases due to improving soil health and productivity as the new agro-ecosystem equilibrium is established.

In a survey on farmers' adoption of improved fallow in Kenya, the reasons farmers gave for not continuing to plant improved fallows included lack of labour, land, seed and technical assistance (Amadalo *et al.* 2003). On the other hand where fallow land is intercropped with a combination of cereal and legume crops such as lablab and pigeon pea using no-till seeding, labour and input requirement is lower and the system can be practised without herbicides (Owenya *et al*. 2011).

Awareness, education, and research and development

Slash-and-mulch systems, particularly CA-based systems, have great potentials to enhance the livelihoods of poor people. However, the successful adoption of these systems by farmers has been attributed to, among others, increase in awareness of farmers on the new set of technological options (CIAT 2010). In Honduras, where farmers have been practising an alternative system to slash-and-burn called "Quesungual", the major obstacles to large-scale adoption are the extensionists and their professional superiors who are too faithful to the "industrial" production-based, single-crop focus and are unfamiliar with a demand-driven participatory extension (Welches and Cherrett 2002).

Policies and institutions

Clearing the land by fire is illegal in some countries, but fire is still the cheapest, easiest and fastest method for land clearing. With no knowledge of the new and more productive alternative methods, no monetary incentive to adopt them, lack of enforcement by the governments and corruption within law-enforcement agencies, farmers may continue to flout laws and practise unsustainable slash-and-burn (Harrison *et al.* 2009). Thus it is important that enabling policies are formulated to encourage and accelerate the adoption of alternatives to slash-and-burn, and that institutional support with effective strategies, knowledge and capacity is established in order to enable the implementation of such policies.

Examples in bioenergy feedstock production

Region: East Africa
Country: Kenya
Crop/Feedstock: Maize (*Zea mays*)

Improved fallows in maize farms in western Kenya[27]

The World Agroforestry Centre and its research and development agencies have promoted improved fallows in Kenya between 1997 and 2002.

Agriculture in Western Kenya is dominated by subsistence farming, with maize as the main staple crop, often intercropped with bean. cassava, soybean, sugar cane, sweet potatoes and sorghum are grown as well in this region. Maize yields are low: on average 1 tonne per hectare per season (t/ha/s).

One way to improve crop yields is to use organic and inorganic fertilizers. However, use of organic fertilizers, such as animal or plant manure, is limited by the small quantity available on farms and their quality is often low. At the same time, use of commercial inorganic fertilizers is constrained both by the lack of resources to purchase them and by the unreliable returns of fertilizer packages recommended with hybrid crop seeds.

Traditionally, farmers would restore soil fertility by leaving part of their land uncultivated for many years, while using more fertile land for maize production. Since the early 1990s, long periods of fallows have no longer been possible, due to demographic growth and increasing land scarcity. These have been replaced by short periods of fallow, lasting only one or two seasons. Continuous cultivation of land has also become a relatively common practice.

In western Kenya, about half of the farmers leave 10 to 25 percent of their cropland fallow during the short-rains period, but since the fallow period does not last long enough to improve soil fertility sufficiently, the yields of subsequent crops are typically as low as those of the preceding season.

Scientists at the National Agroforestry Research Centre in Maseno, Kenya, researched these issues and found that the functions of natural fallows can be improved and accelerated by using short-duration improved fallows of selected leguminous trees, shrubs and herbaceous cover crops.

The scientists selected 82 farmers and performed with them on-farm trials to assess the benefits of short-duration (usually between 6 months and 1 year) improved fallows from 1997 to 2002. The improved fallows that showed the best performances were mixed species fallows composed either by sesbania (*Sesbania sesban*) and siratro (*Macroptilium atropurpureum*); sesbania and groundnut (*Arachis hypogaea*); sesbania and tephrosia (*Tephrosia vogelii*/*Tephrosia candida*); or sesbania, crotalaria (*Crotalaria grahamiana*), and

27 The information included in this section was either adapted or excerpted from: World Agroforestry Centre (2003).

tephrosia.

At the end of the fallow period, the trees, shrubs and/or herbaceous legumes are cut down and the biomass (leaves, twigs, branches) is incorporated into the soil while the land is being prepared for the next crop. Such fallows, if well established, can add between 100 and 200 kilograms of nitrogen per hectare per year. The maize yields in the 82 farms increased from 1.7 t/ha/s to 4.1 t/ha/s on average, with peaks of more than 5 t/ha/s using the sesbania, crotolaria, and tephrosia improved fallow combination.

According to the scientists from the National Agroforestry Research Centre, another factor that limits maize yields in western Kenya is the lack of potassium and phosphorus in soils. Compared to nitrogen, however, smaller quantities of these nutrients are required, and generally farmers can afford to purchase them.

The economic benefits of improved fallow systems are significant. Given equal additions of phosphorus (50 kg/ha), the return to land is 85.5 percent higher in the case of improved fallows (US$350/ha per year) than under continuous maize cropping (US$189/ha per year).

Due to these results, since 2002 thousands of farmers in western Kenya have begun practising improved fallow systems and have substantially increased their crop yields and revenues.

Region: Australia/Oceania
Country: Australia
Crops/Feedstocks: Sugar cane (*Saccharum officinarum*); soybean (*Glycine max*)

Soybean improved fallow increases profitability of sugar-cane plantation in eastern Australia[28]

In 2006, farmer Russell Young implemented an improved fallow planted with soybean on his 60 ha sugar-cane farm located on the Rita Island area of the Burdekin district in Australia. He planted this legume in a short-rotation with sugar cane, in order to increase nutrient content in the soil, and, at the same time, sell soybean seeds to the market.

Prior to this, the farming system implemented by the Young family used to be based on conventional farming practices: monocultivation of sugar cane; burning of residues, and addition of mineral fertilizers, mainly nitrogen (N). Russell Young identified the need to grow a legume crop in order to improve soil health and farm productivity, and he decided to grow soybean on the early plant cane area, which represented around 60 percent of the total planted area each year. Sugar-cane yields did not decrease with the addition of a secondary crop, and remained stable at around 122 tonnes/ha.

In 2006's US dollars, the traditional system provided a US$1 332/ha farm gross margin at a price of sugar of US$230/t, while the improved fallow system provided a

28 The information included in this section was either adapted or excerpted from: Young and Poggio (2007).

farm gross margin of US$1 430/ha. This was due to the lower production costs under the improved fallow system (US$626/ha) compared to the conventional system US$683/ha), thanks to reduced spending for fertilizers and for weed control. In addition, under the improved fallow system, less cultivation operations were required, reducing the time spent on tractors (2.65 hrs/ha) and the associated costs compared to the conventional system (4.99 hrs/ha). Last, but not least, despite the cultivation of a second crop – soybean – total labour requirements were lower under the former (12.55hrs/ha) than under the latter (13.82 hrs/ha). At the same time, the sale of soybean seeds provided additional income, with a gross margin of US$415/ha.

Overall, the benefits associated with the implementation of the improved fallow system on this 60 ha sugar-cane farm in Australia were remarkable: reduced number of operations before planting; reduced sediment, chemical and nutrient losses; lower chemical and fertilizer inputs; improvement in soil chemical, physical and biological components; diversification of farm revenue; improved farm profitability, and less time required to cultivate the same amount of sugar-cane farming area.

Furthermore, the adoption of the improved fallow system was expected to improve cane productivity by around 10 percent over the long term.

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3.2 COMMUNITY-BASED FOREST MANAGEMENT (CBFM)

Marco Colangeli

Key features

"Broadly defined, CBFM encompasses the management of forest lands and forest resources by or with local people, individually or in groups, and for commercial or non-commercial purposes" (FAO 2011).

Over the past few decades, some of the fundamental perceptions regarding the role, rights and responsibilities of communities in forest management have begun to change. CBFM aims at partially shifting decision-making prerogatives away from the central government or corporate entities towards local authorities and resource-user groups. The objective is to empower communities and resource users traditionally marginalized from decision-making, in order to enable them to develop and manage their resources and reduce conflicts with the national government (FAO 1999; FAO 2010c).

The engagement of end-users is a key pre-requisite for the effective management of forests and forest resources, including for energy production. Indeed, recognizing local actors as key forests stakeholders and promoting their inclusion in the management of forests greatly contributes to improve local livelihoods and rural development as well as ensuring forest conservation (FAO 2011). In order to achieve participation of the local population, an important component of CBFM is the establishment of a policy and institutional framework.

According to the Forest Management Bureau of the Philippines (2003-2004), some of the goals of CBFM include, but are not limited to, the achievement of sustainable management of forest resources; the empowerment of the local communities and improvement of their well-being; the enhancement of social justice, and the creation of security of tenure (forest management agreements/permits/rights) where the central authority entitles forest communities to use and develop the forestland and resources for several years. CBFM should not be intended as total devolution of power to the local communities; instead, a fundamental component of CBFM is the establishment of partnerships and dynamic interactions among different stakeholders (Unasylva 1999).

When CBFM has a commercial component, community members can organize themselves into associations, cooperatives, or enterprises. There are several tools to help entrepreneurs access investment capitals, identify markets, and build marketing capabilities. FAO's Market Analysis and Development Approach (MA&D) provides important planning and decision-making tools that enable those with a direct stake in forest resources to become part of sustainable forest utilization, management and decision-making. FAO's MA&D comprises the following components:

1. <u>Assess the existing situation</u>: the objective of Phase 1 of MA&D is to help villagers discover the products that are best suited to their economic situations while

ensuring that the resources are used sustainably. In order to ensure viable enterprises and reduced risks, potential entrepreneurs learn to select enterprise ideas that take into account social, environmental, institutional and technological factors.

2. Identify products, markets and means of marketing: market analysis is vital when establishing a CBFM programme. Support from government entities or NGOs is needed to perform this successfully, because often poor communities do not have sufficient understanding of market mechanisms and the associated opportunities. Through the second phase of the MA&D approach the potential entrepreneurs gather information needed to allow them to assess the viability of products short-listed in the previous phase, and decide upon the most sustainable and appropriate types of enterprises. Products short-listed during Phase 1 are subjected to in-depth feasibility studies in order to identify potential markets and to evaluate scale, trends and constraints related to access.
3. Preparation of enterprise development plans: the aim of Phase 3 is to formulate an Enterprise Development Plan (EDP) that integrates all the strategies and services needed for the success of the new enterprises. The EDPs are then analysed to assess what assistance entrepreneurs will need to effectively start their enterprises.
4. Start-up phase of the enterprise: in Phase 4, entrepreneurs are guided through the process of mobilizing financial resources and receive training according to the needs expressed in their EDPs. They are assisted in the start-up phase of their enterprises and they learn to monitor enterprise activities. During a pilot phase, entrepreneurs can test their capacities for establishing links with business service providers, and for refining operational and organizational mechanisms. Finally, entrepreneurs are trained to strengthen their abilities in marketing and natural resources management.

Potential benefits

Water availability and quality

CBFM may contribute to preserving both water availability and quality through the reduction of sediments and erosion. Commonly caused by forest alteration, erosion takes place starting from superficial runoff and subsequent transport of the material to streams and other water bodies. Maintaining a healthy native land cover will greatly reduce this risk (FAO 2008). In a study on water quality in the context of CBFM in the Philippines, Pasa (2011) attributed the better water conditions found in a forest managed with a communit-based approach to the smallholders protecting the area against illegal logging, slash–and-burn farming and river poisoning.

Biodiversity

Most CBFM programmes aim at conserving or increasing biodiversity of a given area while, in the meantime, providing a source of subsistence to the local community. Since the 1980s, when the concept of CBFM began to be applied in different contexts, there have been considerable achievements in biodiversity conservation as a result of the inclusion of local communities in the decision-making process. In the Bwindi World Heritage Site, in Uganda, communities used FAO's MA&D approach to identify and select viable enterprises that successfully improved their livelihoods and contributed to the conservation of the biodiversity of the forest (Mujuni *et al*. 2003).

The experience from Bwindi and the variety of forest management situations and institutional set-ups where MA&D has been applied all over the world shows that community-based forest enterprises offer an adaptable approach to assist local communities in developing strategies to exploit the opportunities that their natural assets offer in a sustainable way (Mujuni *et al.* 2003).

Productivity/income

Income from utilization of forests may contribute to poverty reduction for community members under CBFM. Instead of travelling long distances, men can work in nearby forests, while women, who are less likely to work far from home, can be employed in the forest management process.

A case study of Nepal's CBFM efforts highlighted the benefits of CBFM in a small-scale furniture enterprise, which generated year-round employment for four individuals from within the community and for an additional skilled worker from outside the community, with an associated income for these individuals above the local average (Suzuki *et al. 20*07; FAO 2007/2009).

Access to energy

CBFM can improve access to energy for local populations by increasing long-term availability of fuelwood through the development of sustainable harvest programmes. By managing their forests, local communities can plan and organize harvests in a sustainable way, so that, over the long run, there will be a more even and balanced access to energy and other forest resources. In Niger, for instance, during the period 1983-2003, CBFM programmes funded by donors created over 300 fuelwood markets. In Senegal, similarly sponsored programmes ongoing since the 1990s have focused on income-generating activities such as fuelwood production in the context of a CBFM (ESMAP 2010).

Challenges

Input and labour requirements

Wood production jobs tend to be seasonal in most regions of the world. Due in part to this seasonality, the availability of skilled workers can be a limiting factor in some areas, especially during peak periods. For the same reason, in order to be successful CBFM should include a diverse set of activities beside wood production.

FAO's MA&D provides tools to assess input and labour requirements prior to the implementation of a CBFM enterprise development plan.

Access to market

A major challenge faced by cooperatives of workers involved in CBFM is represented by access to markets. Without a well established supporting infrastructure, products can hardly make it to the market, with potential repercussions on the profitability of the business.

A market analysis should always be undertaken, for both local and non-local markets. FAO's MA&D provides tools to conduct this type of analysis.

Access to finance

FAO's MA&D emphasises the fact that entrepreneurs should always try to find other ways of starting their activities than through external funding, for instance through: Saving Loans Groups; hiring equipment initially instead of purchasing it, and grouping together in cooperatives in order to save costs.

In some cases, however, management of forests and forest products at community level may require external financial support. As demonstrated by several case studies (Sjoholm and Luono 2002; Dugan and Pulhin 2007), microfinancing can be effective in some cases. Through microfinancing, community members can receive loans to purchase the equipment and inputs they need in order to manage the forest correctly (as in the case of thinning and pruning) and to get additional income for forest protection and conservation activities. These loans can then be paid back thanks to the resulting increase in income (FAO RAP 2007/2009).

Awareness, education, and research and development

"Good governance and education seem essential to the sustainability of the world's forests and the nearby communities" (Sanders 2002). The successful development and implementation of CBFM schemes requires that all parties involved are aware of their role and of the benefits of CBFM. Education and training are also essential for the development of the human resources needed for sustainable forest management (Rebugio and Camacho 2005).

Conflicts may arise in the context of CBFM. For this reason, according to FAO (2002) it is important to:

- increase knowledge about conflict in CBFM;
- understand the interactions between participatory forest management and conflict, and to understand that they need to be studied, evaluated and planned together, and
- provide tools and aids for training in conflict analysis, selection of appropriate strategies, negotiation, and facilitating resolution processes.

Policies and institutions

Many community-based management efforts around the world lack the legal support needed to provide a way for local people to establish enforceable legal rights to the resources on which they depend, or to play a meaningful part in planning and managing those resources (Unasylva 1999). State law has a necessary place in local management initiatives: it is needed to help define the rules by which community-based institutions interact with outsiders, to delineate the limits of state power and to protect both individual rights and wider societal interests such as the environment (Unasylva 1999).

More precisely, in order to enable successful CBFM schemes, governments need to ensure: clear and stable tenure arrangements; fair taxation systems, and the provision of infrastructures for small enterprises (business service providers, training facilities, financing partners, roads, etc.).

Further, governments could facilitate the exchange of information, experiences and know-how between different CBFM schemes.

Most of the time, CBFM is chosen by national governments in order to reduce or manage conflicts with the local communities over the management of forest resources (FAO, Forestry web site; Buckles 1999). However, such conflicts and their resolution can be particularly challenging in some cases, putting the successful implementation of CBFM at risk (FAO 2002).

Examples in bioenergy feedstock production

Region: East Africa
Country: Tanzania
Crop/Feedstock: Fuelwood

Community-based forest management among pastoralist communities for the sustainable production of timber and fuelwood in the Suledo forest in Tanzania[29]

The Suledo forest has traditionally been used by the resident Masaai pastoralist communities as a grazing area. The increasing population in the districts surrounding the forest over the period 1991-2007 placed increasing pressures on the forest, resulting in unregulated timber harvesting and charcoal production. The Government of Tanzania became increasingly concerned about the damage to the forest, and in the early 1990s took steps to protect it by declaring the forest a reserve. The forest boundary was cleared, boundary beacons were placed around the perimeter and a forest inventory that focused on timber trees was performed.

No consultation with the surrounding communities was undertaken, and local residents began the protest, asking the Government to let local communities manage the forest. This request was endorsed by the Government, which committed resources to facilitate local-level planning and capacity building under the Land Management Programme (LAMP 1991-2010a; LAMP 1991-2010b).

Starting with a land use planning exercise in each village, an area of forest was set aside for each village and local laws were enacted to protect the forest. The forest itself was then divided into three zones: a grazing zone covering about 80 percent of the area; an agricultural expansion zone covering a surface of roughly 5 percent of the total, and a fully protected forest zone with an extension equal to 15 percent of the total.

Each village was then assisted in the establishment of a Village Environmental Committee which had the legal mandate to act as forest manager. This Committee met regularly in order to discuss emerging issues and possible solutions. Each Village Environment Committee established a patrol team responsible for patrolling the forest, and for issuing fines and arrest illegal forest users, ensuring compliance with the relevant by-laws.

At the overall forest level, a Zonal Environmental Committee comprising the members of each Village Environmental Committee was established, in order to discuss overall forest management issues, and ensure coordination between individual villages.

In 2002, the nine villages surrounding the Suledo forest were awarded the UN Equator Initiative and received a prize of US$30 000 in recognition of their efforts towards sustainable management of their forest resources.

29 The information included in this section was either adapted or excerpted from: Sjoholm and Luono (2002).

Region: South East Asia
Country: Philippines
Crop/Feedstock: Fuelwood (firewood and charcoal)

Forest harvesting through Community-Based Forest Management for the production of sustainable fuelwood in the Philippines[30]

Forest harvesting by communities offers great potential to reduce poverty in the Philippine uplands. A study was conducted to assess the potential for second growth forest in the Philippines to be used commercially on a sustainable basis (i.e. through a CBFM approach) by thousands of poor upland communities.

In addition to timber revenue, additional income could be generated from branches and thinnings sold as woodfuel or converted to charcoal. Most rural villagers already possess the necessary skills for manual flitching of timber from natural forests. They also know how to plant and tend tree farms since trees have always been an important component of their farming systems. Furthermore, policies set forth in the Community-Based Forest Management (CBFM) Programme of the Government of the Philippines envisage the active involvement of rural poor in the management of both tree plantations and natural forests.

The aforementioned study produced the following estimates:

- The Philippines has about 2.56 million ha of second-growth forests of which approximately 1.5 million ha are production forests.
- Second-growth production forests contain an average timber volume of 145 cubic meters (m^3) per ha, equivalent to a gross national volume of approximately 217.5 million m^3.
- The current market value of timber produced in the Philippines is around US$60 per m^3.
- A two-person team using manual flitching saws can produce an average 0.25 m^3 per day, or a potential daily income of US$7.50 per person day (0.25 m^3 x US$60 ÷ 2 persons = US$7.50 per person day).
- The current average income per family in rural upland communities of the Philippines is less than US$2 per day.
- Timber harvesting by communities in these second-growth forests has the potential to bring about a 375 percent increase in rural family income (US$7.50 ÷ US$2 = 375 percent).

30 The information included in this section was either adapted or excerpted from: Dugan and Pulhin (2007).

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3.3 CONSERVATION AND SUSTAINABLE USE OF PLANT GENETIC RESOURCES AND SEEDS

Amir Kassam, Maizura Ismail

Key features

Farmers' access to quality seed and plant genetic resources is essential to meeting the demands of a growing world population in the face of challenges such as natural resource depletion and degradation, increased climate variability, and the emergence of new pests and plant diseases. However, the lack of capacity to conserve and optimally use plant genetic resources, the loss of crop diversity due to natural disasters, and the introduction of uniform modern varieties in place of heterogeneous traditional crop varieties, may undermine the efforts to foster global food security and sustainable development.

Plant genetic resources are the fundamental biological building blocks for seeds and planting material of traditional varieties, modern cultivars, crop wild relatives and other wild plant species. The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) defines these resources as "any genetic material of plant origin of actual or potential value for food and agriculture" (FAO 2009). The conservation and sustainable use of Plant Genetic Resources for Food and Agriculture (PGRFA) and the adoption of varieties with higher yield potential and that perform well under unfavourable climatic conditions may enable farmers to cope with the changing environment and increase their productivity.

A supporting component of the aforementioned Treaty is the Global Plan of Action (GPA) for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture[31] (GPA). The second version of the GPA includes a list of 18 priority activity areas critical to ensuring sustainable conservation and use of PGRFA, organized under four main groups (FAO 2011a):

- *in situ* conservation and management
- *ex situ* conservation
- sustainable use, and
- building sustainable institutional and human capacity.

In situ conservation and management

In situ conservation and management of PGRFA may occur either through natural evolution or by human intervention on-farm by generations of farmers and plant breeders, and by indigenous and local communities. *In situ* conservation was defined by the

31 The GPA was adopted by the FAO International Technical Conference on Plant Genetic Resources that affirmed government-level commitment in national efforts to strengthen food security, and later endorsed by the Conference of the Parties to the Convention on Biological Diversity (CBD) and the World Food Summit.

Convention on Biological Diversity (CBD) as "the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties" (FAO 2010). The GPA identified four activity areas in which *in situ* conservation may be improved:

- *Surveying and inventorying plant genetic resources for food and agriculture.*
- *Supporting on-farm management and improvement of plant genetic resources for food and agriculture.*
- *Assisting farmers in disaster situations to restore crop systems.*
- *Promoting in situ conservation of crop wild relatives and wild food plants.*

Ex situ conservation

Ex situ conservation entails the conservation of biological diversity components outside their natural habitats. The main storage infrastructures are specialized facilities known as gene banks that are maintained by public or private institutions, while some germplasm is conserved *ex situ* in botanical gardens and gene banks. The GPA listed the following three activity areas to improve the *ex situ* conservation of PGRFA:

- *Supporting targeted collecting of PGRFA.*
- *Sustaining and expanding ex situ conservation of germplasm,.*
- *Regenerating and multiplying ex situ accessions.*

Sustainable use

Conservation alone is not enough as PGRFA are only of value when they are used. Conservation and use of PGRFA are mutually reinforcing – PGRFA are more likely to be conserved if they are seen as useful; at the same time, if they are conserved, PGRFA are more likely to be used continuously. The GPA identified the following five activity areas in order to promote the sustainable use of PGRFA:

- Expanding the characterization, evaluation and further development of specific subsets of collections to facilitate use.
- Supporting plant breeding effort, genetic enhancement and base-broadening effort.
- Promoting diversification of crop production and broadening crop diversity for sustainable agriculture.
- Promoting development and commercialization of all varieties, primarily farmers' varieties/landraces and underutilized species.
- Supporting seed production and distribution.

Building sustainable institutions and human capacity

The GPA listed the following six activity areas to strengthen institutions and promote capacity building:

- Building and strengthening national programme.
- Promoting and strengthening networks for PGRFA.

- Constructing and strengthening comprehensive information system of PGRFA.
- Developing and strengthening systems of monitoring and safeguarding genetic diversity and minimizing genetic erosion of PGRFA.
- Building and strengthening human resource capacity.
- Promoting and strengthening public awareness of the importance of PGRFA.

Farmers' role in conservation and sustainable use of PGRFA

Farmers play a central role in the relationship between biodiversity and ecosystem services, by influencing, in particular, which organisms are present and regulate the populations of specific organisms, such as "weeds", "pests", "diseases" and their vectors (Martínez and Amri 2008). Traditionally, farmers depended upon their own skills and resources to develop the crops that they need, including through domestication of wild species, selection of plant characteristic according to growing conditions and preferences, and informal seed supply systems (Tripp and van der Heide 1996; Subedi *et al.* 2003).

At the field level, the farmers may contribute towards conservation and sustainable utilization of PGRFA by:

- *maintaining or undertaking on-farm conservation of PGRFA*;
- *maintaining or adopting sustainable agriculture practices by diversifying crop production and utilization of broader crop diversity, including local varieties and "diversity-rich" products;*
- *commercializing underutilized crops and species, and*
- *building local capacity and networks for seed production and distribution of PGRFA.*

According to FAO (2011b), sustainable crop production intensification will continue to depend, *inter alia,* on the availability and use of input responsive and efficient crop varieties that are better adapted to ecologically-based production practices than those currently available, which were bred for high-input agriculture. The targeted use of external inputs will require crop plants that are more productive, use nutrients and water more efficiently, have greater resistance to pests and diseases, and are more tolerant to droughts, floods, frosts and higher temperatures. Those new crops and varieties will be deployed in increasingly diverse production systems where associated agricultural biodiversity – such as earthworms and other soil organisms, pollinators, predators of pests, nitrogen fixing trees and shrubs, and livestock – is also important.

Potential benefits

Biodiversity

Plant genetic resources may act as insurance to future unforeseen challenges to agriculture and are essential for our ability to adapt, including to new pests and diseases, climate change, other environmental challenges, as well as to changing consumer demands. For example, wild relatives of current crops may contain traits that could be bred into such crops to increase their resistance and versatility in the face of future challenges. Maintenance of natural habitats in protected areas is also particularly needed for species with recalcitrant seed[32] storage behaviour, which are difficult to conserve *ex situ* (Ouédraogo 1995). Towards this end, conservation and sustainable use of PGRFA may contribute towards biodiversity through the establishment of protected areas designed to support sustainable agricultural development. Protected areas managed with agriculture can help maintain the capacity of people to adapt to change (McNeely 1995).

Agrobiodiversity

The link between agrobiodiversity and sustainable use and conservation of PGRFA is mutually reinforcing. The more a variety of crops or animal breeds is used, the less it is endangered, and vice versa (Thies 2000). Agrobiodiversity provides the foundation for the improvement of PGRFA, and at the same time the conservation and sustainable use of PGRFA will contribute to future agrobiodiversity. In order to be able to continually adapt agriculture to ever changing conditions, plant breeders need to develop and maintain new varieties, and at the same time genetic diversity underpins the whole process of producing new varieties (FAO 2010).

Farmers have always played a key role, by maintaining germplasm from time immemorial, and they are the major depositors of materials held in the national gene banks and at regional gene banks such as the Southern African Development Cooperation (SADC) Plant Genetic Resources Centre (SPGRC). Farmers benefit from the collections in that, if they ever lose whole or some of their materials, they can always get them from the gene bank. Crop restorations are done in case of crop losses due to floods, change in farming systems, relocation of homesteads to pave way for other development activities like dam building, road extensions, etc. The *ex situ* materials are used for crop improvement and plant breeding trials for increased agricultural production.

Productivity/income

Genetic diversity contributes to income generation and food security stability by: reducing the risks of crop failures faced by farmers; compensating for yield losses with yields from other crops; providing options for use of different varieties that might be tolerant to biotic and abiotic stresses according to local conditions, and acting as an insurance for future adverse conditions such as new diseases or climatic change (Nnadozie *et al.* 2003).

Genetic diversity may also preserve the potential for development of new genetic characteristic of value in crops.

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32 Recalcitrant seeds are seeds that do not survive drying and freezing during ex situ conservation Moreover, these seeds cannot resist the effects of drying or temperatures less than 10 °C; thus, they cannot be stored for long periods because they can lose their viability.

Challenges

Access to market

Farmers involved in the production of seeds are not able to sell them on the formal market without meeting legal requirements of variety propriety documentation and production field registration, and without inspections by the relevant authorities. Without government support, the significant investments required to comply with seed certification regulations are beyond the reach of most farmers. Therefore, the seeds produced are sold through local agricultural retailers and at local community fairs, in unmarked bags (Guei 2010).

Availability of modern varieties that are the products of formal plant breeding, as well as the changing nature of agricultural production, may threaten the richness of the landraces diversity. Widespread adoption of modern varieties and use of fertilizer and irrigation, which often offer yield increases, lower the demand for landraces adapted to marginal growing conditions. This may result in farmers having less interest in maintaining the landraces and more interest in uniform modern varieties and continuous cropping, thus threatening the source of genetic diversity on which further progress depends and that is of particular importance to the more marginal and diverse agricultural environments (Tripp and van der Heide 1996).

Awareness, education, and research and development

A growing number of plant breeders work in industrial or governmental agencies that do not contribute to the education of the next generation of plant breeders, while educational institutions lack resources and programmes of sufficient size and scope to adequately educate/expose students to applied plant breeding. Due to this and to the fast pace of technological progress in plant breeding, which increases the need for continuous development of established plant breeders, the industry might not have sufficient future plant breeders (Baenziger *et al.* 2009).

More needs to be done to raise awareness of the importance of the conservation and sustainable use PGRFA among governments, as well as to encourage wider participation and stronger coordination in the development of policies, legislation and regulations among the various ministries, state, regional or provincial governments and other institutions having responsibility for different aspects of PGRFA (FAO 2010).

Since the 1990s, donors and international organizations have encouraged policies of economic liberalization, among others, in the seed sector, reducing government investment in public-sector plant breeding and seed systems, with the expectation that the private sector would fill the gap. In Africa, for instance, there is currently less government financial support than in 1985 (up to ten times less in some countries) (Guimarães *et al.* 2006).

However, producing and commercializing quality seeds in tropical conditions require heavy investment in infrastructure and high levels of technology, particularly in terms of specialized harvesting, processing and handling equipment, and drying and storage (Guei 2010). For this reason, seed companies tend to concentrate on producing hybrid seed for high value crops grown by larger farmers and market them in more productive, wealthier areas (Neate and Guei 2011). Public investment is particularly needed to improve crops that do not promise substantial short-term economic returns such as minor and underutilized crops (FAO 2010).

Policies and institutions

Plant breeding, seed systems and associated research require large and long-term financial, physical and human resources investments and commitment. The public and private sector successes in this area greatly depend on government support, as well as on external development assistance (FAO 2010).

The reduction in investments in public-sector plant breeding and seed production and the privatization of the seed sector have reduced the source of new varieties and quality seeds of crops for the smallholder farming sector. Private seed companies generally avoid production of self-pollinating crops, including many of those grown by smallholder farmers, as opportunities for commercial seed production are very limited, because farmers are able to save their own seeds for planting (Neate and Guei 2011). For crops with less market opportunities, such as self-pollinated crops, seed production systems have essentially collapsed in several countries (FAO 2010).

The ITPGRFA recognized the enormous contribution of indigenous, local communities and farmers to the conservation and development of PGRFA and identified three measures to protect and promote farmers' rights, which are: protection of traditional knowledge relevant to PGRFA; the right to equitably participate in sharing benefits from the use of PGRFA, and the right to participate in national decision-making on the conservation and sustainable use of PGRFA. However, the ability of farmers to continue supporting the objectives of ITPGRFA is seriously threatened by a lack of benefit-sharing, secure rights to land and biogenetic resources, erosion of cultural values, and agricultural policies that promote industrial agriculture and monocultures (Argumedo *et al.* 2011).

There is also a conflict between the interests of developed countries, which are concerned with access to genetic resources and with protecting their intellectual property, and those of developing countries, which are interested in sharing the financial and technological benefits derived from using genetic resources they provided. Intellectual property rights are only relevant in downstream activities, even if they benefit from values created upstream (Correa 2000). For example, seed companies can claim exclusive ownership of the results of their use of genetic resources under intellectual property rights. On the other hand, indigenous and local communities and farmers who are directly involved in producing or maintaining genetic resources from genetic erosion may not be fairly compensated or given ownership of the resources they provided (Brush 2000).

All forms of conservation, *in situ* and *ex situ*, are vulnerable and subject to numerous risk factors. *In situ* conservation of PGRFA is potentially vulnerable to technological innovation and diffusion, economic and political change, and environmental factors, while *ex situ* methods are potentially vulnerable to genetic drift within collections, loss of seed viability, equipment failure, security problems, and economic instability (Brush 2000). The benefits from *ex situ* conservation of PGRFA are substantial. However, as all other human institutions, gene banks, for example, depend on unpredictable public and political support, are usually inadequately funded, have limited storage and regeneration facilities with obsolete equipment, and are not adequately backed up. It is also important to ensure that genetic diversity contained within the *ex situ* facilities can serve the needs of poor farmers (MEA 2005).

Examples in bioenergy feedstock production

Region: East Africa
Country: Tanzania
Crop: Maize (*Zea mays*)

Introduction of disease resistant maize cultivars in the Southern Highlands of Tanzania[33]

Until the 1990s, the Southern Highlands (SH) of Tanzania used to supply around half of domestic maize (*Zea mays*) production. During the second half of the 1990s, however, this area was affected by serious outbreaks of maize diseases such as the Grey Leaf Spot (GLS).

The lack of improved maize varieties at reasonable costs limited productivity in the SH of Tanzania during this phase. The situation was further exacerbated by the collapse, in 2000, of the national company for the production and marketing of certified seeds – TANSEED – which severely disrupted the certified seed system for locally developed varieties. In addition, some traders started marketing fake or un-adapted seeds, causing even more harvest failures and a loss of confidence in so-called improved seeds among farmers.

In this context, FAO and the World Bank decided to join forces and provide the Uyole Agricultural Research Institute (ARI-Uyole) and the Ministry of Agriculture of Tanzania with funding to assist the maize improvement programme, particularly for facilitating the formation of new GLS-tolerant maize varieties.

After three seasons of on-farm demonstrations of new high yielding hybrids, a high level of awareness on the disease resistant maize cultivars was reached in four districts in SH. The key role played by these demonstrations was confirmed by the increase in the demand for seeds by local rural communities, particularly for hybrids involved in the demonstrations, namely hybrids UH615 and UH6303. The hybrid UH6303 ranked first in terms of farmers' preference in three out of four districts, due to its agronomic attributes, and to the popularity obtained following the successful release of this new disease-resistant maize hybrid for the SH of Tanzania. The maize improvement programme also validated new locally-bred varieties.

Since the collapse of the organized seed production and distribution system in 2000, access to locally-bred certified seeds by farmers had been limited, particularly in rural areas. The FAO/World Bank sponsored programme facilitated the establishment of a public-private partnership between ARI-Uyole and two private seed companies, with the aim of initiating a seed production and delivery system. Two private seed companies, Mbegu Technologies Inc. and Highland Seed Growers Limited, embarked on certified seed production during the 2004/2005 season. In order to facilitate economic access to these seeds by poor farming communities, both private seed companies agreed to start

33 The information included in this section was either adapted or excerpted from: Lymo (2005).

distributing seeds in small packs (0.5-1 Kg), starting with the newly released, farmer-preferred hybrid UH6303.

Region: Southern Africa
Country: Zimbabwe
Crop/Feedstock: Sorghum (*Sorghum bicolor*)

The Southern Africa Sorghum Landrace Research and Development (SALRED)[34]

The Mutoko Community Seed Bank Project was established in 1995 following a SADC/GIZ[35] sponsored "Sorghum Landrace Study" the previous year. The study collected information from farmers in the semi-arid regions of Zimbabwe on the availability of traditional crop seeds. The study also explored the potential benefits of a small grain seed supply programme in the rural communities living in the study areas.

The objective of the project was to enhance farmers' livelihoods through the conservation and sustainable use of plant genetic resources. The project aimed to improve farmers' access to seeds through outsourcing, exchange and communal storage; to introduce new crops and diversify farming; to promote local production and exchange of good quality disease free seed, and to strengthen the links between farmers, input suppliers and markets.

The project started in 1996 with the establishment of four community groups, one from each of the four participating wards, with each one of the latter representing one seed bank. The main institutions involved in the project were SALRED, the farmers, and Zimbabwe's Department of Research and Extension (AREX).

The four seed banks followed the same design, using as much as possible locally available resources. Local farmers provided labour force, whereas SALRED provided financial assistance. Some of the activities undertaken in the project included:

- construction of community seed storage structures;
- farmer-to-farmer seed sourcing and exchange;
- introduction of new crops such as cassava and jatropha in the areas;
- organization of seed fairs and green shows;
- on-farm seed multiplication and marketing;
- on-farm characterization of landraces;
- farmers' training in seed production, selection and storage, and
- farmers exchange visits.

34 The information included in this section was either adapted or excerpted from: Mafa and Manda (undated).
35 South African Development Community (SADC); Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

The project had several successes, including a marked diversity increase in the area. The number of traditional varieties of pearl millet (*Pennisetum glaucum*) increased from three to nine and four improved varieties were introduced. The traditional varieties of finger millet (*Eleusine coracana*) increased from zero to five, while three improved varieties were introduced. The number of traditional varieties of cowpeas (*Vigna unguiculata*) increased from one to five, and two improved varieties were introduced. The number of traditional varieties of mungbean (*Vigna radiata*) increased from zero to three. Six improved varieties of peanuts (*Arachis hypogaea*) and eight traditional varieties of pumpkin (*Cucurbita spp.*) were introduced. Last, but not least, the number of traditional varieties of sorghum (*Sorghum bicolor*) increased from one to ten, and four improved varieties were introduced.

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3.4 FOREST BUFFER ZONE

Marco Colangeli

Key features

According to Wild and Mutebi (1996), a Forest Buffer Zone (FBZ) is defined as: "any area, often peripheral to a protected area, inside or outside, in which activities are implemented or the area managed with the aim of enhancing the positive and reducing the negative impacts of conservation on neighbouring communities and of neighbouring communities on conservation".

In other words, a FBZ is a forested area between two surfaces with different land covers that mitigates the influence of each of these surfaces on the other one. Generally, the buffer zone is an area that limits the impacts on, and contributes to, the protection of a natural park, a body of water or a surface having a certain type of vegetative cover.

FBZs can be classified as:

- Riparian FBZ: an area of trees, shrubs and grasses existing where agricultural or forested land is traversed by water bodies, adjacent to streams, lakes, ponds, and wetlands (USDA 1997).
- Non-riparian FBZ: an area of trees, shrubs and grasses contiguous to rangeland, forestland, agricultural land, urban or built-up land, and barren land.

FBZs are mainly characterized by native vegetation and can be managed to maximize their benefits. In some cases, in addition to contributing to protection and conservation, FBZs may be managed to produce biomass and to provide phytoremediation (Dimitriou and Aronsson 2005).

Many studies report the contribution to erosion reduction performed by riparian buffer zones, and the associated reduction in the sediments entering the water. Forested soils trap a great deal of sediments moving down from upstream areas outside the buffer zone even in non-riparian areas. FBZs trap not only sediments, but also excessive fertilizers, pesticides and other chemicals washed out via superficial runoff. It is estimated that a buffer zone with a width of 50 m can remove 80 to 90 percent of nitrogen, 85 to 90 percent of runoff sediments, and more than 90 percent of the herbicides running off crop fields (FAO 2008).

The complex root system present in forested soils, which is characterized by a symbiosis between the trees and mycorrhizal fungi, absorb nitrogen, phosphates and other nutrients, reducing their impact on adjacent water bodies or areas with different land covers.

In addition to the benefits described above, FBZs serve many other important purposes as well, such as creating wildlife habitats, with positive effects on biodiversity, and increasing the aesthetic and recreational value of the area (FAO 2008).

Potential benefits

Soil quality

FBZs tend to have a positive effect on downstream soil quality, as excess nutrients and pesticides are trapped upstream. Moreover, the mitigation of erosion performed by buffer zones limits the leaching of colloids in the soil and leads to an improvement in the quality of the substrate. Densely rooted riparian forest buffers can also mitigate the risk of erosion, by dispersing the energy of flood events.

Water availability and quality

Anbumozhi *et al.* (2005) studied the impact of FBZs on water quality in three watersheds in India, Indonesia and Japan. In all locations, there was strong agricultural pressure upstream, and a high concentration of chloride and nitrate ions in water. The results of downstream water tests in watersheds with forest buffers (although not continuous and having various widths) demonstrated a reduction in the concentrations of the aforementioned pollutants ranging from 19 percent to 43 percent. The results demonstrate the positive impact that forest buffer zones can have in reducing the influence of agricultural nutrients and chemicals on surface water quality.

Biodiversity

Forest Buffer Zones are very rich in biodiversity. Within the limited space of a buffer zone (average width of 50 m), there can be high flora as well as fauna diversity.

Productivity/income

Tree crops and multipurpose trees planted in buffer zones can provide a number of products for local use, and offer important income generating opportunities.

Agroforestry is practised in FBZs in many parts of Africa, in order to protect both primary and secondary forests. Buffer zone agroforestry systems using a large number and variety of indigenous trees are particularly good at providing buffer zone functions to forests threatened by human pressure, while at the same time producing income through the harvest of fuelwood, timber, fruit and other goods from multipurpose trees.

Access to energy

In Sweden and other northern European countries, hygrophilous forest strips (willows and poplars) contiguous to water bodies on one side and agricultural land on the opposite side, are often used as buffer zones, as well as for bioenergy production and phytoremediation (Dimitriou and Aronsson 2005). These plants are managed through the technique of coppicing[36] and generate biomass used for the production of heat and power. During the

36 Coppicing is the practice of regularly cutting down trees, which naturally send up several tall straight stems from a bole, such as willow, alder, oak, chestnut, poplar etc, near to the ground to produce strong straight shoots. There is increasing interest in this practice for its performances in fuel production. For a more in-depth description of coppicing, see section 3.13 on *Sustainable Forest Harvest*.

growing period (three years), the roots uptake several excess nutrients and pollutants from the runoff water of nearby fields. This represents a very cost effective water treatment and biomass production system.

Challenges

Opportunity costs

FBZs may compete for land with agricultural production and thus there are opportunity costs attached to them. In addition, depending on the species included in a Forest Buffer Zone, it may take a few years before the benefits of such FBZ are realized.

As described above, however, FBZs can be managed to produce a number of goods and services, e.g. to produce biomass and/or to provide phytoremediation. In addition, the environmental benefits associated with FBZs can positively affect agricultural productivity in the surrounding areas.

Awareness, education, and research and development

It is important that FBZs are managed with a community-based approach. Farmers need to understand the benefits of this practice in order to fruitfully maintain the balance between agricultural production and environmental conservation.

Further, illegal logging is a major threat in some regions of the world. Without community awareness, this issue may seriously impact the success of FBZs.

Policies and institutions

Although many countries have in place National Forest Action Plans, Environmental Action Plans and Biodiversity Action Plans, rarely FBZs are explicitly mentioned in national policy and legislative documents.

In a report by Ghana's Water Resource Commission (2008) on the establishment of a buffer zone policy for managing river basins in Ghana, the following main challenges were identified:

- How to obtain public acceptance of using vegetation to buffer valuable aquatic resources from the impact of adjacent human use of the land.
- How to establish buffer zones of sufficient width along the targeted river/stream courses and water bodies, particularly in built-up areas where housing, commercial and other activities have been present for a long time.

So far, only a few countries have developed policies and legal instruments to promote the development and implementation of the buffer zone approach through the facilitation of revenue sharing (e.g. in Nepal), and the decentralization of decision-making with the creation of by-laws (e.g. in Ghana) (Ebregt and De Greve 2000).

Examples in bioenergy feedstock production

Region: North America
Country: United States of America
Crop/Feedstock: Maize (*Zea mays*)

Watershed scale impacts of buffers and upland conservation practices on agrochemical delivery to streams from maize cultivation, Nebraska, USA[37]

A study was conducted to estimate the watershed scale impacts of grass and forest buffers by comparing sediment and losses of chemicals used in agriculture from two watersheds in Nebraska (USA), one with conservation buffers and one without. The conservation-watershed included 0.8 km of grass buffers and 0.8 km of riparian forest buffer. The main cultures in place were corn (*Zea mays*) managed using a minimum tillage technique, corn-beans-alfalfa managed in rotation, terraces and grassed waterways. The control watershed had no buffers and the continuous maize cultivation was traditionally tilled. Both contiguous watersheds underwent the same application rate and method for atrazine, which a herbicide widely used in maize cultivation. Rainfall derived runoff events from 2002-2003 were monitored for water runoff, total suspended solids (TSS), and for phosphorous and atrazine loss.

Total rainfall during the April-June monitoring period was similar in 2002 and 2003; however, the conservation-watershed produced only 27 mm of runoff, compared to 47 mm from the control. An estimated 75-80 percent of all cropland runoff from the conservation watershed passed through the riparian forest or grass buffer. For the two years of the study, TSS and phosphorus losses per hectare were reduced by 97 percent and 96 percent in the conservation watershed compared to the control watershed. This was partially a result of a 45 percent reduction in the amount of water runoff from the conservation watershed. Atrazine was applied to corn at the same rate in each watershed; however, atrazine loss per hectare of corn was 57 percent less in the conservation watershed.

During the years of the study (2002 and 2003), other conservation practices (minimum tillage, crop rotation, terraces and waterways) reduced total suspended solids by 83 percent compared to the control watershed, and buffers reduced TSS of an additional 14 percent. For 2002, other conservation practices reduced atrazine mass loss by 29 percent, and buffers accounted for an additional 31 percent.

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37 The information included in this section was either adapted or excerpted from: USDA Forest Service - National Agroforestry Center and University of Nebraska (2004).

Region: East Africa
Country: Uganda
Crop/Feedstock: Cassava (*Manihot esculenta*); maize (*Zea mays*); sugar cane (*Saccharum officinarum*); groundnut (*Arachis hypogaea*); fuelwood

Tree species selection for buffer zone agroforestry: the case of the Budongo Forest in Uganda[38]

Since 1987, Uganda has included buffer zones in forest management and conservation strategies. The 1997-2007 Management Plan of the Budongo Forest39 prescribed internal zoning of the forest into a core Strict Nature Reserve (SNR) and two buffer zones (Zones I and II) with different management systems. According to the plan, 30 percent of the area of the Budongo Forest had to be set aside as "core" reserve area, 7 percent as Buffer Zone I, and the rest as Buffer Zone II. Buffer Zone I was set all around the core reserve area, and only the collection of fuelwood, herbal medicines, fruits, mushrooms and tubers for food was allowed in this zone. The remaining area of the Budongo Forest was categorized as Buffer Zone II. In addition to all activities permitted in Buffer Zone I, logging was allowed as well in Buffer Zone II.

In the areas surrounding the forest, agriculture is practised and the major crops are cassava (Manihot esculenta), maize (Zea mays), sugar cane (Saccharum officinarum), groundnut (Arachis hypogaea), millet (Eleusine coracana), beans (Vicia spp.), potatoes (Solanum tuberosum), coffee (Coffea spp.), bananas (Musa spp.), and tobacco (Nicotiana spp.).

The farmers living near the forest were asked to indicate the indigenous arboreal species that best satisfied their needs. Among a selection of 27 different species that can be used as woodlots, boundary planting and shade trees (multistrata tree planting), three were identified by farmers for integration in the Budongo Forest buffer zone farming systems: umbrella-tree (Maesopsis eminii), nigeria eworo (Vernonia amygdalina), and Lasiodiscus mildbraedii.

The participation of local communities in the selection of species and technologies was an important first step in the decision-making process. Selection and ranking of tree species by farmers was largely based on availability of such species (abundance), quality and multiplicity of services from the species, utilization history and requirements, and management knowledge.

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38 The information included in this section was either adapted or excerpted from: Kasolo and Temu (2008).

39 The Budongo Forest is an area located in western Uganda at an altitude of 1 100 m.a.s.l. The total area of gazetted forest reserve is 825 km2, of which 428 km2 are forested. The forest has an irregular margin, which gives it a very long boundary. The twelve parishes that border the forest are inhabited by local communities engaged in a variety of activities within and outside the forest.

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3.5 INTEGRATED PEST MANAGEMENT (IPM)

Amir Kassam, Maizura Ismail, Marco Colangeli[40]

Key features

Integrated Pest Management (IPM) is an ecosystem approach to crop protection that incorporates different management strategies and practices to grow healthy crops, prevent pest attack and minimize pesticide use. The IPM concept as an approach to pest control was introduced in the 1960s when crop protection specialists became aware of the adverse effects of chemical pesticides use, such as resistance to pesticide, occurrence of secondary pests, environmental damage and human health hazards (FAO 2003). IPM is founded on the idea that the first and the most fundamental line of defense against pests and diseases in agriculture is a healthy crop in a healthy agro-ecosystem in which the biological processes that underpin protection are protected and enhanced (FAO 2011).

These features of IPM are exemplified in the definition included in the the International Code of Conduct on the Distribution and Use of Pesticides, which refers to IPM as "the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms" (FAO 2003). The following are the general principles for using IPM in sustainable crop intensification programmes (FAO 2011):

- *Use an ecosystem approach to anticipate pest problems* by using a diverse range of pest resistant crop varieties, crop rotations, intercropping, optimal planting time and weed management. The use of Conservation agriculture systems, involving minimum soil disturbance, organic mulch and diversified cropping, enhances the population of natural enemies of pests early in the cropping cycle, provides them refuges and help drive their food webs.
- *Undertake contingency planning* for when credible evidence of a significant pest threat emerges.
- *Analyse the nature of the cause of pest outbreaks* when the problem occurs, and develop control strategies accordingly which should take advantage of beneficial species of pest predators, parasites and competitors, along with biopesticides and selective low-risk synthetic pesticides.
- *Determine how much production is at risk*, in order to establish the appropriate scale of pest control campaign or activities. Infestation of more than 10 percent of a crop area in an outbreak demands a rapid policy response.
- *Undertake surveillance to track pest patterns* in real time, and adjust response.

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40 Marco Colangeli is the author of the second example.

In its implementation, and in line with the above principles, IPM is a continuous, step-based, scientifically supported decision-making process that identifies and reduces risks from pests by emphasizing prevention and non-chemical pest control methods, without endangering the profitability of farming. Ciesla (in FAO 2001) divided the IPM process into two main steps:

- The *decision-making process* – during which pest, its host and various available pest management tactics are given careful consideration and monitored in terms of resource management, ecological, economic and social consequences.
- The *action process* – during which IPM methods designed to reduce pest populations to non-damaging levels are implemented (or not, if pests are at non-damaging level) and then eventually adjusted based on the monitoring of results.

According to Fisher (2000), in order to be effective the decision-making process should comprise three main steps:

- *Identify key pests and the damages they cause*: careful consideration of the pest, its host, resource management objectives and the ecological, economic and social consequences of the various available strategies (FAO 2001). As some insects, weeds and other living organisms may be innocuous, beneficial or may be controlled naturally, monitoring and identification may avoid unwarranted or incorrect pesticide use.
- *Monitor pest population on a regular basis:* scouting practices to detect pests and determine if action is needed, as well as for early detection before pest population becomes established.
- *Determine the potential for economic loss:* the action threshold, beyond which pest population becomes an economic threat and pest control action must be taken, is set (US EPA, undated).

After the decision-making process, the next step is based on a combination of strategies and methods to prevent, reduce and maintain pest population below the threshold level. IPM methods are different for each crop, country, region and even location, depending on the varieties used, the climatic and agro-ecological conditions, the local agronomic practices, the pest problem and the available crop protection options. IPM strategies cannot be delivered in a pre-determined prescriptive "package"; instead pest issues need to be understood and control measures need to be developed to fit local requirements and adjusted based on the monitoring of results.

The decision-making process is the basis of subsequent strategies chosen, including no action, and the action process may consist of one or a combination of ecologically, economically and socially acceptable tactics (FAO 2001). Certain IPM strategies are preventive measures to pest problems, while others are used to suppress pest population. Prevention consists of tactics designed to either reduce the probability of the pests and diseases occurrence or to create environmental conditions inhospitable for its build-up, while suppressive tactics are directed against the pest or disease to control or suppress build-up (FAO 2001).

The action process consists of two main steps:

- *selection and implementation of management tactics:* based on the decision-making process, regulatory, cultural, biological, physical, genetic and/or chemical strategies, or combination of strategies, are implemented (Table 2), and
- *evaluation:* the effectiveness of management strategies or combination of strategies is evaluated in order to identify potential adjustments and improvements.

Effective, less risky pest control strategies should be chosen first, including the use of highly targeted chemicals, such as pheromones to disrupt pest mating, or physical control, such as trapping or weeding, followed by additional pest control methods, such as targeted spraying of pesticides and broadcast spraying (US EPA undated). If pesticides are used, they should target specific pests, be as least toxic as possible to beneficial organisms and be in the environment only for a short period (Fisher 2000).

Table 2
Overview of IPM strategies

Types of strategies	Description and examples
Regulatory	Local, national, regional and international policies, guidelines and regulations. • *Preventive*: guidelines/code of conduct/ certification; quarantines at the borders; quarantine zones when pests are discovered; inspection at point of entry for pests; pest risk analyses for new trade agreements; import ban legislations
Cultural	Application of cultural methods in Conservation agriculture cropping systems to reduce pests. • *Preventive*: plant and soil analysis; crop rotation; intercropping with pest repellent crops; minimum soil disturbance, cover cropping and mulching; managing of sowing, planting or harvesting periods; tillage management; hand-picking of pests and hand-weeding; hygiene control; cold/heat treatments
Biological	Using beneficial organisms such as to suppress pests. • *Suppressive*: introduce natural pest predators; introduce new pest predators; augmentation of natural pest predators; use of parasites and pest diseases; biological insecticides; introduction of sterile male
Physical	Using physical structures to evade or diminish pest. • *Preventive*: raised beds and drip irrigation; terracing • *Suppressive*: border plants; trap crops; traps; barriers; use of fire to control pests; remove dead or diseased plants/parts; use of kaolin and diatomaceous earth, use of oil and soap
Genetic	Choosing varieties of crops that are resistant to pests for cultivation. • *Preventive*: disease-resistant varieties and hybrids
Chemical	Using pesticides and biopesticides. • *Preventive*: pheromones; special plant extracts such as Rotenone, Neem, Pyrethrum • *Suppressive*: use of copper products; chemical pesticides

Source: Compiled and adapted from: Ferro (1996); Fisher (2000); FAO (2001 and 2011); and USAID (undated)

Integrated weed management

Among the pests, weeds are a relevant biotic constraint as they compete with crops for water, soil nutrients, light and space and thus reduce crop yields. Shetto and Kwiligwa (in ILCA 1990) noted that weeds can deprive the crop of 30-50 percent of the applied nutrients and 20-40 percent of the soil moisture. Integrated weed management combines the use of complementary weed control methods such as grazing, herbicide application, land fallowing, physical removal, and biological (CSIRO 2011). While in many agro-ecologies, herbicides have become a principal component of weed control measures because of their effectiveness and relatively low operational costs, this is a short-sighted development which should be challenged by promoting alternative integrated weed management practices (FAO 2006) and production systems such as Conservation agriculture in which a judicious use is made of herbicides alongside other effective weed-suppressing practices such as minimum soil disturbance, mulch cover and diversified crop rotation (Blackshaw *et al.* 2007; Upadhyaya and Blackshaw 2007; Owenya *et al.* 2011).

Potential benefits

Soil quality

IPM may contribute to a reduction in the use of pesticides, by giving preference to other pest control methods and, when the use of pesticides is unavoidable, by promoting an optimal use of them, giving priority to low-risk pesticides. These pesticides pose lower risks for natural ecosystems and biodiversity, and may also reduce the risk of long-term crop losses due to land degradation (Hoddle 2006). The use of CA as an integral part of an IPM strategy has a significant positive effect on soil quality, including soil biodiversity, soil moisture, and productive capacity for healthy crops and root systems. The lower mineral plant nutrition requirement and increase in organic forms of nutrients with CA reduce the excess free sugars and amino acids in the plants that are known to attract pest attacks (Chaboussou 2004).

Water availability and quality

Effective use of IPM strategies can affect water quality by reducing the use of chemical pesticides, and by leaving less residual fertilizers, especially nitrate, in the soil profile after harvest. In addition, IPM may improve crop health, raising the efficiency with which crops use fertilizers. Healthier crops also tend to be more competitive with weeds and less dependent on herbicides (Waldron *et al.* 2005). IPM may also affect water availability and quality in a number of other ways (Waldron *et al*. 2005), including through:

- practices that strictly adhere to safe pesticide use when use of chemical control is warranted, including: following pesticide label instructions; preventing spills while mixing and loading; avoiding back siphoning while filling sprayers; calibrating pesticide application equipment before use; mixing only the amount of pesticide needed; never rinsing pesticide application equipment near wellheads, ditches, streams or other water sources, and triple rinsing or pressure rinsing pesticide containers before disposal or recycling, and

- planning that takes into consideration important information on soil properties that may affect pesticide movement such as its texture, permeability and organic matter, as well as on pesticide chemical properties that may affect potential risk of leaching or surface runoff such as degradation rates, soil absorption, water solubility, and volatility.

Biodiversity

Certain site-specific IPM strategies such as maintaining unsprayed refuges within fields may reduce development of genetic pesticide resistance and allow the conservation of natural enemies within the fields (Midgarden *et al.* 1997). Reducing pesticide applications and increasing diversity within farms can increase the level of pollination services (FAO 2011), providing habitats for pollinating insects and ground nesting birds as well.

Agrobiodiversity

The reduction in the use of pesticides may create conditions suitable for soil biota and root symbioses. The increase in above- and below-ground biological activity and biodiversity may attract birds and larger animals, thus further increasing the farm's agrobiodiversity (Reganold *et al.* 1987). IPM under Conservation agriculture may have a positive impact on agrobiodiversity both below and above ground, enhancing the population of pest parasites, predators and competitors.

Productivity/income

As pesticide costs represent a major share of total farm production costs, a reduction in pesticide use may increase farmers' income (Hoddle 2006). IPM may also influence the level and variability of production and the associated production- and income-related risks. The potato IPM programme for Andean weevil in Equador was estimated to have saved US$87 per hectare in the Central region and US$42 per hectare in the South, as well as caused less damage in the North, where the moth is a serious problem, with net benefits generated estimated at US$62 per hectare (Norton *et al*. 2005).

The productivity and economic benefits of IPM compared to conventional pest management practices include:

- reduced or virtual elimination of pesticide cost, and increase in yield and income even when considering the increased monitoring costs (Gallagher *et al.* 1994), and
- reduced energy consumption in alternative agricultural systems because synthetic fertilizers and pesticides are not used (Brenner 1991).

Human health and safety

With reduced use of agrochemicals, the potential benefits of IPM include reduced health risks, especially to the pesticide applicators[41]. IPM may also positively affect food safety (Norton *et al*. 2005). Around the globe, use of transgenic crops with Bt (*Bacillus thuringiensis*) gene as part of the genetic control strategy has consistently resulted in significant reductions in insecticide applications[42].

Challenges

Pest issues

Biological strategies are generally considered as the most important component of an IPM programme. However, improper application of biological control may disturb the ecological equilibrium, causing unwanted decline of native flora and fauna due to the actions of deliberately imported and released exotic natural enemies (Hoddle 2006). On the other hand, genetic strategies, such as the introduction of genetically engineered crops, have resulted in significantly greater concerns including in terms of food safety, environmental safety, and gene flow into progenitor populations and weedy crop relatives (Hoddle 2006).

In determining the suitable IPM strategies, only mortality tests are considered when a choice between several pesticides must be made. Sublethal effects of pesticides on the physiological and behavioural processes in natural enemies, such as interference with the feeding behaviour by repellent, antifeedant, reduced olfactory capacity effects or more drastic effect, may not be taken into consideration, therefore not fully assessing the real risk (Desneux *et al.* 2007). IPM allows for use of reduced-risk pesticides. However, pesticides are registered as reduced-risk because of the very low toxicity to humans. They may still have negative impact on key natural enemies and be responsible for substantial disruption of long-term biological control of key pests, as well as on pollinators such as bees that may result in reduced pollinating ability (Hoddle 2006).

Implementation costs

IPM programmes may be self-generating due to the savings on production inputs in the long run, but they may require a long-term investment (Dhaliwal *et al.* 2004). Although the use of agrochemicals might decrease, with a decrease in the associated costs, the cost of pest monitoring – with the associated labour – might increase (Norton *et al.* 2005). The application of IPM may be as expensive as chemical control if the research

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41 A study on IPM programme in Indonesia found that farmers who went through IPM training on rice crops not only sprayed 63 percent less often but also reduced their use of the more highly toxic organophosphate pesticides, while still achieving the same yields as before (Kishi *et al.* 1995).

42 For example, transgenic rice crops grown in China reduced insecticide by 80 percent, increased yields by 6 percent and eliminated pesticide poisonings on humans (Huang *et al.* 2005).

and development, extension and training costs are taken into account (FAO, undated). According to FAO (2011), sustaining IPM strategies requires effective advisory services, links to research that responds to farmers' needs, support to the provision of IPM inputs, and effective regulatory control of chemical pesticide distribution and sale. Farmer Field Schools that draw on indigenous knowledge are considered to be one of the most effective and low cost means of promoting and sustaining IPM programmes at local levels.

Awareness, education, and research and development

IPM is a "sophisticated" method of pest and disease management that requires training and precise knowledge on the epidemiology of different pests and diseases, the development cycles of the organisms involved, their natural enemies, and their relation to the environmental conditions (FAO 2011).

Farmers seldom adopt complicated management practices even when they are promoted as sustainable and cost-effective, if the alternative is as simple as one spray to eliminate all. Pesticides may still be the main method of pest and disease management, as alternative technologies such as biological control and transgenic crops are often stigmatized (Hoddle 2006).

One of the main reasons why farmers fail to adopt IPM is the lack of IPM solutions for the specific pest/crop/location in which they operate (Rajotte *et al*. 2005). Significant investments in IPM research and technology development are required to build the ecological knowledge base needed for the multitude of cropping systems, pests, environments, and pest complexes (CAST 2003).

Lack of awareness of the net benefits of IPM among farmers – with many of them still believing that pesticides are the only solution to pest issues – is another reason for the relatively low adoption of IPM strategies and methods (Rajotte *et al*. 2005; Nyambo and Youdowei 2007). This is further exacerbated by the aggressive promotion of chemical pesticides, including through private extension services. On the national and NGOs-provided extensions, there is inadequate expertise and information on IPM and what it entails for them to participate fully in the promotion of IPM (Nyambo and Youdowei 2007).

The participatory approach to introducing IPM is an effective method of IPM technology development and dissemination. This includes the Farmer Field School approach which improves the adaptive research and training capabilities of farmers (Hoddle 2006). Through this, farmers are given the opportunities to gain a practical understanding of agro-ecological factors and management practices which affect pest populations and behaviour (Carney 1999). In turn, this may refresh farmers' roles as resource persons in their participation with extension agents and scientists (Ooi 1998).

Core to IPM development is also the involvement of women farmers. IPM has shown that it may increase the involvement of women in decision-making (Hoddle 2006). Hamilton *et al.* (2005) cited a study on IPM practices in different parts of the world by IPM Collaborative Research Support Program (CRSP) researchers, that documented overall high levels of participation by women in both export and domestic agricultural markets and in pesticide regimes. Understanding women's roles in pest management, household agriculture and economies, as well as women's participation are keys to IPM programme success in all phases (Hamilton *et al.* 2005).

In light of the above, there is a continuous need to maintain effective awareness of the value of IPM strategies, and to ensure that education systems teach and promote IPM approaches to pest control. Equally, participatory IPM research and technology development should be part of the core national priority to provide alternative ecological strategies to farmers.

Policies and institutions

There is a lack of coordination of plant protection activities, particularly between research, extension and farmers (Nyambo and Youdowei 2007). In the IPM context, the experimental approach for testing ideas and hypotheses necessitates hands-on field experience. However, development in IPM may be hindered by the work of many IPM theorists who have inadequate appreciation of reality; and of ecologists who are primarily interested in fundamental ecology (Way and van Emden 2000). Government subsidies for pesticides may represent an obstacle to the adoption of IPM by farmers (Dhaliwal *et al.* 2004).

Unlike agrochemicals that give farmers more or less total control of pest management within their own plots, an IPM programme may only be successful if all the farmers in a given region effectively take part. Neighbouring fields where no IPM is practised are a substantial source of potential contamination to the adjacent areas (FAO, Undated). This is especially important in the case of mobile pests. Some farmers may also free-ride on neighbouring farmers' participation in IPM without paying the costs (Dhaliwal *et al.* 2004)

The trading of an IPM technology may require investments and, in many cases, overcoming regulatory hurdles, including when crossing national borders. Biocontrol techniques may require mass rearing of beneficial insects, import and distribution of pheromones, or regulatory approval of a virus that controls an insect, while availability of potentially useful biotechnologies is constrained in countries where biosafety rules are not in place (Rajotte *et al.* 2005). Regulatory obstacles regarding use of exotic natural enemies may be a major issue in ensuring the safety of IPM application. Other complications include unresolved disputes on transgenic crop plants and the pest management benefits this technology offers vs. the potential environmental problems that could arise from the unintended spread of transgenes (Hoddle 2006).

Examples in bioenergy feedstock production

Region: East Africa
Country: Kenya
Crop/Feedstock: Maize (*Zea mays*)

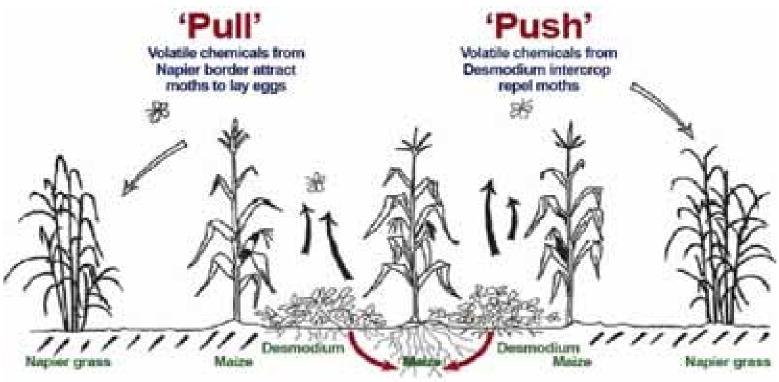
"Push-Pull" Integrated Pest and Nutrient Management in maize plantations in the Lake Victoria region, Kenya[43]

As in many other parts of Africa, in the Lake Victoria region of Kenya, stemborer pests (*Busseola fusca*), witchweeds (Genus *Striga*[44]) and poor soil fertility are the main constraints to efficient production of cereals. When they proliferate together, they often lead to complete crop failure. The use of the "Push-Pull" technology may efficiently control the pests and progressively improve soil fertility. The "Push-Pull" system may simultaneously improve cereal productivity, enable production of year-round quality fodder (thereby allowing for integration with livestock husbandry), diversify income streams, and enable smallholders to enter into the cash economy. It may also improve soil fertility, protect fragile soils from erosion, and enable a minimum (or a no-) tillage system.

The technology is appropriate for resource-poor smallholder farmers, as it is based on locally available plants, affordable external inputs, and fits well with traditional mixed cropping systems practised in many low soil-fertility areas of the world. Labour requirements are medium for the establishment of this technology and low for its maintenance, while knowledge requirements are medium for advisers and low for land users.

Figure 3

Diagram of "Push-Pull" technology on maize plantations in Eastern Africa



Source: adapted from ICIPE, www.icipe.org

43 The information included in this section was either adapted or excerpted from: Liniger *et al.* (2011).

44 Striga is a genus of the family Scrophulariaceae, diffused in Africa, Asia, Australia and parts of North America responsible for major weed infestations. Infestations of this root-parasitic plant are favoured by poor soil conditions and infertility coupled with low crop vigour (Mohamed *et al.* 2001).

In Lake Victoria, this management method involves intercropping maize with a repellent plant, such as silverleaf tick-clover (*Desmodium uncinatum*) which acts as a "push" for the stemborer and a suppressor for witchweeds, while an attractant trap plant, such as napier grass (*Pennisetum purpureum*) is planted as a border crop around the maize plantation ("pull").

Thanks to this IPM method, the stemborer moths, attracted to the volatile compounds emitted by the napier grass, lay eggs on napier grass. The grass secrets a sticky substance and physically traps the stemborers' larvae. The grass also serves as a haven for the stemborers' natural enemies. Napier is also an important carbohydrate-rich fodder grass. The silverleaf tick-clover, a perennial cover crop, produces repellent volatile chemicals that push the stemborer away. The plant also effectively suppresses witchweeds through the production of root exudates. Furthermore, silverleaf tick-clover, a legume, fixes nitrogen, conserves soil moisture, enhances arthropod abundance and diversity, and improves soil organic matter, thereby making cereal cropping systems more resilient and adaptable to climate change. Silverleaf tick-clover is a low-growing plant and, thus, it does not interfere either with crop growth or with harvesting operations.

Through the application of this IPM method, maize yields may increase on average by 25-50 percent where stemborer is the only pest, and by 300 percent in areas affected by both stemborer and witchweed. In addition to increased maize production, the economic benefits of this IPM method include increased fodder production, reduced financial constraints from the reduction of fertilizer inputs thanks to nitrogen-fixing legumes, and reduced workload as weeding is minimized.

Region: Africa
Crop/Feedstock: Cassava (*Manihot esculenta*)

Integrated Pest Management of cassava mosaic virus and cassava mealybug in sub-Saharan Africa[45]

Cassava (*Manihot esculenta*) was imported from Latin America to Africa in the 1700s. Over time, cassava spread to more than 40 countries in sub-Saharan Africa, and Nigeria is currently the largest producer in the world (FAOSTAT 2011). In the 1960s, the cassava mosaic disease became a major problem. The mosaic disease is transmitted by a white fly (*Bemisia tabaci)* as well as by planting cuttings from infected plants; it reduces cassava yields by 30 to 40 percent. In the early 1970s, another pest began to threat the cassava industry in sub-Saharan Africa – the cassava mealybug (*Phenacoccus manihoti*).

In the 1970s, cassava mosaic and mealybug control programmes were introduced. Breeding of mosaic-resistant cassava commenced in 1971 at the International Institute of Tropical Agriculture (IITA) in Tanzania, starting from some hybrid plants selected during the colonial period. These hybrids were resistant to the mosaic disease but offered very

45 The information included in this section was either adapted or excerpted from: IFPRI (2009).

poor performances in terms of productivity.

After six years of research (from 1971 to 1977), IITA developed the high-yielding mosaic resistant Tropical Manioc Selection (TMS), through the hybridization of resistant varieties. The TMS varieties increased cassava yields by 40 percent without fertilizer. In 1977, the IITA released four high-yielding mosaic resistant varieties capable to yield, on average 19 tons/ha (against a local average of 13 tons/ha). Moreover, TMS varieties reach their peak yield between 13 and 15 months after planting, compared to 22-24 months for local varieties. In subsequent years, TMS cassava varieties began to spread throughout most of Africa.

Another major pest – the cassava mealybug – was accidentally introduced in the Congo Basin in the early 1970s through infested planting materials from South America. The mealybug spread throughout the cassava belt of Africa, sharply reducing cassava yields. In the 1980s, the cassava mealybug threatened to wipe out cassava in Africa. The pest was spread by the wind as well as through the exchange of infested planting materials. The mealybug feeds on the cassava stem, petiole, and leaf near the growing point of the cassava plant. During feeding, the mealybug injects a toxin that causes leaf curling, slowing of shoot growth, and eventual leaf withering. Yield loss in infested plants is estimated to be up to 60 percent of root and 100 percent of the leaves.

To tackle the mealybug infestation, an Africa-wide biological control centre was established at the IITA in Nigeria, with the participation of an international group of scientists and donors. Researchers and policy-makers analysed a number of options and decided that the classical biological control solution, i.e. the reuniting of predators with their previously dislocated prey, was the best approach to pursue.

The researchers eventually found a wasp (*Apoanagyrus lopezi*) native to Central America that feeds off the mealybug. From 1981 to 1994, the wasp was released in 120 sites in about 30 African countries. A survey covering the whole of Nigeria found cassava mealybug infestation levels of below 10 mealybugs/tip, with only 3.2 percent of all tips being stunted. The field studies revealed that the introduction of *A. lopezi* led to some competitive displacement, but not to the extermination of indigenous parasitoids or predators. The wasp was effective in bringing the mealybug under control, with a reduction of 2.5 tons/ha in yield losses.

Through the implementation of two IPM methods (i.e. selection of high-yielding mosaic resistant varieties and biological control of mealybug), two major pests threatening cassava production in Africa were defeated.

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3.6 INTEGRATED PLANT NUTRIENT MANAGEMENT (IPNM)

Amir Kassam, Maizura Ismail, Marco Colangeli[46]

Key features

Plant nutrition is a key determinant of yields, and is believed to account for some 55 percent of yield increases in developing countries over the past three decades (FAO 1998). Increased biomass synthesis, including economic yield, is dependent on suitable flows of plant nutrients to the crops, without which agricultural intensification may lead to land degradation and economic loss for farmers. On the other hand, excessive nutrients, inefficient cropping systems management and inefficient residues use may result in losses of plant nutrients, thus causing environmental hazards, which may also result in economic losses for farmers (FAO 1998). Heavy reliance on chemical inputs, such as chemical fertilizers, may also result in increased production costs and introduction of agrochemicals to the ecosystems, thus raising serious concerns for human and animal health (Kumar *et al.* 2004). Increasing costs of fertilizers, may further limit poor farmers' access to these inputs, limiting their potential to increase yields (FAO 2009).

The negative effects of too little or too much input may be avoided through good management and balanced fertilization. The introduction of Integrated Plant Nutrient Management (IPNM) may be a more ecologically, socially and economically viable way of meeting the plant nutrient needs, thus increasing production. IPNM refers to "maintenance and adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of benefits from all possible sources of plant nutrients in an integrated manner" (Dudal and Roy 1995).

Optimal nutrient supply is determined by the production methods used, the prevailing prices of fertilizers, the cost of mobilizing local nutrient sources and the commercial value of the crop (FAO 1998). Operating at plot, farm and village or territory levels, plant fertilization must be carried out in a sustainable way, with focus on the management of soil health in cropping systems, rather than on an individual crop or nutrient, and on the farming systems, rather than the individual field. Management of soil health requires far-reaching changes in soil management, and nutrient cycling and conservation calls for a system approach to managing plant nutrition in which soil is recognized as a "living" system (Bot and Benites 2005; FAO 2011). IPNM can be practised in tillage-based production systems in which it is more difficult to maintain soil health and quality because tillage leads to loss of soil organic matter and structure, increased compaction and runoff, increased agrochemical pollution and reduced nutrient use efficiency.

The alternative approach is the practice of IPNM in Conservation agriculture (CA)

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46 Marco Colangeli is the author of the second example.

systems[47], in which the focus is on the enhancement of soil health and functions, leading to production intensification and efficient use of applied nutrients in combination with biologically fixed nitrogen by legumes in the cropping system (FAO 2010a). Thus, nutrient management in CA must be formulated within this framework of soil health (Shaxson *et al.* 2008; Kassam and Friedrich 2009), and would need to attend to the following four general aspects simultaneously, namely that:

- *biological processes* of the soil are enhanced and protected so that all the soil biota and micro-organisms are privileged and that soil organic matter and soil porosity are built up and maintained;
- *biomass production and biological nitrogen fixation* for keeping soil energy and nutrient stocks are sufficient to support higher levels of biological activity, and for covering the soil;
- *access to all nutrients* by plant roots in the soil, from natural and synthetic sources, is adequate to meet crop needs, and
- *soil acidity* is kept within acceptable range for all key soil chemical and biological processes to function effectively.

Consequently, research on successful nutrient management strategies as part of any IPNM approach must pay close attention to issues of soil health management. This means managing: (a) the *microscopic* integrity of the soil-plant system particularly as mediated by soil living biota, soil organic matter, soil physico-chemical properties, available soil nutrients, adapted germplasm, and (b) the *macroscopic* dimensions of landscapes, socio-economics and policy support. Given that CA principles and practices offer substantial benefits to all types of farmers in most agro-ecological and socio-economic situations, CA-based IPNM approaches to nutrient management and production intensification would be more effective for farmer-based innovation systems and learning processes such as those promoted through Farmer Field School (FFS) networks (Kassam and Friedrich 2009).

Essential and beneficial plant nutrients

Acute deficiency of nutrients in plants is associated with definite visible symptoms and growth is limited by the nutrient that is in shortest supply. An increase in the deficient nutrient will usually result in increased growth and yields[48]. Plants may also experience damage caused by acute toxicity, where excessive supply of nutrient results in toxicity symptoms, such as poor or no growth, poor yield, low quality, damage to soil and plant health, as well as lowered disease resistance.

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47 For a description of *Conservation agriculture*, see section 1.1.

48 Roy *et al*. (2006) listed 16 elements for higher green plants that are considered essential for their full growth and development depending on their stage of development and yield levels. Of this, carbon (C) and oxygen obtained from the gas CO_2, and hydrogen (H) obtained from water (H_2O) make up 95 percent of plant biomass. The remaining 13 elements are divided into two groups – macronutrients and micronutrients, and taken up by plants in specific chemical forms.

In order to make decisions on how much to apply to ensure optimal plant nutrition for healthy crop and sustained yields, farmers may undertake evaluation or assessment of soil fertility. The status of soil fertility or the available nutrient for crop production in the soil may be estimated through soil testing and plant analysis, including total analysis of the selected plant part, tissue testing, and crop logging (Roy *et al* 2006). If existing soil fertility is insufficient to supply nutrients to crops, IPNM may assist farmers in improving fertility by adding external inputs that are economically, environmentally and socially acceptable.

Commercial mineral fertilizers

For many farmers, the bulk of nutrient input will be provided by the addition of commercial chemical fertilizers (also referred to as mineral, synthetic, inorganic or artificial), which come either in the form of straight fertilizers that provide only one of the three major nutrients (N, P or K), or in the form of complex/compound fertilizers, which contain at least two out of the three major nutrients. However, heavy reliance and improper utilization of synthetic fertilizers have given rise to concerns regarding soil compaction, decrease in soil organic matter, groundwater quality deterioration and surface water eutrophication, as well as issues related to limited access to inputs and finance.

Organic fertilizers and biofertilizers

IPNM promotes the achievement of required plant nutrition for sustaining the desired level of crop productivity through a pre-planned integrated use of alternative sources of fertilizers, with chemical fertilizers integrated into the system to maintain or increase productivity. Alternative sources of nutrients are: organic fertilizers or nutrient that are derived mainly from substances of plant and animal origin, either in their original forms or processed, and biofertilizers or microbial inoculants. Sources of organic fertilizers and biofertilizers include:

- crop residues;
- green manure;
- farm yard manure (FYM) and animal slurry;
- biogas plant slurry;
- compost;
- recyclable wastes from various sources that do not contain harmful substances above permissible limits;
- oilcakes, and
- biofertilizers.

Crop residues

Crop residues are the bulk of the crop biomass left after removal of the main produce from the field, including straw, stalk, husk, stubble and trash of grain after the grain has been harvested. Most crops produce a large amount of residues, which may be used as sources of plant nutrients. Other uses include as fuel feedstock, livestock feed, roofing material and bedding for animals. Crop residue may be retained in the fields to act as soil cover or mulch while decomposing, after which it contributes to the plant nutrient in soil, as in CA systems. It may also be applied to the fields as compost after undergoing composting process.

Green manure

Green manure refers to green plants that provide a living mulch cover while green or cut soon after flowering to provide surface residues and to add nitrogen or other nutrients to the topsoil. Usually of the legume family, green manure is often specifically grown, either *in situ* or cut and carried from somewhere else, for this purpose. Legumes such as pigeon pea (*Cajanus cajan*), green gram (*Vigna radiate*), cowpea (*Vigna unguiculata*) and lablab (*Dolichos lablab*), are often used as green or green-leaf manure, as they are characterized by a high N content and also contribute to the soil N content through the nitrogen-fixation function. Examples of perennial woody multipurpose legumes are *Leucaena leucocephala* (subabul), *Gliricidia sepium*, and *Cassia siamea*; and examples of non-grain legumes include *Crotalaria, Sesbania, Centrosema, Stylosanthes* and *Desmodium (*Roy *et al.* 2006; FAO 2010b).

Farmyard manure (FYM) and animal slurry

FYM refers to livestock dung and urine, as well as spilled feed, bedding/litter and any other material that may have mixed with livestock dung and urine. FYM is one of the main sources of organic plant nutrients used since ancient times to maintain and enhance soil fertility for crop production. Besides N, P, K and micronutrient supply, FYM also contributes to soil carbon, soil biological activities and soil physical structure (UME 2002). FYM is applied to the soil directly, as partially air-dried dung, or after composting. Grazing animals may directly contribute dung, or the dung may be collected, dried and stored for future use as fuel or fertilizer; the dung may also be added to compost heap to activate the microbial “heating” process (Sharma 2001).

When applied to the soil, FYM needs to be incorporated immediately to minimize N loss to the air and to allow for organic matter decomposition by soil micro-organisms, thus making nutrients available for uptake by crop plants. Decomposition occurs faster under warm, moist conditions, while rain after application reduces volatile losses of N, although there is potential for runoff and leaching. In some regions, FYM is also used as fuel and use of FYM as fertilizer may give rise to a competition.

In countries that are currently shifting towards intensive labour-saving animal production systems, where straw bedding for livestock is not needed, plant nutrient may be obtained in the form of animal slurry. Animal slurry consists of dung and urine, partly mixed with a small portion of straw and water in order to improve fluidity. The semi-liquid nutrient source is mechanically collected, stored and distributed (Roy *et al.* 2006).

Biogas plant slurry

Animal waste, human waste and plant materials may also be used to produce energy for cooking and lighting from biogas. Biogas is produced from the fermentation or anaerobic digestion of the composite waste. The residual material in slurry form can be used as manure and directly applied to land or used for composting.

Compost

Compost refers to "organic manure or fertilizer produced as a result of aerobic, anaerobic or partially aerobic decomposition of a wide variety of crop, animal, human and industrial wastes" (Roy *et al*. 2006). Although organic waste products, such as leaves, roots, crop residues, hedge clippings, bagasse, sawdust and kitchen wastes, may be applied directly to the soil, they may develop better soil-improving effect after decomposed through composting process. Composting is a biological process during which micro-organisms convert organic matter to a stable humus-like product under controlled conditions. Roy *et al.* (2006) identified three main types of composting:

- *rural compost*: produced from materials on-farm and other rural areas, such as straw, leaves, cattle-shed bedding, fruit and vegetable wastes, and biogas plant slurry;
- *urban or town compost*: prepared from urban and industrial wastes, city garbage, sewage sludge, factory waste, etc.;
- *vermicompost:* compost produced using earthworm, whereby the earthworms eat biomass and excrete it in a digested form, along with beneficial micro-organisms, actinomycetes, plant nutrients, organic matter, enzymes and hormones.

Traditional composting methods using passive aeration and infrequent turnings or static aeration may take several months. Methods applied to expedite the aerobic decomposition process include shredding and frequent turning, mineral N compounds, effective micro-organisms, use of worms, cellulolytic organisms, forced aeration and mechanical turnings, which may reduce the composting period to about four to five weeks (Sharma 2001).

Oilcakes

Oilcakes are the residues from oilseeds after the oil has been extracted. Non-edible oilcakes are usually used as manure, while edible oilcakes are used as livestock feed as well as applied to the soil. Oilcakes have a higher nutrient content, particularly of N and P, than normal crop residues, and as such decompose faster (their N may be available to plants in 7 to 10 days) to furnish available nutrients for plant uptake (Roy *et al.* 2006).

Biofertilizers

Some soil micro-organisms play unique and beneficial roles in agriculture through their function as atmospheric N-fixer, P-solubilizer, decomposer and plant growth promoter. This group of micro-organisms, known as biofertilizers or microbial inoculants, consist of living or dormant bacteria, fungi, actinomycetes and algae, alone or in combination.

Biofertilizers can be grouped into four main categories (Roy *et al.* 2006): N-fixing biofertilizers; P-solubilizing/mobilizing biofertilizers; composting accelerators, and plant-growth-promoting rhizobacteria (PGPR).

Potential benefits

Soil quality

To produce biomass, crops consume plant nutrients from the soil. If the crops are utilized, either as food, feed or fibre, away from the farm after being harvested, the nutrients are also removed from the farm, causing loss of nutrients in the production area. Nutrient is also lost through the natural flow that occurs through wind and water movement as part of the natural erosion process. Future productivity may be affected if the nutrients are not replenished to maintain or improve soil nutrient status. Through IPNM, farmers are encouraged to assess the soil quality status before deciding on fertilization measures to ensure correct quantities and avoid overuse of N, which may disrupt the natural N-cycle, as well as the use of fertilizer application methods that minimizes losses of nitrogen to air and/or water.

Farmers are also encouraged to increase soil cover by increasing crop growth, applying surface mulches and/or changing to perennial crops, as well as ensuring an early establishment of the crop by modifying farming practices and applying no-till soil management (Aune and Øygard 1998) or CA based production systems (FAO 2011). Farmers are also trained to use a combination of mineral and organic fertilizers obtained from sources on and off the farm (Roy *et al.* 2006). In CA systems, these practices enhance and maintain good soil health, minimize erosion as well as replenish nutrient that has been transferred out of the farm.

Use of organic fertilizer and biofertilizer as promoted under IPNM may also increase the organic matter in the soil[49]. Use of compost as soil conditioner, fertilizer to increase vital humus or humic acids, and natural pesticide for soil, may also reduce erosion, increasing land and stream reclamation. Compost also has a substantial buffering capacity and generally has a pH above neutral, thus reducing liming costs in agriculture (Dimambro *et al*. 2006).

Water availability and quality

With regard to water quality, IPNM benefits stem mostly from the reduced agrochemical use as a result of complementary use of other nutrient sources. As not all nutrients applied to the soil are taken up by the crop, the remainder fertilizer left in the soil, removed by

49 An ongoing study by the Rodale Institute comparing organic (FYM and legume-based) and conventional grain-based farming systems since 1981 showed that soil carbon was significantly higher in both the organic-animal and organic-legume systems than in the conventional system. High soil carbon is associated with higher water content of the soils, which accounted for the higher corn and soybean yields in the drought years in these systems (Pimentel *et al* 2005).

water leaching through the soil or in runoff, or lost to the atmosphere by volatilization, may become an environmental hazard (FAO 1998). IPNM aims to supply balanced, efficient, yield-targeted, site- and soil-specific nutrient supply, with growing emphasis on monitoring and controlling the unwanted side effects of fertilization and the possible adverse consequences for soil health, crop diseases and pollution of water and air (Roy *et al*. 2006). This can be optimized under CA systems (Friedrich *et al.* 2009). Contamination of synthetic fertilizers in surface water may cause eutrophication, which may result in explosive growth of algae that, in turn, may cause disruptive changes to the biological equilibrium and impact on the population of aquatic organisms. Fertilizers may also cause nitrates pollution in groundwater, which may reduce supply of drinking water (Ongley 1996).

Climate change mitigation

Several studies investigated the role of plant nutrients in increasing greenhouse gases emission. In addition to carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are emitted by agriculture and strongly contribute to the greenhouse gas effect. Emission rates greatly vary according to climatic, soil and environmental conditions, and depending upon N input rates[50]. Evidence suggests that with CA, all GHGs are reduced because of reduced fossil fuel and fertilizer use, improved soil drainage which reduced CH_4 and N_2O emissions, and because of carbon sequestration (Kassam *et al*. 2009; Baig and Gamache 2009; Lindwall and Sonntag 2010).

Productivity/income

Complementing organic fertilizer with mineral fertilizer has been documented to increase and sustain crop productivity over the years[51]. Production of more straw may also mean more material for feed, building, soil conditioner and fuel. Evidence from different parts of the world shows that with CA, nutrient productivity (efficiency) is higher, and even less nutrients, particularly nitrogen, are needed to maintain a given output (Friedrich *et al.* 2009; Crabtree 2010).

With the incorporation of organic fertilizers and biofertilizers, and thanks to the effective utilization of both on-farm and off-farm wastes through recycling, farmers have greater access to plant nutrition (Roy *et al.* 2006). At the same time, allowing farmers

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50 According to Grant *et al.* (2006), even under favourable environmental and climatic conditions, N_2O emissions rose exponentially with rates of spring-applied urea once rates exceeded maximum economic values of 10 g N m^2 for irrigated wheat in southern Alberta. The study concluded that N_2O emissions increase little with N fertilizer at low application rates, but raise sharply at application rates greater than 10 g N m^2.

51 A study of rice farming under IPNM in Orissa, India, showed significant increase in grain yields with increasing level of green manure Gliricidia sepium with inorganic fertilizer P due to the overall improvement in soil properties such as water and nutrient retention (Kaleeswari and Subramanian 2004). In Madagascar, where bat and bird guano is mined for rice farming, farms using the guano maintain yield of 6 ton/ha after 2 years compared to farms using only chemical fertilizer (Buliga 2010).

to use synthetic fertilizer alongside organic fertilizers and biofertilizers may reduce decomposition problems of crop residue with low N concentration in soil with insufficient available N.

Challenges

Competing use of residues

Use of crop residues as a nutrient source and mulch cover may increase competition with other traditional uses such as for animal feed, especially during winter, building material, livestock bedding and fuel. Use of FYM as fertilizer may also increase competition with traditional use as fuel in some regions[52]. Use of green manure is also limited by competing use as feed. On the other hand, where CA systems have been introduced, it is possible to raise biomass output to a higher level and manage a more effective allocation balance across competing use of functional biomass (FAO 2011).

Awareness, education, and research and development

Knowledge gaps between scientists and farmers in IPNM, inadequate understanding and absence of dedicated national programmes, lack of knowledge on composting are some of the major challenges to IPNM adoption and scaling-up. However, a more serious challenge is the promotion of IPNM in CA systems. In some countries, lack of knowledge and awareness amongst the farmers on the agricultural causes of land degradation (particularly tillage and poor attention to soil health management) and on the proper use of synthetic fertilizer raise serious concern about the possible excessive use of fertilizers, which may lead to water and soil pollution. According to FAO (2006 and 2011), there is a need for:

- provisioning and packaging of appropriate and farmer-friendly extension materials on CA-based IPNM;
- establishment and promotion of Farmer Field Schools for community-based learning and development of “Soil Doctors”;
- elaboration and proper communication of monetary and environmental benefits of IPNM in CA systems;
- promotion of the adoption of participatory approaches by all stakeholders (NGOs, the private sector, industry, researchers, academics, etc.) to promoting CA-based IPNM, and
- increased technological research and development effort need to be paid to IPNM in CA.

52 In Pakistan, for example, land degradation in intensive cropping areas further exacerbated as the amount of FYM available for use as green manure for crops decreased, due in part to the fuel demand, and became insufficient to meet crop requirements (Solaiman and Ahmad 2006).

Policies and institutions

Adoption of IPNM is linked to an enabling socio-economic environment, including improved market for agricultural products and rural infrastructure, ensuring competition among dealers of agricultural inputs and outputs, and access to credit (Aune and Øygard 1998).

Government subsidies for fertilizers have resulted in increased fertilizer imports and use in a number of developing countries. Some of the existing economic and agricultural policies tend to favour soil degrading tillage and cropping practices such as monoculture of major cereal crops, and external chemical-based inputs agricultural production, at the expense of diversified farming systems and soil conserving crops and practices (Sherchan and Gauchan 2008). Principle of soil health and nutrient management and elaboration of environmental and economic benefits derived from sound IPNM need to be mainstreamed, while policy briefs and position papers to elaborate the substantive economic and environmental benefits of adopting IPNM in CA systems need to be prepared (FAO 2006 and 2011).

Examples in bioenergy feedstock production

Region: West Africa
Country: Burkina Faso
Crops/Feedstocks: Sorghum (*Sorghum bicolor*); maize (*Zea mays*)

Rebuilding soil fertility in sorghum and maize plantations in Burkina Faso through IPNM[53]

Lompo *et al.* (2000) analysed two different agro-ecosystems in Burkina Faso, near the villages of Thiougou and Kirsi. Thiougou is situated 130 km south of the capital Ouagadougou, near the Ghanaian border, while Kirsi is about 150 km north of the capital.

Climatic conditions in Thiougou are relatively favourable to agricultural production, with a reasonable amount of surface vegetation, which limits erosion. The climatic conditions in Kirsi are less favourable. Production systems are quite fragile and unstable, with low and uneven annual rainfall spread over time and space. About 15 percent of the area is taken up by bare patches called *zipellé*, i.e. crusted and infertile land resulting from heavy rainfall events following prolonged periods of drought.

At the time the study was conducted, a variety of crops were grown on the two sites, including millet, groundnuts, and cowpea; but sorghum and maize were predominant. Livestock were reared extensively, including donkeys, oxen, sheep, goats, chickens, guinea fowl, and pigs. Due to the low soil fertility and the adverse natural conditions, maize and sorghum productivity was low and sometimes farmers had to rely on off-farm income. The production systems were managed mainly by households farming with limited equipment, and applying only limited amounts of organic fertilizers. The amount of mineral fertilizer applied per hectare of cultivated land was low in both villages as most farmers could not afford mineral fertilizers.

After the 1974 drought, farmers started using dung collected from pens and rainy season enclosures[54], and developed new methods of composting. Composting became the most widely adopted method of producing organic fertilizers, with some farmers, particularly in Thiougou, adding rock phosphate to improve the quality. Following the doubling of mineral fertilizer prices in 1994, almost 50 percent of households in both villages composted manure, with each household producing on average 6.7 tons of organic fertilizer per year. Farmers put compost in their planting pits[55] and on some fields. They

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53 The information included in this section was either adapted or excerpted from: Lompo *et al.* (2000).

54 Dung is usually collected when the herd is kept in an enclosure, or deposited on fields when the animals graze there in the dry season. It is used on maize and sorghum crops in the household fields and in planting pits on the zipellé.

55 Planting pits are a traditional method of regenerating encrusted and denuded soils, mainly on impoverished soils to bring them back into cultivation. Prepared in the dry season, farmers dig holes 15-20 cm wide and 10-15 cm deep. Earth from the hole is mixed with organic matter and returned to the pit as seed beds where farmers may also add mineral fertilizer if needed.

also used a significant amount of *tampouré*, a mixture of household waste and earth. In Thiougou, up to 90 percent of the smallholders began to produce and apply compost to their fields. In Kirsi, farmers also started adding urea in their planting pits in order to improve soil moisture, increase fertilizer efficiency, and reduce damages to plants. Rock phosphate was virtually unavailable on the market in Kirsi, so farmers used wood ashes instead, which they found to be equally effective and more easily accessible.

Farmers in both Thiougou and Kirsi invested a considerable amount of effort in improving the quality of their soils, using soil and water conservation techniques, and using their knowledge to adopt and adapt techniques. The combined use of planting pits with stone lines and the production of compost supplemented by Burkina Phosphate, led to soil fertility and crop yield increase and produced relevant environmental benefits. In Kirsi, for instance, 739 hectares of *zipellé* were rehabilitated thanks to adoption of IPNM techniques.

Region: South Asia
Country: Bangladesh
Crop/Feedstock: Sugar cane (*Saccharum officinarum*)

IPNM in sugar-cane production in three agro-ecological zones in Bangladesh[56]

In Bangladesh, sugar cane is cultivated over 172 000 ha and, under traditional agriculture, mineral fertilizer is added at an average rate of 85 kg/ha of N, 69 kg/ha of P, and 72 kg/ha of K (FAO FertiStat 1998). On average, Bangladesh sugar-cane plantations yield around 41 t/ha of cane.

In order to improve productivity and soil physic-chemical properties, cane yield and juice quality, the Bangladesh Sugarcane Research Institute, in the 1999-2000 growing season, performed field experiments in three different agro-ecological zones: Ishurdi in the High Ganges River Flood Plain, Thakurgaon in the Old Himalayan Piedmont Plain, and Sreepur in the Madhupur Tract.

The soil in all locations had low content of naturally occurring nutrients for sugar-cane cultivation and farmers applied mineral fertilizers at the two rates suggested by the 1997 Fertilizer Recommendation Guide of Bangladesh (FRG'97) in order to achieve Moderate Yield = 80t/ha of cane (MYG) or High Yield = 100t/ha of cane (HYG).

Two sugar-cane varieties were used for the field experiments, *lsd 26* and the local *Misrimala*. Six different treatments were tested to evaluate which offered the best performances. Mineral fertilizers (N, P, K, S, Mg, Zn) were applied to achieve MYG or HYG; organic fertilization included: cowdung or press mud (a by-product of sugar extraction), the green manure crop *Sesbania bispinosa* (GM); and mustard oil cake (MOC).

56 The information included in this section was either adapted or excerpted from: Bokhtiar *et al.* (2002).

The experimental treatments and fertilization rates were as follows:

T_0 = control – no fertilizer
T_1 = recommended fertilizer amount for MYG (as per FRG'97)
T_2 = 12.5 t/ha of cowdung/press mud + T_1
T_3 = recommended fertilizer amount for HYG (as per FRG'97)
T_4 = 12.5 t/ha of cowdung/press mud + T_3
T_5 = GM (2.8 tons dry matter per hectare) + T_3
T_6 = 500 kg/ha of MOC + T_3

The lowest cane yield was recorded in T_0 fields in all locations (67.3 t/ha; 55.2 t/ha; and 55.0 t/ha). The highest cane yield was recorded in T_4 treatments in all locations (127.5 t/ha; 119.6 t/ha; and 124,8 t/ha). Data on yields, number of tillers, and sugar content were significantly higher in fields that received application of fertilizer through Integrated Plant Nutrient Management, with T_4 showing the best performance (89.3 percent yield increase over T_0). Cowdung/press mud alone led to an 16–20 percent increase in cane yield over the rates of N, P, K, S, Zn, and Mg recommended by the FRG'97 for HYG.

All treatments incorporating organic fertilizers (T_2, T_4, T_5, T_6) produced higher yields than fields fertilized only with recommended mineral fertilizer rates (T_1 and T_3) in all agro-ecological zones.

The Bangladesh Sugarcane Research Institute, following this and similar studies, suggested to farmers the most cost-effective fertilization plan for sugar-cane farms: an IPNM system using 12.5 t/ha of cowdung or press mud with mineral fertilizer at the rate for HYG in order to maximize production, cane quality and sugar content, and achieve optimal economic benefits.

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3.7 NO- OR MINIMUM TILLAGE

Maizura Ismail

Key features

Land tillage is used in agriculture to break and mix the soil in order to: eliminate weeds; loosen and aerate soil, and incorporate organic matter into lower soil layers. However, over time, tilling affects soil negatively by exposing it to erosion and accelerating decomposition of organic carbon, destroying its structure, contributing to soil compaction and harming soil life.

Minimum and especially no- (or zero) tillage may help reduce erosion by maintaining the soil structure. Furthermore, the resulting increase in the earthworm population may improve soil fertility, aeration, and water filtration, as well as increase plant nutrient uptake. This may lead to improved cropping performance, as well as greater resistance to various kinds of disturbances.

In place of tilling, weeds can be managed through: crop rotation; intercropping; the establishment of forage crops; allelopathic suppression; green manuring, and responsible use of herbicides.

Different agricultural management approaches promote different degrees of tillage based on their principles and associated practices in relation to weed management and soil fertilization. As an example, while Conservation agriculture[57] promotes no-tillage and allows for the use of herbicides, Organic Agriculture[58] allows for minimum tillage during soil preparation, while the use of herbicides is not allowed.

Potential benefits

Soil quality

Tillage affects soil quality in many ways, causing many forms of soil degradation such as: loss of soil depth; decline in soil organic matter; compaction of the soil causing reduced porosity and reduced soil moisture at critical times (Shaxton and Barber 2003). Excessive tillage may also kill soil life, particularly earthworms, which are vital for organic matter and soil aggregate formation.

While tillage creates a good seedbed in the short term, it may also create a good seedbed for the weeds. Ploughing may: propagate weeds by bringing to the soil surface weed seeds buried during ploughing in the previous seasons, and in the case of weeds that propagate through sprouts or roots, spreading pieces of weed sprout or root cut and mixed by the ploughing implements from one field to another (Friedrich 2005).

57 For a description of *Conservation agriculture*, see section 1.1.
58 For a description of *Organic Agriculture*, see section 1.3.

Tillage mixes the different soil layers and exposes the soil to mediums such as wind and rain. Once exposed, soil becomes vulnerable to erosion. Soil particles that are held together in aggregates, for example, may break when hit by rain droplets. Loose finer soil particles may settle in and block surface pores, causing soil surface to seal over; a process that is known as crusting. With the formation of surface crust, the soil water infiltration is reduced and rain is more likely to run off than to flow into the soil (USDA 2001; Wall *et al*. 1987).

Changes in the water, aeration and temperature conditions of the exposed soil also bring about faster decomposition of the soil organic matter (USDA 1996). Soil aggregates with more organic matter are larger, stronger, and more stable to better resist compaction that could be caused by tillage operation and equipment (Daum 1996). In addition to changing the amount of soil organic matter, tillage practices affect the depth of soil organic matter (Lewandowski 2003).

The wheels of tilling equipment and tillage tools may create compaction of the soil surface, reducing the amount of water infiltration and increasing erosion and surface run-off. Soil compaction destroys the soil structure that provides desirable pore space for storage and movement of air and water. Oxygen in these pores is vital for seed germination and root development, while water is important for plant nutrient uptake (Daum 1996). According to Daum, although some tillage equipment such as moldboard ploughs may aerate soil and increase percolation at the surface, it creates a compacted layer, known as ploughpan or hard pan, just below tillage depth. Weed species are also more tolerant and competitive on compacted soil with bad drainage, thus undermining crop growth.

Tillage may also increase erosion by removing crop residues from the previous season, exposing soil to erosion medium and harming the soil life vital for formation of soil aggregates and structure.

Water availability and quality

As mentioned above, under conventional agriculture, compaction and crusting may develop due to excessive tillage. This condition may degrade soil quality by reducing infiltration rates and water-holding capacities, which in turn may increase the amount of runoff. Erosion and runoff from agricultural land may result not only in reduced crop production, but also lower quality surface water, and damages in drainage and irrigation networks (Wall *et al*. 1987).

Soil also needs to capture the rainwater and store as much as possible in order to minimize the impact of drought. However, tillage practices may increase loss of moisture in the exposed soil. In addition, tillage practices may remove soil cover that increase soil capacity to store moisture, thus increasing soil's vulnerability to drought (Sullivan 2002; Bot and Benites 2005). Improved water filtration and erosion control may improve the quality of surface water and enhance groundwater resources.

Climate change mitigation

Under no- or minimum tillage, fossil fuel consumption for farming activities and machinery, especially those linked to land preparation and planting, may be lower than under conventional agriculture. In addition, under no- or minimum tillage, more carbon can be sequestered in soils.

Moraes Sá *et al.* (2008) compared conventional tillage (CT) and zero-tillage (ZT) systems, and the soil organic carbon stock and balance in four tropical sites – three in the Cerrado region of Brazil, and one in the highlands of central Madagascar. The ZT cropping systems in the sites were organized in random plots with three replicates and compared with CT under monoculture. The mean carbon sequestration rate for ZT was 1.66 Mg ha^{-1} yr^{-1} (from 0.59 to 2.60 Mg ha^{-1} yr^{-1}) whereas in different CT systems there were emissions of C ranging from 0.54 to 1.25 Mg ha^{-1} yr^{-1}.

Productivity/income

Soil tilling is one of the most energy consuming farming operations. By minimizing tillage, farmers may be able to reduce production costs, particularly during peak periods such as land preparation and planting, as well as reduce investment and maintenance costs of tilling machinery in the long term.

Challenges

Pest issues

Some pest populations are controlled through tillage. For example, in the first years of conversion to no- or minimum tillage, weed species tend to proliferate, thus increasing the dependence on herbicides (Thiombiano and Meshack 2009). However, the use of herbicides tends to decrease once the field achieves equilibrium or other, non-chemical weed control practices are introduced (mulch, crop rotations).

Awareness, education, and research and development

For over 2 000 years, farmers have believed that they must plough the land to get a good crop (Friedrich *et al.* 2008). Farmers also traditionally remove soil cover and keep the farms “clean” because “it is well accepted that a clean farm is synonymous with hard work and is the opposite of laziness” (Thiombiano and Meshack 2009). Reversing the mindset of farmers, landowners and investors would take time, education, research and effective communication on benefits and cost saving of no- or minimum tillage agriculture. The level of awareness at both institutional and community levels, including policy-makers, extension workers and other actors such as NGOs and private sector, needs to be increased, in addition to further research activities and database development.

Examples in bioenergy feedstock production

Region: South America
Country: Brazil
Crop/Feedstock: Soybean (*Glycine max*); maize (*Zea mays*)

No-tillage by soy and maize smallholders as part of a watershed management strategy in Rio do Campo, Brazil[59]

The adoption of no- or minimum tillage in Brazil can play an important role in improving land and water management of tropical soils, which are prone to soil and water losses under conventional land preparation methods. Widespread adoption of no- or minimum tillage in Brazil is associated with strong participation by farmers in the development and implementation of the system, and as well as to policies and incentives to improve the environmental land and water quality at the watershed level.

In the southern regions of Brazil and in the Cerrado, this system has contributed to enhancing the productivity and sustainability of annual cropping systems, on both large and small farming units, especially among producers of soybean (*Glycine max*) and maize (*Zea mays*). In particular, smallholders have benefited through reduced labour requirements and increased profits.

No- or minimum tillage has a number of advantages compared to conventional agriculture, such as reduced soil erosion and increased soil carbon sequestration. However, at least in the short term, more herbicides and pesticides may be required, with potential risks in terms of water contamination.

These issues and potential trade-offs were considered and addressed in an integrated manner in the context of the Rio do Campo watershed management in Brazil. No-tillage was promoted within the watershed, in combination with a number of other strategies to improve the help of the watershed, including: the construction of a separate water supply for chemical sprayers, the implementation of biological control programmes to reduce pesticide use, and the development of riparian zones to counteract contamination problems.

The management of the Rio do Campo watershed has been recognized as a positive model in Brazil, thanks to the following achievements:

- a 7 percent increase in the catchment area's forested areas;
- the expansion of the area under agriculture (16 percent for soybeans and 63 percent for maize);
- the expansion of no-tillage agriculture in the watershed;
- installation of farm demonstration units to continually update producers and extension personnel on new technologies;

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59 The information included in this section was either adapted or excerpted from: Bossio *et al.* (2008).

- a 12 percent increase in water productivity over a 10 year period;
- reduced flood risk;
- a steady and reliable water supply to the city of Campo Mourão, Paraná, and
- reduced water turbidity, from 286 to 33 NTU over 12 years.

The Rio do Campo case illustrates the positive linkages that can be developed between farmers, local institutions and the private sector to improve public health, control soil erosion (e.g. through no-tillage) and reduce water pollution at the watershed level.

Although adequate policies and economic incentives accelerated the adoption of no-till systems at the landscape level, the system itself was initially tested and implemented by farmers almost independently of governmental initiatives. The greatest asset in the process of change was the local capacity and knowledge of local people.

Region: East Africa
Country: Mauritius
Crop/Feedstock: Maize (*Zea mays*)

Minimum tillage in maize slope cultivation in Rodrigues, Mauritius[60]

Minimum tillage was tested by the maize (*Zea mays*) producers of Rodriguez, Mauritius, as a possible solution to the high labour costs for manual land preparation on their slope cultivations, where the use of machinery is not possible.

Before exploring minimum tillage, maize planters used to plough their fields with garden forks, which is a labour intensive and time consuming activity. The maize slope cultivation was also causing erosion as ploughing used to be carried out at the beginning of the rainy season after the soil had been softened by the first rain.

A multistakeholder initiative was established in order to address these issues and especially the high labour requirements of maize slope cultivation. Farmers Participatory Research (FPR) was implemented to ensure the active participation of farmers throughout the process and awareness was raised among them on the use of herbicides as an alternative to tillage to control weeds. During the stakeholder meetings that were held between farmers, researchers, extensionists, community leaders, NGOs, and policy-makers to discuss the focus of the initiative, minimum tillage was identified as the most important issue, followed by the development of drought-tolerant varieties (droughts are one of the biggest threats to the Mauritian maize industry).

Under this initiative, a number of trials were carried out between 1999 and 2002. Four different management systems (of which three with different variations of no- or minimum tillage) were tested in ten trials, namely: one control plot consisting of the normal ploughing with garden forks; one plot with minimum tillage practices consisting

60 The information included in this section was either adapted or excerpted from: Govinden *et al.* (2003).

of ploughing narrow strips only; one plot with no-tillage practices consisting of clearing weeds with a hoe, and another no-tillage plot consisting of herbicide spraying.

During a project evaluation workshop in 2001, it was found that erosion was reduced under these systems, and that weeds had not increased. With regard to the key issue of labour requirements, all three no- or minimum tillage systems were found to be effective in reducing these requirements. In particular, the no-tillage plot with herbicide spraying required only 21 percent of the labour required by the control plot, leading to a saving of MUR 5450 (US$187,10) per hectare, after considering the cost of the herbicide (MUR 700, equal to US$24,03 per hectare). The plot with minimum tillage and ploughing of narrow strips only led to a similar saving (MUR 5 410, equal to US$185,70) compared to the control plot. Even though more labour was required in this case, no costs had to be borne for herbicides.

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3.8 POLLINATION MANAGEMENT

Hien Ngo, Marco Colangeli[61], Rainer Krell

Key features

Pollination is the transfer of pollen grains between the reproductive parts of the flower (i.e. anthers and stigma) to produce fruits or seeds (Shukla *et al.* 1998). Wind, water and animals are all vectors for pollination. Bees are the most important pollinator group of these animal pollinators (Free 1993). In a recent review, it was found that approximately 85 percent of the 352 000 flowering plant species worldwide need animal pollination for successful reproduction (Paton *et al.* 2008; Ollerton *et al.* 2011). In terms of agriculture, approximately two-thirds of our crop species depend on animal pollination for fruit production.

Examples of bioenergy crops that benefit from animal pollination are: oilseed rape, sunflower, oil palm, coconut, soybean, groundnut and probably also Jatropha (Klein *et al.* 2007; Vaknin 2010; Wainer *et al.* 2005).

In a recent assessment, the global economic contribution of animal pollination services was estimated at €153 billion/yr, representing 9.5 percent of the value of the world agricultural production used for human food in 2005 (Gallai *et al.* 2009). The crops that most depend on pollination services are high-value crops, averaging values of €761/tonne compared to €151/tonne for those crops that do not depend on animal pollination. These figures do not include the contribution of pollinators to increased crop seed production, nor to pasture and forage crops. Furthermore, these figures do not include the contribution provided by pollinators to maintaining the structure and functioning of wild ecosystems – as these remain uncalculated. Vegetables and fruits are the types of crops that are most reliant on pollinator services, followed by edible oil crops.

Trends in demands for pollination services

Unfortunately, natural pollinators are declining worldwide (Williams 1982; Biesmeijer *et al.* 2006; Fitzpatrick *et al.* 2007; FAO 2008a), due to habitat degradation, fragmentation and destruction (Rathcke and Jules 1993; Aizen and Feinsinger 1994; Cunningham 2000), pathogens, and the misuse of chemical herbicides and pesticides (Kevan 1975; Johansen 1977; Kremen *et al.* 2002; Brown and Paxton 2009).

The global population of managed honey bee hives has increased by 45 percent during the last half century. Instead, the fraction of agriculture that depends on animal pollination has grown by more than 300 percent during the same period (Aizen *et al.* 2009). The decline of natural pollinator populations and the relatively slow increase in managed pollinators is likely to soon create a deficit that will impact productivity. Such an impact is expected to be larger in the developing world (Aizen and Harder 2009), in part because

61 Marco Colangeli is the author of the examples.

of current much higher dependence on natural pollinator services and relatively lower numbers of managed bee colonies, and also often significant habitat destruction.

Pollination Management

Pollination Management is a practice that involves increasing crop yield and quality through adequate pollination, and ideally, at the same time, preserving pollinator biodiversity. Incorporating pollinator conservation into a targeted production and landscape management scheme can result not only in higher yields of selected bioenergy crops, but also of many food crops (CGRFA 2007).

Good management for pollination through managed honey bees is very different to management with local natural pollinator populations. The former is relying mostly on the mobility and perennial character of managed honey bee colonies and their capacity to store large quantities of food in short periods of time, e.g. from large areas of monocultures. The latter is largely focused on the management of agro- and natural biodiversity at farm and landscape levels and reduced agrochemical use. In addition, semi-social and solitary bee populations very much depend on the synchronicity of their life cycles with those of available food sources, due to their shorter life spans during different periods of the year. This also means that out of synchronicity crop cycles will not benefit from, nor contribute to, these natural pollinator populations.

Considering the trends discussed, good pollination management with honey bees and natural pollinators will increasingly so become a significant element of comprehensive food security and livelihood/prosperity programmes[62].

Basic agronomic practices

Pollinator food sources (pollen and nectar in accessible flower species) need to be present in abundance at short distances from colony and nesting sites at the proper time of the bees' life cycles. Most bee species have relatively short adult life spans and at different times of the year. Specifically managed field margins, vegetative buffer strips and/or permanent hedges (Lagerlof *et al.* 1992; Steffan-Dewenter and Tscharntke 1999; Steffan-Dewenter *et al.* 2002), intercropping, multistory agroforestry, crop rotation coordinated between neighbours, nectariferous crop varieties flowering in periods synchronized with adult bee foraging periods (Roubik,1995) contribute to higher pollinator abundance and diversity, i.e. better pollination services to crops. Intercropping (of different flowering species) influences foraging patterns of pollinators (Osborne *et al.* 1999) and increases cross-pollination which improves not only yields (Williams *et al.* 1986 on oil seed rape) but also plant health (Hajjar *et al.* 2008) which in turn reduces the need for pesticides.

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62 FAO has assembled an initial survey of good pollination practices, profiling nine pollinator-dependent cropping systems from around the world: http://www.internationalpollinatorsinitiative.org. The profiles provide detailed information on the impacts of specific practices on pollination services and the research or traditional systems supporting these practices, their socio-economic aspects, environmental costs, benefits and replicability. Other publications (Roubik 1995, FAO 2008b; GEF/UNEP/FAO 2009; Dicks al.*et al*. 2010) outline the main features, agronomic practices, and policy-based approaches to improve pollinator habitats.

Some bee species nest in hollowed stems and twigs (e.g. leaf cutter bees), a few nest on the ground (some bumble bees), yet most nest in the ground to depths of less than 30 cm. Thus appropriate areas of the farm need to be left without cultivation or with no tillage[63]. Tillage beyond 15 cm of depth will damage bee nests (Roulston and Goodell 2011). The same hedge rows that provide additional floral resources throughout the season also provide potential nesting sites (Kearns *et al.* 1998; Goulson *et al.* 2008).

Most social bees in South and Central America require cavities in live trees for nesting or branches to suspend their nests; such trees need to be conserved in sufficiently large forest patches near pollination requiring areas.

On a landscape scale, but also at farm scale, spatial continuity (distance to food) is as important as habitat diversity (type and abundance of food) and heterogeneity in space and time (e.g. distance between nest and flowers and flowering at different times of the year) to provide abundant and divers food sources and nesting sites at the most appropriate times (Osborne *et al.* 1991). Natural and semi-natural habitats may have to be created or be conserved where still available (far more economical). Conservation efforts at landscape scales are easier in collaboration between many farmers, foresters and conservation agencies. For example, a large forest fragment, or a large natural land strip and significant connections between habitats are easier to maintain in an area of 20 or 100 collaborating farms than by providing all diversity on each farm.

The most important agronomic practice for good pollination management next to providing food and nesting site diversity, is the elimination or at least reduction of any toxic agents, i.e. agrochemicals. Pesticides and insecticides also directly poison non-target insects such as pollinators (Johansen 1977). Integrated Plant Nutrient Management[64] (IPNM) and Integrated Pest Management[65] (IPM) are only first steps in a direction that eventually should lead to complete biological control of pests and soil fertility. But also herbicide and fertilizer use, even on crops not depending on animal pollination, have a negative impact on bee abundance and diversity, particularly with small bees (Corbet *et al.* 1991; Kovacs-Hostyanszki *et al.* 2011) by reducing plant diversity and altering the size and number of on-farm flowers, i.e. by reducing nest and food resources. In contrast, landscape heterogeneity and biodiversity protects ecosystem services such as predation of pestiferous insects and crop pollination (Thies and Tscharntke 1999; Tscharntke *et al.* 2005).

Switching to or improving farming practices that reduce, eliminate or do not require any use of chemicals in agricultural landscapes (such IPM, organic agriculture, biodynamic or energy farming practices, rotation, field edges and hedges, agroforestry) will benefit existing and future pollinators, and will also have a number of positive environmental effects, e.g. in terms of water quality, soil quality, biodiversity, reduced GHG emissions, and predation of pestiferous insects.

Adding to this management practices for increased agro- and natural biodiversity and landscape heterogeneity will further increase those benefits (Thies and Tscharntke

63 For a description of *No- or Minimum Tillage*, see section 3.7.
64 For a description of *Integrated Plant Nutrient Management (IPNM)*, see section 3.6.
65 For a description of *Integrated Pest Management (IPM)*, see section 3.5.

1999; Kremen *et al.* 2002; Tscharntke *et al.* 2005). Especially since conservation of native bee populations requires very little capital investment from the farmer, while potentially increasing yields. Also the introduction of managed commercial bee colonies, difficult in many rural areas, becomes unnecessary unless the habitat for native pollinators has been too severely degraded or very large monocrop areas are planted with pollinator requiring crops (e.g. potential risk of large jatropha plantations).

In regions where access to agrochemicals is limited or where their use leads to indebtedness of farmers, diversified biological control based farming practices create winning conditions for all, i.e. better: farmers' health and incomes, pollinator survival and diversity, environmental services of all kinds, government budgets (less compensation and damage repair) and services (more prevention). In intensive agrochemical use zones a transition to no agrochemicals is likely to take longer, but is also to increase in cost the more it is delayed.

If careful land use planning and wildflower conservation goes along with bioenergy development, the resulting improved pollination services can benefit all crops (including those used for food and feed) and thus make another valuable contribution to food security and better livelihoods.

With so many diverse benefits, government investment in better pollination management is highly cost effective and will reduce negative impacts from bioenergy development whether with pollinator dependent or independent energy crops.

Potential benefits

Biodiversity

Better pollination can contribute to the preservation of ecosystem integrity (Costanza *et al.* 1997; Allen-Wardell *et al.* 1998).

Biodiversity conservation, that is necessary for more stable and abundant pollinator populations and thus implicitly for increased crop yields, contributes also to fulfilling other global environmental and social commitments (CBD, UNFCCC, UNCCD[66], PGRFA[67]), and can contribute through income diversification and stabilization to reduced rural poverty (MDG 1[68]).

Agrobiodiversity

Self-pollination, or inbreeding can reduce the quality of the resulting fruit and the overall productiveness of many plants (Sleper and Poehlman 2006). In addition to improving fruit

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66 The United Nations Convention on Biodiversity (CBD), the UN Framework Convention on Climate Change (UNFCCC), and the UN Convention to Combat Desertification (UNCCD), known as the Rio Conventions, are the three main international legally-binding agreements for sustainable development. They represent the legal outcome of the 1992 United Nations Conference on Environment and Development (UNCED).

67 PGRFA – International Treaty on Plant Genetic Resources for Food and Agriculture.

68 MDG 1 – Millennium Development Goal 1: Eradicate extreme poverty and hunger.

quality and yield, cross-pollination has been attributed to reducing the spread of diseases and pests (Hajjar *et al. 20*08). In the case of oil-seed rape (*Brassica napus* L.), a bioenergy crop, cross-pollination results in higher yields than when crops were self-fertilized (Williams *et al.* 1986). The foraging pattern of bees can depend on the spatial and temporal dynamics of available resources (Osborne and Williams, 2001) and some species forage by restricting their floral visits to specific plant species (Chittka *et al.* 1999). Therefore, to encourage bees and other pollinators to out-cross targeted crops (i.e. bioenergy crops) and improve yields, there should be a high diversity of intercrop species in farming schemes.

Productivity/income

Better pollination can increase or help maintain the stability of crop yields (Costanza *et al.* 1997; Allen-Wardell *et al.* 1998).

Indirect benefits include the resulting increase in income with all its social, economic and agricultural implications. Increased yields from pollination have also been linked to less expansion in crop areas (Garibaldi *et al.* 2009) and thus could reduce some of the indirect land use change impacts from some energy crop development.

The same improved agronomic and conservation practices that are beneficial for insect pollinators are also known to contribute to higher crop yields and income resilience against climatic and economic variability in most crops, including in bioenergy crops which yield independent of animal pollinators.

Wainer *et al.* (2005) demonstrated that in experiments with sunflower (*Helianthus annuus*) seed production increased almost 80 percent in the presence of pollinators compared to those without (Wainer *et al.* 2005). In the case of soybeans, there was almost a 40 percent increase in both the number of pods and average pod weight of pollinated soybean compared to those without pollination (Juliano 1976). Finally, in a study of legumes in Kenya, pollinator abundance and visitation was associated with an increase of yields anywhere from 25-99 percent (GEF/UNEP/FAO 2010).

Challenges

Competition between crops and wild species

It is well known that many biofuel crops are quite dependent upon pollinators, including rapeseed, canola, sunflower, oil palm, and cottonseed. What is less well known is that biodiversity is also threatened by massive flowering crop plants such as oilseed rape, which in some cases are more attractive to bees than wild flowers. In a large field of oilseed rape, a crop often planted for biofuel production, a bee can visit 2 000 flowers in an hour, simple because the flowers grow so densely. In neighbouring fields of wild plants, there will be fewer plants that are more spread out in comparison, therefore pollination services may be diverted away from wild flowers. Careful land planning and wildflower conservation is needed to avoid the decline of wild flowers in agricultural areas planted with biofuel crops (Holzschuh *et al.* 2011).

Awareness, education, and research and development

Conceptually the biggest challenge is to implement pollinator conservation with limited knowledge of pollinator (life cycle) requirements in terms of habitat, food and nest sites and of exact economic impact of such measures. However, practically, good pollination management (FAO 2008b) through the implementation of known good agricultural and conservation practices favourable to pollinator populations is possible, feasible and beneficial to farms individually and to the national economy as a whole (Znaor *et al.* 2005; Zanoli *et al.* 2007).

Pollinators thrive in response to two simple measures: reducing pesticide use, and encouraging floral diversity on-farm or near farms.

Pollination Management practices can thus be incorporated into any existing Integrated Pest Management (IPM) and soil fertility practices and programmes.

Favourable agricultural and conservation practices can be implemented now without detailed knowledge of all pollinator requirements through environment-friendly agricultural practices with good Pollination Management (FAO 2008b) and sensitive conservation practices. Tools for evaluation of such practices together with farmers, for example in farmer field schools, have been developed (FAO/IFAD 2010).

Conserving or promoting beneficial insects, such as pollinators, has been overlooked as a factor in improving or even maintaining farming practices. Farmer field school type research and learning experiences are among the fastest ways of learning and introducing new practices to farmers (FAO 2004).

Even though beneficial insect management has not yet played a major role in production system research, with perhaps the exception of biological pest control, systematic work on interaction of conservation practices and production methods is lacking in attention to pollinators on all levels from taxonomy to life history and plant-insect interactions.

Executing proper risk assessment across full product and farm production cycles to estimate costs of alternatives and establish baselines for regular evaluations that lead to better political and technical choices and timing (ALARM 2009; FAO 2009).

Policies and institutions

A key challenge is the creation of a political and economic environment that provides appropriate incentives for good pollination practices.

All institutions involved in agriculture and conservation research, training and policies incorporate tailored programmes into their current activities involving pollinator conservation at national, regional and local levels. These programmes are best if specific and relevant to their respective regions.

Joint efforts between civil society organizations, farmers' organizations and government agencies assess pollinator populations in targeted systems. Carefully gathered data will allow then to subsequently monitor any change of these populations and implement conservation strategies.

Supportive policies are implemented with coordination, resources and collaboration across several institutions from agriculture, environment, trade, research and education, to energy, which in the end is not so different from what already is being practised or is necessary for sustainable bioenergy production in general.

Government involvement in disseminating information regarding pollinator importance in combination with possible incentives for farmers is critical for joint efforts towards pollinator conservation.

Examples in bioenergy feedstock production

Region: South East Asia
Country: Malaysia
Crop/Feedstock: Oil palm (*Elaeis guineensis*)

Increased yields in oil palm plantations through pollination management in Malaysia[69]

Although native to west Africa, the oil palm's high commercial value has led to its introduction in many regions of the world. Malaysia was the first country (1917) to embark on large scale planting and processing of oil palm (*Elaeis guineensis*) but oil palm plantations of southeast Asia failed to produce fruit until the 1980s. The necessary cross fertilization was generally believed to be via wind pollination. Failure was blamed on the heavy rains in the region and to make the plantations viable, hundreds of local people were employed to pollinate the palms by hand. This costly process did increase yields, which remained significantly lower than in Africa though.

Research on pollination biology of oil palm in its native west Africa revealed the relationship between the pollinating weevils, *Elaeidobius spp*., and the male and female inflorescences of the palms. Following intensive screening tests and after obtaining clearance to import the beetles into Malaysia, a captive breeding programme began. Two releases of the weevil (*E. kamerunicus*) were made in 1981 on two oil palm estates in the country. Within a year of the release of *E. kamerunicus* into Malaysia, the weevils had spread throughout the entire Peninsula and were thriving in all the plantations, with impressive increases in yields. It was estimated that Malaysian palm oil output in 1982 alone increased by 400 000 tonnes and palm kernels by 300 000 tonnes, with a total value of US$370 million. Within five years, pollination deficits fell virtually to zero, and fruit production rose from 13 to 23 million tons. Subsequently, the weevil was successfully introduced to Sabah, Papua New Guinea, the Solomon Islands, Sumatra and Thailand.

Thanks to this small west African weevil, Indonesia and Malaysia became the world's leading producers of palm oil. In addition, a co-benefit was that the weevil success encouraged plantation owners to look into natural biological control to manage the palm's insect pests, so that chemical treatments, harmful to the pollinating weevil and so likely to depress palm fruit yields, could be avoided.

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69 The information included in this section was either adapted or excerpted from: Smith *et al.* (2011).

Region: South America
Country: Brazil
Crop/Feedstock: Canola (*Brassica napus*)

Honey bee contribution to canola production in Southern Brazil[70]

Canola (*Brassica napus*) belongs to the family *Brassicaceae* and is cultivated in southern Brazil for both edible oil and biodiesel production.

A study was conducted to evaluate the development of *B. napus* cultivar *Hyola 432* from pre-blooming to pod harvesting, in a field of 13 ha in the Três de Maio, Rio Grande do Sul State, Brazil. There were two apiaries in the region, one with 20 and the other one with 18 colonies, at about 0.2 km and 1 km from the crop's boundaries; potential wild bee areas were very small, since they were reduced due to the presence of native fragments throughout the region. Data gathering was performed between July and October 2007; temperature, precipitation and relative humidity were respectively 14.6 °C, 2.8 mm and 74.6 percent.

Apis mellifera, as well as other pollinators, were counted throughout the blooming period in order to determine their abundance. This procedure was performed by three 30-minute periods within the day, twice a week, at temperatures over 12 °C, totaling 27 h of records. Records were made over a transect of 300 m in length and 1 m wide. Insect *Apis mellifera* was identified at the species level, whereas other insects were indentified at the order level.

Concerning the pollination efficiency test, seed productivity was compared between four experiments:

- autogamy, covering the inflorescences during the entire anthesis period;
- control, allowing spontaneous insect access;
- geitonogamy - manual pollination between flowers of the same plant;
- xenogamy - manual pollination between flowers from different plants.

To evaluate the autogamy, geitonogamy and xenogamy treatments, the plants were protected with wooden frames.

During the blooming process of canola plants, 8 624 insects were recorded on flowers in the 27 hours transect survey. Insects detected included species of Hymenoptera, especially *A. mellifera* (99.83 percent), Diptera, Lepidoptera and Coleoptera. The attractiveness of *B. napus* flowers to *A. mellifera* was found to be associated with the availability of food resources, namely nectar and pollen. Moreover, intense visitation of bees to canola flowers is due to the fact that the crop blooms in winter. During this season, food resources from wild flowers are scarce because most native plants are not in bloom. The abundance of food resources offered by *B. napus* increased flower attractiveness and, consequently, bee pollination, resulting in higher seed productivity.

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70 The information included in this section was either adapted or excerpted from: De Souza Rosa *et al.* (2011).

The result of the aforementioned study highlights the importance of *A. mellifera* for canola pollination. *A. mellifera* was found to be the most frequent pollinator of *B. napus* flowers. In treatment without bees (autogamy), the average number of pods per plant was 128, while in control (spontaneous insect access), this value was equal to 189. The total average number of seeds in plants pollinated through autogamy was 1867 (per plant), whereas, when insects were free to visit canola flowers, each plant produced on average 3 449 seeds. In other words, the presence of pollinators increased productivity of canola seeds by 184 percent if compared to autogamic pollination.

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3.9 PRECISION AGRICULTURE

Marco Colangeli

Key features

In "conventional" agriculture, farmers tend to practise the same crop management throughout their fields; the selection of crop varieties, land preparation, fertilization and the application of pesticides and herbicides are conducted without considering crop variability between and within fields on the same farm. Therefore, optimum growth and development are not achieved; furthermore, inputs and labour may be used inefficiently.

Precision Agriculture (PA) is based on the recognition of spatial and temporal variability in crop production, which can be quite significant in large farms. PA takes this variability into account in farm management, with the aim of increasing input efficiency and productivity, and of reducing environmental risks. Since the 1980s, a range of information technologies have become available, providing farmers with new tools and approaches to understand the nature and extent of crop variability, and enabling them to develop the most appropriate management strategy for a specific location, increasing the efficiency of input application (Tran and Nguyen 2006).

Precision agriculture integrates numerous technologies that enable the collection, interpretation and analysis of data to support a range of management decisions (Batte and VanBuren 1999). PA makes use, for instance, of Global Positioning System (GPS) and optical sensors and, to a lesser extent, Geographic Information System (GIS) and remote sensing.

GPS allows users to identify latitude, longitude and elevation with an accuracy of between 100 m and 0.01 m (Lang 1992). Thanks to this technology, farmers can determine the exact locations of soil types, monitor pest occurrence and weed invasions, and locate water holes, boundaries and obstructions. GPS data is then combined with data from field measurements (e.g. yield monitors and soil sampling) and transferred to the machinery applying the inputs (e.g. seeding, fertilizing, and spraying). Direct application of GPS systems on machines helps to control these machines according to the data collected in the system and even to autocontrol the movement, for example in controlled traffic systems or with autosteer options for farm machinery.

Direct sensors, such as green seekers and weed seekers, can be used without GPS data as well to optically control directly the machines. For example, a green seeker sensor on the fertilizer spreader can adjust the fertilizer rates according to the specific crop needs, while small-scale farmers can use a simple colour scheme to compare with the colour of their crop leaves and determine the respective fertilizer rate. With regard to irrigation, specific soil moisture sensors, or more accurate plant turgor sensors, can automatically control the irrigation equipment to provide the exact amount of water required at the right time.

GIS can be used to combine the data collected with field sensors (e.g. soil sampling, yield monitors, and machinery movement) with GPS data, in order to understand the relationships between the various elements affecting a crop on a specific site. GIS can also be used to guide equipment in order to avoid overlap or ensure correct spacing, and to record application parameters.

Various other technologies are used as well in PA to measure humidity, vegetation, temperature, vapour, etc.

Through the application of the aforementioned technologies, farmers can systematically collect and storage key data and information about their farms. This helps farmers improve the management of their production systems over time (Tran and Nguyen 2006).

Certain PA technologies are quite capital-intensive and this limits their widespread adoption, especially in developing countries. However, the advantages of PA in terms of crop production efficiency should incentivise its further diffusion in the future, in both developed and developing countries, including in the production of key bioenergy feedstocks.

Potential benefits

Soil quality

In a study of PA in developed countries, Segarra (2002) highlighted the following advantages for farmers:

- Better decision-making in agricultural management: agricultural machinery, equipment and tools help farmers acquire accurate information, which is processed and analysed for appropriate decision-making, e.g. in land preparation, seeding, in the application of fertilizers, pesticides and herbicides, and in irrigation and drainage.
- Reduced environmental impact: the timely application of optimal quantities of agrochemicals avoids excessive residues in soils and thus reduces environmental pollution.

Water availability and quality

According to Segarra (2002), PA methods such as precision irrigation and fertigation (i.e. the application of water soluble fertilizers through an irrigation system) have positive effects on both water conservation and water quality, due for instance to the reduction of fertilizer leaching.

Climate change mitigation

Additional benefits of PA are related to reduced GHG emissions from agricultural production. Thanks to precise and localized distribution of fertilizers, for instance, nitrous oxide emissions can be substantially reduced (Smith *et al.* 2007; Ag Carbon Market Working Group 2009; 21st Century Agriculture Policy Project 2008).

Productivity/income

The most immediate economic benefits for farmers, particularly large-scale farmers with large machines, arise from the GPS guidance of the equipment, which allows for accurate spacing of machine passes, avoiding gaps and overlaps; in the case of controlled traffic systems, through the GPS guidance, it is possible to access the field at any time for timely operations.

A number of other more general economic benefits of PA were reported by Segarra (2002), namely:

- Yield increase: the precise selection of crop varieties, the timely application of optimal quantities of fertilizers, pesticides and herbicides, and precise irrigation led to optimal crop growth and development, with a yield increase compared to "traditional", uniform crop management practices.
- Efficiency improvement: advanced PA technologies allow farmers to increase the efficiency in the use of land and time/labour in farming.
- Reduced production costs: the application of optimal quantities of agrochemicals at the appropriate time reduces production costs (Swinton and Lowenberg-DeBoer 1998). In addition, the higher yields that can be achieved further reduce these costs per unit of output (Tran and Nguyen 2006).

Challenges

Input and labour requirements

In many cases, the required actions to respond to the existing variability are not known and have to be determined on each farm, such as calibrating specific fertilizer recommendations.

Adoption costs and technology challenges

The adoption of PA has been limited for various reasons (Tran and Nguyen 2006):

- Gathering information for devising PA strategies is expensive and time consuming.
- The benefits of PA are not immediately apparent; gains tend to be spread over a long period of time and it is difficult to estimate the costs and returns to users.
- Although diminishing, the costs of certain PA technologies remain high for users, and the required hardware and software may not be affordable for farmers in developing countries.

Another technology-related issue is the accuracy and reliability of the fertilizer and pestide application equipment, which tend to be much lower compared to those of the measurements and geographic data recording.

Awareness, education, and research and development

In addition to costs, another barrier to the deployment of PA is represented by the availability of skilled people and the lack of training for producers and service providers on the use of PA technologies, especially with regard to the software, data management and resource analysis (Wiebold *et al.* 1998).

Examples in bioenergy feedstock production

Region: South America
Country: Brazil
Crop/Feedstock: Sugar cane (*Saccharum officinarum*)

Autoguidance system operating on a sugar-cane harvester[71] in Chapadão do Sul, Mato Grosso do Sul, Brazil

In Brazil, the adoption of mechanized harvest techniques has caused an increase in sugar-cane (*Saccharum officinarum*) harvest losses. In addition, mechanization has increased the vegetative and mineral impurities that are taken to the mill together with the harvested cane.

Recently, precision farming techniques have been applied to improve the efficiency in the use of agrochemicals and other agricultural inputs, contributing to a decrease in the production costs of sugar-cane-based ethanol. In recent years, in Brazil, 39 percent of the sugar-cane plantations have adopted autoguidance technology, 31 percent have adopted georeferenced soil sampling, and 29 percent have adopted variable rate fertilizer and lime application. The use of machines steered by GPS with autoguidance can improve the mechanized system. In particular, autoguidance systems reduce overlap between passes of machines; increase operational speed; allow for a higher accuracy of farming operations, and increase the time available to finish the operation. The cost reduction achieved by the use of this technology is substantial.

In Chapadão do Sul, in the State of Mato Grosso do Sul, Brazil, a field-based test was conducted by the IACO Agrícola S/A mill, in order to compare the accuracy, operational field capacity and efficiency of an autoguidance system driving the passes of a sugar-cane planter machine over the field to those of a manual driving system. The 7.8 ha field used for this test had a clay soil type and a slope of less than 5 percent. The 1.5 year-old cane was being harvested for its first cut. The average cane yield was 120 t/ha in the same field in previous years. The tractor used to plant the cane was equipped with an autoguidance system. The driver of the manual guidance tractor had six months of experience with the planter. The results of the test showed that the manually-guided system had an error[72] (0.183 m) five times higher than the autoguidance system (0.039 m).

The results of this test show that PA in sugar-cane planting helps to reach optimal planting density, with an increase in productivity[73]. In particular, the results of the tests show that the use of an autoguidance system operating on a sugar-cane planter and harvester can increase the field pass-to-pass accuracy relative to the planned row track,

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71 The information included in this section was either adapted or excerpted from: Baio (2011).
72 Mean error in planting density accuracy. Sugar cane is planted on double rows distant 1,5 m + 0,5 m. The values considered in this study concern the error in planting distance between the double rows, as the planters have fixed interrow width.
73 Higher plant density leads to an increase in sugar-cane yields through more efficient use of nutrients and water and better light interception (Bull and Bull 2000).

leading to a reduction of in-row soil compaction and root damage, with positive effects on sugar-cane yields over time.

Region: South East Asia
Country: Indonesia
Crop/Feedstock: Oil palm (*Elaeis guineensis*)

Mapping and identifying basal stem rot disease in oil palms in North Sumatra with QuickBird imagery[74]

The application of remote sensing technology and precision agriculture in the oil palm (*Elaeis guineensis*) industry is increasing. A study was conducted by Santoso *et al.* (2010) to investigate the potential for detecting oil palms infected by basal stem rot disease and for mapping the disease in north Sumatra, Indonesia, through the use of high resolution QuickBird[75] satellite imagery. The basal stem rot disease represents a major threat to the oil palm industry, especially in Indonesia. It is caused by *Ganoderma boninense* and the symptoms can be seen on the leaf and basal stem. At present there is no effective control for this disease and thus early detection is essential.

The aforementioned study used QuickBird imagery to detect the disease and its spatial pattern. Firstly, oil palm and non-oil palm object segmentation based on the red band was used to map the spatial pattern of the disease. Secondly, six vegetation indices derived from visible and near infrared bands (NIR) were used to identify palms infected by the disease. Finally, samplings from four fields with different plant ages and degrees of infection were used to assess the accuracy of the remote sensing approach.

The results showed that image segmentation effectively delineated areas infected by the disease with a mapping accuracy of 84 percent. The resulting maps showed two patterns of the disease: a sporadic pattern in fields with older palms, and a dendritic pattern in younger palms with medium to low infection. The field samplings showed that oil palms infected by basal stem rot had a higher reflectance in the visible bands and a lower reflectance in the near infrared band. Different vegetation indices performed differently in each field. The atmospheric resistant vegetation index and the green-blue normalized difference vegetation index identified the disease with an accuracy of 67 percent in a field with twenty-one-year-old palms and high infection rates.

This case study suggests that high resolution QuickBird imagery offers a quick, detailed and accurate way of estimating the location and extent of basal stem rot disease infections in oil palm plantations.

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74 The information included in this section was either adapted or excerpted from: Santoso *et al.* (2010).

75 QuickBird is a high resolution satellite owned and operated by DigitalGlobe. Using a BGIS 2000 sensor, QuickBird collects image data to 0.61m pixel resolution degree of detail. This satellite is an excellent source of environmental data useful for analyses of changes in land usage, agricultural and forest climates.

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3.10 RAINWATER HARVESTING AND MANAGEMENT

Amir Kassam, Maizura Ismail, Marco Colangeli[76]

Key features

According to Balke (2008), rainwater harvesting (RWH) is the collection, filtration and storage of local rainwater and surface runoff for domestic consumption, livestock and crop production on stored soil moisture or with irrigation. In semi-arid areas, rainfall falling on a catchment area (runoff area) is diverted to a retention or cultivation area (run-on area). The water can be stored in the soil as for crop growth immediately or in cisterns and reservoirs for later use for irrigated production. The various kinds of RWH for agricultural applications can be seen as water collecting and supplying methods for crop and animal production ranging between rainfed and irrigated agriculture.

RWH that is applied in water scarce regions is characterized by irregular and scarce precipitation, longer lasting dry periods between seasonal or irregular rainfall, ephemeral rivers and no shallow groundwater of appropriate quality. Such regions are considered marginal for normal rainfed crop production but crops can be produced if there is water for irrigation. Where RWH is applied, the size of the productive land is enlarged because water is harvested from a wider area and concentrated for use in a relatively smaller area. There are several RWH techniques to catch precipitation. In many dry and semi-dry regions around the globe the water supply for human beings, cattle and small-scale farming depends mainly or completely on RWH.

However, in areas with rainfed agriculture, the aim of soil management is to harvest maximum amount of rain water falling on the surface of the agricultural land by ensuring that infiltration ability of the soil is high to cope even with the most intense rainstorms. This is certainly an explicit objective in crop production based on Conservation agriculture[77] (CA) systems (Friedrich *et al*. 2009; Kassam *et al*. 2009) in which good soil structure is maintained with minimum mechanical soil disturbance (no-till direct seeding) and the soil surface is protected with an organic mulch from residues and green manure cover crops which also provide organic substrate for soil biota and increase soil organic matter, and the cropping system is diversified with several crops including legumes (FAO 2011). This allows maximum amount of rainfall to be harvested *in situ* and stored in the soil, and in groundwater and deeper aquifers, because of the good soil structure and storage volume, and drainage to deeper layers.

In examples of catchment level water harvesting, yields of rainfed crops can be doubled or even quadrupled by using techniques of RWH because the catchment areas deliver an increased quantity of water to the cultivated areas from a much larger harvesting surface so that the crop plants can access soil moisture over a longer period of time. Such

76 Marco Colangeli is the author of the second example.
77 For a description of *Conservation agriculture*, see section 1.1.

results also require an optimum time of planting, the choice of appropriate crops and varieties, a good management of soil fertility, pest control and crop rotation (Hatibu and Mahoo 2000). Similar results are reported under normal agricultural land use with Conservation agriculture systems because of improved soil moisture conditions *in situ*, reduced evapotranspiration and longer growing season as well as the consequent reduced risk of drought and heat stress (FAO 2011; Basch *et al.* 2012).

In semi-arid areas, water is the limiting factor to increasing production. Droughts and dry spells, as well as erratic and high intensity rainfall that may result in intense surface runoff due to the inability of soil to absorb a high amount of water in such a short time, further increase the risks of crop failure (Duveskog 2003). This situation is exacerbated under tillage agriculture in which soil structure is often poor and soil evaporation relatively high. Similarly, in subhumid and humid climatic zones with higher rainfall, tillage farming tends to cause high erosion in agricultural land, resulting in soil and soil nutrient losses from the farms, as well as nutrient leaching (Chapin *et al.* 2002). Thus it is an imperative in all climatic zones that the impact of rainfall on soil surface and runoff be reduced and that effective rainfall is as high as possible and water resources are efficiently managed for multiple purposes.

Unlike medium- and large-scale irrigated agriculture, which can be costly in terms of infrastructure development and scheme management, strategies in rainwater harvesting may be relatively low in investment cost and may be implemented by any farmers according to factor such as relevant climatic region, agro-ecological zones, topography and cropping systems. In the case of rainwater harvesting and management based on runoff, this was broadly defined by Critchley and Siegert (1991) as the "collection of runoff for its productive use". However, Liniger *et al.*, (2011) has elaborated five strategies for improved rainwater management, which aim to:

- *Divert/drain runoff and run-on*: strategies to allow safe discharge of surplus water when there is water excess due to water soil saturation or rainfall rate in excess of infiltration rate, either in humid environments or during wet seasons in subhumid conditions. This may reduce leaching of nutrients, soil erosion or landslides, and may be achieved through the use of graded terraces, cut-off drains and diversion ditches, etc.
- *Impede runoff:* strategies to slow runoff, thereby allowing more time for the water to infiltrate into the soil, thus reducing soil erosion. Applicable to all climates, this may be achieved through the use of vegetative strips, earth and stone bunds, terraces, etc.
- *Retain runoff*: strategies to avoid runoff and retain water on the farm to encourage infiltration. Crucial in subhumid to semi-arid areas, where rainfall limits plant growth, this is achieved through application of minimum soil disturbance, mulching, vegetative cover, cross-slope barriers, etc.
- *Trap runoff*: strategies to harvesting runoff water. These strategies may be applied in areas where rainfall is insufficient and runoff needs to be concentrated to

improve plant performance through application of planting pits, half moons, as well as in environments with excess water during wet seasons, followed by water shortage through the use of dams and ponds for future irrigation, flood control or hydropower generation.

- *Reduce soil evaporation loss*: strategies to reduce water loss from the soil surface through application of soil cover by mulch and vegetation, windbreaks, shade, etc. This is mainly appropriate in drier conditions where evaporation losses can be more than half of the rainfall.

Farmers have come up with many ingenious ways to cope with the environment and ensure enough water to fulfil crop requirements. Rainwater harvesting and management in the semi-arid areas is generally further categorized in terms of water conservation technologies or practices into a few types (FAO 1998) as follows:

- *In situ rainwater conservation:* the practice of capturing rainfall where it falls, reducing runoff, increasing infiltration and minimizing evaporation. Examples include:

  soil cover: use of vegetation to cover the surface of soil either through cover cropping or cultivation of crop specifically to protect soil from the erosion medium, or by leaving crop residue on the farm after harvest to shield the soil. Soil cover may prevent loss of topsoil through erosion, formation of compaction and runoff.[78]

  contour cropping: entails making sure that cropping techniques follow contour lines, where soil roughness, formed by clods and small hollows, are laid perpendicular to the slope to slow down the runoff sheet as much as possible (Roose 1996). This method is effective only on gentle slopes, with reduced ability for soil roughness *to hold back water* the steeper the slope.

  terracing: developed on steep slopes as a result of constructing cross-slope barriers, progressively levelled by water and/or tillage erosion. It may have flat or slightly backward or forward-sloping bed, depending on soil, water and nutrient conservation objectives. Also sometimes lined with stone bunds or lines, ditches or trenches and vegetation.

- *Microcatchments*: consisting of small structures such as holes, pits, basins, bunds constructed for the collection of surface runoff from within the vicinity of the cropped area. The farmers usually have control over the catchment and the storage area. The structures are usually associated with specific agronomic measures to increase soil fertility, such as use of compost, manure and/or mineral fertilizers. Examples include:

  zaï/tassa/likoti/shimo (planting micropits): microplanting pits or holes or "basins" are around 15-20 cm in diameter and 10-15 cm in depth that collect rainwater to help with crop establishment and growth. Prepared before the start of the rains, farmers usually put a small amount of compost or manure into them to

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78 For a more in-depth discussion of *Soil Cover*, see section 3.12.

improve soil nutrient fertility. They are maintained for future use with minimal soil disturbance.

demi-lunes (halfmoons): the demi-lunes are 3 m x 3 m at their widest part and are connected with each other by earth bunds producing a continuous water-harvesting structure. They do not only harvest water, but the fine soil particles loaded with organic material in it "fertilize" the trees continuously (Bot and Benites 2005).

semi-circular bunds: semi-circular bunds are earth embankments in the shape of a semi-circle with the tips of the bunds on the contour. Semi-circular bunds of varying dimensions, are used mainly for rangeland rehabilitation or fodder production, as well as for growing trees and shrubs and crops (Critchley and Siegert 1991).

trapezoidal bunds: trapezoidal bunds are used to enclose larger areas (up to 1 ha) and to impound larger quantities of runoff which is harvested from an external or "long slope" catchment. The name is derived from the layout of the structure which has the form of a trapezoid – a base bund connected to two side bunds or wingwalls which extend upslope at an angle of usually 135 degrees. Crops are planted within the enclosed area. The general layout, consisting of a base bund connected to wingwalls is a common traditional technique in parts of Africa. The concept is similar to the semi-circular bund technique: in this case, three sides of a plot are enclosed by bunds while the fourth (upslope) side is left open to allow runoff to enter the field (Cricthley and Siegert 1991).

- *Macrocatchments* (for farming): larger catchment outside the arable land that are designed to provide more water for crop or pasture land through the diversion of storm floods from gullies and ephemeral streams or roads directly onto the agricultural field. Examples include:

  check-dams: check-dams are small-scale, low cost structures constructed across a stream to slow or hold the flow of rainwater. The small dams retain excess water flow during monsoon rains in a small catchment area behind the structure. Check-dams affect the flood-load deposit during the monsoon, decrease the erosive force of water and increase the contact time of water with soil surface, ultimately increase the recharge of rainwater in the ground, as well as extending and maximizing the time available to make use of monsoon rain (Redlich 2010).

- *Small dams/ponds*: They are structural interventions for the collection and storage of runoff from the surrounding external land surfaces of various types including hillsides, roads, rocky areas and open rangelands that act as reservoirs to be used for different purposes including irrigation, livestock and/or domestic use during dry periods. Sometimes runoff is collected in furrows/channels below terraces and banks.

In recent years, it has become clear that no-till farming in the form of CA is one of the best ways of *in situ* water harvesting on agricultural lands in all agroclimates. With

CA, runoff is minimized so that effective rainfall is maximized. The concept, principles and locally adapted practices of CA have been shown to be applicable in all continents and most agro-ecologies if constraints to adoption and dissemination can be overcome (Kassam *et al.* 2010 and 2011).

Potential benefits

Soil quality

Through application of rainwater harvesting, farmers may address land degradation issues including: *aridification* through decrease of average soil moisture content and change in the quantity of surface water; *loss of fertile topsoil* through capturing sediment from catchment and conserving within cropped area; *physical soil deterioration*, such as compaction, sealing and crusting, and soil *chemical and biological degradation*, where soil fertility experiences a decline and soil organic matter content is reduced (Liniger and Critchley 2007). Where water harvesting is based on runoff water being channelled into a collecting site or conserving within cropped area, the area experiencing runoff will suffer from loss in top soil. However, when *in situ* water harvesting is practised based on CA, there is a marked improvement in many of the soil quality parameters over time such as soil organic matter, infiltration, soil water storage and drainage, erosion, and soil biodiversity (Rockström *et al*. 2007 and 2009; Thierfelder and Wall 2010a and b; Lahmar *et al*. 2011).

Water availability and quality

While irrigation does reduce the negative impacts of drought and raises productivity, it can be costly, whereas rainwater harvesting may be a viable option for many farmers. The main benefits of implementing rainwater harvesting systems are: increased water availability; reduced risk of production failure; enhanced crop and livestock productivity; improved water use efficiency and water productivity; improved surface and groundwater recharge, and access to water for drinking and irrigation (Liniger *et al.* 2011). With increased households access to sufficient, safe supply of water for domestic use, improved rainwater management may also contribute to food security and health. These may also lead to an overall income increase for farmers.

Productivity/income

Rainwater harvesting can reduce the risks of production failure due to water shortage associated with rainfall variability in semi-arid regions and help farmers cope with more extreme events. As it enhances aquifer recharge, rainwater harvesting may enable crop growth, including trees, in areas where rainfall is normally not sufficient or unreliable (Liniger *et al.* 2011). In the case of *in situ* water harvesting through CA, the improvement in soil quality has a positive impact on factor productivity, biological output and income where surpluses can be sold (Mazvimavi and Twomlow 2008; Thierfelder and Wall 2010a and b).

Challenges

Input and labour requirements

For some technologies, for example for construction of terraces, digging the zai/tassa/likoti/shimo and transporting the manure and/or compost to the farms, there can be increased labour requirement for implementation and maintenance (Liniger *et al.* 2011). Under CA, this is a one-time investment, and is offset by reduction in labour requirement for land preparation subsequently because CA is a no-till system. The operation of creating micropits can be mechanized, but this would raise costs. Some microcatchments are also only effective when rainfall is sufficiently intense to generate surface flow, while farmers may initially need composted organic materials to increase effectiveness. In general, with time the need to retain micro-pits and microcatchments should decrease as soil quality, such as infiltration and soil moisture holding capacity, improves and direct seeding becomes possible with an animal drawn ripper direct seeder.

Land tenure

Where grazing land is being turned into cultivated fields through runoff water harvesting from an adjacent area, there may be potential land use conflicts concerning the rehabilitated land, in particular with pastoralists (Liniger *et al.* 2011). There is a need for better coordination and consultation before RWH technologies are implemented in such an area.

Access to finance

Although there are many varieties of rainwater harvesting technologies, sometimes their widespread use is not feasible, especially for poor farmers. Farmers' decisions to adopt technologies depend on the costs involved in the construction and maintenance. In the past, water harvesting systems that were installed with financial support from outside agencies, such as NGOs and international funding agencies, often failed due to lack of involvement of the beneficiaries in the design formulation and building of RWH systems, and the farmers' inability to organize and pay for maintenance (FAO 2003).

Awareness, education, and research and development

Rainwater harvesting is needed in all agro-ecologies, and not just in the dry semi-arid regions. Indeed, climate change adaptability strategies require that where possible, *in situ* rainwater harvesting be enhanced so that not only can crop production benefit but also water resources can be enhanced in quality and quantity. This means that production systems based on CA, including with trees and livestock, should be promoted because they offer better climate change adaptability and higher water use efficiency and water productivity (FAO 2011). Increased awareness, education as well as research and technology development needs to be directed towards the role of CA systems in rainwater harvesting, including in the dry semi-arid regions, to improve water availability for multiple use.

Policies and institutions

Agricultural water resource planning and management have mostly focused on blue water, or liquid water in water bodies such as rivers, lakes and ponds, which represent only one-third of the real freshwater resource, and less on green water, or moisture in the soil, which represent the rest of the water resources (Falkenmark *et al*. 2001; Karlberg *et al.* 2009). A shift in perspective and investment is needed to include green water as part of water resource options. This will require a shift to *in situ* rainwater harvesting though CA systems. This in turn will require policy and institutional support for uptake and scaling of CA.

Farmers may hesitate to invest time and money in rainwater harvesting without the security of land tenure and access to local markets where they may be able to sell surpluses (Liniger *et al.* 2011). However, when more profitable resource-conserving or resource-improving technologies such as CA and knowledge base are available, and capital and institutional constraints are not limiting, farm-households may undertake productivity-enhancing resource investments. Enabling policies, such as secure rights to land and water, access to markets and institutional arrangements, affordable credit services, and extension systems, create incentives for farmers to invest in options that expand future production and consumption possibilities (Shiferaw *et al.* 2009). Such policies may also need to include financial support to reduce any risks in the initial years to adopting CA systems for *in situ* water harvesting to intensify production.

Examples in bioenergy feedstock production

Region: West Africa
Country: Niger
Crop/Feedstock: Sorghum (*Sorghum bicolor*)

Tassa planting pits for sorghum and millet cultivation in Niger[79]

Tassa planting pits are used for the rehabilitation of degraded, crusted lands. This technology is mainly applied in semi-arid areas on sandy/loamy plains, often covered with a hard pan, and with slopes below 5 percent. Common crops produced in this water harvesting system are millet (*Panicum miliaceum*) and sorghum (*Sorghum bicolor*).

In Niger, *tassa* is an ancient soil and water technique. However, for a long period of time, this technique was abandoned in this African country. In 1988, the International Fund for Agricultural Development (IFAD) funded a ten-year programme of soil and water conservation to reintroduce simple, replicable conservation practices in Niger. In 1989, some of the farmers involved in the project began to revive *tassa* in the region of Tahoua. They rehabilitated 4 hectares (ha) of land, including one field next to a main road. This had an important demonstration effect, and people travelling who could see the impact of this technique on productivity began to replicate it. As a result, the following year (1990) *tassa* was implemented on around 70 ha of land. This was a drought year and only those farmers using *tassa* had a reasonable harvest. Over the next few years, *tassa* was instrumental in bringing a total of 4 000 ha back into production (IFAD 2009). According to FAOSTAT (2011), the average yield for sorghum in Niger was 260 kg/ha in 1989. The farmers of Tahoua obtained a 190 percent yield increase (500 kg/ha) as a consequence of the implementation of *tassa*. Moreover, this microcatchment technique led to the rehabilitation of thousands of hectares of barren land, easing the maintenance, weeding and thinning operations in the field. In addition to other factors, the revival of the *tassa* technique contributed to bring average sorghum yields in Niger up to 300 kg/ha in 2009 (FAOSTAT 2011).

79 The information included in this section was either adapted or excerpted from: Liniger *et al.* (2011).

Region: East Asia
Country: China
Crop: Maize (*Zea mays*)

In situ rainwater harvesting and gravel mulch combination for maize production in the dry semi-arid region of China[80]

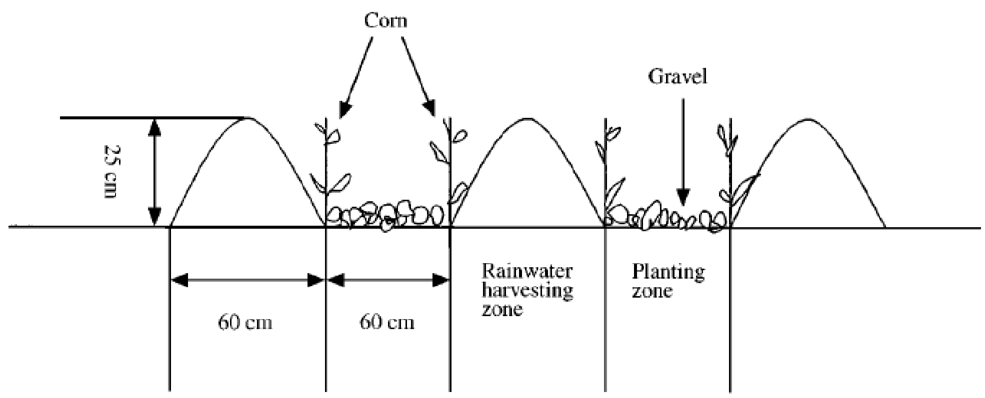
Limited and erratic precipitation in the dry semi-arid Gansu Province in northern China often results in low crop yields and sometimes total crop failure. In 1998, the Chinese *Cold and Arid Regions Environmental and Engineering Research Institute* conducted a field study to determine the effect of a combination of the ridge and furrow technique of *in situ* rainwater harvesting with gravel mulch on maize (*Zea mays*) production.

Gravel mulch (known as "shatian" or "sandy fields" in Chinese) is a technology used to conserve the sporadic and limited rainfall. This technology is successfully implemented in other dry locations throughout the world. Many studies have shown that gravel mulch can be effective in reducing evaporation and runoff, improving infiltration and soil temperature, and controlling soil erosion and salinization.

The system employed in the Gansu Province consisted in shaping the soil surface with ridges and furrows alternately in the flat field. Ridges were 60 cm wide (25 cm high) and served as rainwater harvesting zones; 60 cm wide furrows served as planting zones. Maize was planted 25 cm apart in two rows in the furrows at the base of the ridges. In order to diminish evaporation from the soil, in one plot the furrows were mulched with gravel. In other plots, a plastic film was used to cover the ridges and improve water harvesting. A schematic diagram of the system with crop configuration is provided below.

Figure 4

Schematic diagram of in situ rainwater harvesting combined with gravel mulch system



Source: Li et al. (2000)

80 The information included in this section was either adapted or excerpted from: Li *et al.* (2000).

Four treatments were considered in the field study:

- in T1, the ridges were covered with a 0.008 mm thick plastic film and furrow mulched by 5 cm thick gravel (3–5cm in diameter);
- in T2, the ridges were covered with a 0.008 mm thick plastic film and the furrows were left bare;
- in T3, both ridges and furrows were left bare (no plastic film or gravel mulch).,and
- in T4, there was bare flat soil; this plot represented the control.

Maize was planted on 6 May 1998, and the cultivar was a hybrid of early maturity (Jiudan). Maize was planted in the furrows with a density of 66 700 plants/ha, and flat soil plots (T4) were planted with a density of 110 055 plants/ha due to the lack of ridges.
There were 36 rainfall events during the 1998 maize growing season and the total rainfall was 304 mm. The waterproof plastic-covered ridges produced a high rate of runoff. The average runoff efficiency (runoff/rainfall) reached 87 percent, while the maximum efficiency was 99.6 percent for a total of 224 5 mm of runoff from ridge covered with plastic film (T1 and T2).

The plastic covered ridge and gravel-mulched furrow technique of water harvesting was the most successful treatment; maize yield in T1 was 8.9 t/ha, whereas in T4 (control) yield was 4.7 t/ha in spite of a double planting density. The T2 plot yielded 7.0 t/ha of grain, while the lowest maize productivity was recorded in T3 (3.4 t/ha).

As shown by this study, the plastic covered ridge and gravel-mulched furrow technique of water harvesting and conservation can generate double maize yields compared to “traditional” agriculture in areas characterized by limited and erratic precipitations.

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3.11 REHABILITATION OF DEGRADED LANDS

Amir Kassam, Maizura Ismail, Marco Colangeli[81]

Key features

FAO defined land degradation as "the aggregate diminution of the productive potential of the land, including its major uses (rainfed, arable, irrigated etc.), its farming systems (e.g. smallholder subsistence) and its value as an economic resource" (FAO 2002). As the term "land" refers to more than just soil to include all natural resources, such as climate and water resources, landform, soils and vegetation, land degradation includes any form of deterioration of the natural potential of land that affects ecosystem integrity either in terms of reducing its sustainable ecological productivity or in terms of its native biological richness and maintenance of resilience (GEF 1999).

While some forms of land degradation can happen naturally, others are the results of unsustainable land use (UNEP 2007). The most frequently recognized "causes" of land degradation include: overgrazing of rangelands; over-cultivation of cropland; mechanical tillage[82]; waterlogging and salinization of irrigated agricultural land; deforestation; pollution; and industrial causes (Stocking and Murnaghan 2000).

Examples of land degradation symptoms include:

- *Soil fertility decline*: deterioration in soil physical, chemical and biological properties due to tillage and lack of organic mulch cover, including lowering of soil organic matter, with associated decline in soil biological activity; degradation of soil physical properties, such as structure, aeration, water holding capacity, as brought about by reduced organic matter; adverse changes in soil nutrient resources, including reduction in availability of the major nutrients (nitrogen, phosphorus, potassium), onset of micronutrient deficiencies, and development of nutrient imbalances, and build-up of toxicities, primarily acidification through incorrect fertilizer use.
- *Water erosion*: all forms of soil erosion by water, including sheet and rill erosion; gullying; landslide caused by vegetation clearance and decease in infiltration due to loss in soil structure and compaction.
- *Wind erosion*: loss of soil by wind due to tillage, occurring primarily in dry regions but not exclusively.
- *Waterlogging*: due to poor infiltration and drainage caused by tillage in rainfed lands, rise in groundwater close to the soil surface in irrigated lands, and ponding,

81 Marco Colangeli is the author of the examples.
82 Any form of mechanical tillage, independent of the power source used (manual, animal drawn or tractor), is considered to be a serious degrading force on agricultural land (Montgomery 2007; FAO 2011), and has been shown to cause the loss of soil structure and soil organic matter, leading to soil compaction, creation of hard pans, surface sealing and decrease in infiltration and drainage leading to increase in runoff, erosion and water pollution. In addition, tillage leads to a loss of soil biodiversity, soil health and land's productive capacity (FAO 2011).

where the water table rises above the surface. Linked with salinization, both are brought about by incorrect irrigation management.

- *Salinization*: through build-up of free salts and alkalization, or saline intrusion from sea into coastal soils caused by an excessive use of ground water.
- *Lowering of the groundwater table*: brought about through pumping of groundwater for irrigation that exceeds the natural recharge capacity (FAO/UNDP/UNEP 1994).

Improving land use and agricultural techniques as part of a holistic approach to sustainable agriculture and rural development may contribute towards the conservation and rehabilitation of degraded land (Sombroek and Sene 1993; FAO 2011).

The good practices described in this report are key elements of this holistic approach to sustainable agriculture. In addition, there a number of specific methods aimed at arresting and possibly reversing land degradation, including:

- phytoremediation;
- bioremediation;
- natural regeneration and accelerated natural regeneration and
- enrichment planting.

One of the potential benefits arising from bioenergy feedstock production over other types of agricultural production is the possibility of using contaminated lands and to contribute to their rehabilitation. Increased investments in land rehabilitation, including through the establishment of dedicated bioenergy feedstocks, can contribute to agricultural diversification, rural economic development, and poverty reduction, and reduction in energy dependence and diversification of domestic energy supply, especially in rural areas (FAO 2008).

Phytoremediation

Phytoremediation is an emerging technology that uses various plants to degrade, extract, contain, or immobilize contaminants from soil and water (US EPA 2000). Most phytoremediation techniques involve applying existing agricultural good practices, such as silviculture and horticulture, towards solving environmental degradation. Phytoremediation technologies have been used to clean up metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbons, and landfill leachates (UNEP Undated). Although it has been successfully tested in many locations, full-scale applications are still limited.

Bioremediation

Bioremediation is defined as the use of biological agents to rehabilitate soil and water polluted by substances hazardous to the environment and/or to human health. Bioremediation allows natural processes, either by microbes that live in soil and groundwater or higher organisms, to clean up harmful chemicals in the environment, digesting and transforming them into water and harmless gases such as carbon dioxide. Bioremediation may occur: without any intervention (natural attenuation); with some intervention, where remediation by indigenous microbial populations is stimulated with additional nutrients or other substances as catalysts (biostimulation); or with introduction of exogenous micro-organisms that are capable of detoxifying a particular contaminant (bioaugmentation) (Donlon and Bauder undated).

A research carried out by Arizona State University developed an alternative approach to removing nutrients from waste streams, while at the same time producing high oil-containing fuel feedstock from selected species/strains of microalgae (in particular *Pseudochlorococcum spp.*). The biomass can be used as feedstock for the production of liquid biofuels and/or of fine chemicals, or as animal feed and/or organic fertilizer (AzTE 2011). Potential applications include: algae-based renewable biomass/energy production; microalgal carbon sequestration from fossil fuel-fired power plants; wastewater treatment, and production of algae for organic fertilizers and soil amendments.

Natural regeneration and accelerated natural regeneration

Natural regeneration involves deliberately managing the land to enhance and accelerate the natural processes of ecological succession in order to re-establish a healthy and resilient forest, while assisted natural regeneration is used to accelerate regeneration by assisting the natural processes and it involves cutting or pressing down the weeds around existing naturally-occurring seedlings, protecting the site from fire, and interplanting with desired species if necessary (Blay *et al.* 2004).

Enrichment planting

Enrichment planting is a technique for promoting artificial regeneration of forests in which seedlings of preferred timber trees are planted in the under-storey of existing logged-over forests and then given preferential treatment to encourage their growth (Moura-Costa *et al.* 1994, citing Lamprecht 1986). It entails the planting of valuable species in degraded forests without the elimination of valuable individuals already present and can increase total tree volume and the economic value of forests (Blay *et al*. 2004).

Potential benefits

Soil quality

One of the main objectives of phytoremediation and bioremediation is to restore soil quality. In Australia, replacement of native plants with shallow-rooted annual crops have caused rising water tables and the mobilization of salt, resulting in farmland affected by secondary salinity. Incorporation of deep-rooted perennial species into catchments dominated by annual crops and pastures forms part of the strategy for managing dryland salinity in Southern Australia, which may also have a positive effect on other environmental problems, such as erosion and loss of biodiversity through habitat removal (Harper *et al.* 2008).

Water availability and quality

Another key objective of phytoremediation and bioremediation is to restore water quality. For example, plants can be used to clean up contaminants in streams and groundwater, especially trees with deeper root penetration, where the roots allow for the treatment of contamination at greater depths (UNEP undated). Microalgae may be effective in performing these dual functions of effectively removing nutrients from waste streams, thus contributing towards wastewater treatment, and producing high oil-containing fuel feedstocks (AzTE 2011).

Biodiversity

In degraded areas, natural revegetation may take a long time because it is dependent on animal and windborne seeding. With phytoremediation, replanting that takes into consideration all aspects may aid ecosystem restoration in a few years. In some cases phytoremediation can help restore wild species diversity through habitat growth, in addition to aiding in remediation of soil and water (US EPA 2000).

Climate change mitigation

Over-grazed, degraded lands are no longer capable of storing large quantities of carbon. Improved grazing management can lead to an increase in soil carbon stocks by an average of 0.35 tonnes C/ha/yr but under good climate and soil conditions improved pasture and silvopastoral systems can sequester 1–3 tonnes C/ha/yr (FAO 2010). When grasslands are converted to agricultural land, soil carbon stocks tend to decline by an average of about 60 percent, and a further diminishing takes place along with land degradation.

Productivity/income

Many poor farmers in developing countries depend on lands already affected by a certain degree of degradation and contamination. Growing dedicated bioenergy feedstocks on these lands can have a positive effect on the livelihoods of these farmers and can also contribute to the rehabilitation of these lands if certain good practices are implemented.

Using microalgae for bioremediation and bioenergy production not only removes nutrients from waste streams, but also recycles them in the form of renewable biomass. This process requires no added nitrate and/or ammonia, and it produces minimal sludge, and 20-40 times more fuel feedstock per land area compared to conventional oil crop production. It may also be cultured in arid and semi-arid environments, causing no competition with oilseed plants for limited agricultural land (AzTE 2011).

Challenges

Pest issues

The plants that are most suitable for remediating land contaminated with a particular contaminant may or may not be native to a particular area. Appropriate control techniques, such as the use of sterile plants, should be used to ensure that genetic contamination or invasive spread that results in native ecosystems being damaged do not occur (US EPA 2000).

Land tenure

Part of degraded and contaminated lands in developing countries is used by local communities for several activities, including agriculture and livestock. When land rehabilitation programmes are designed and bioenergy development is planned on these areas, these land uses, which are often informal, should be considered and local communities and land-users should be consulted.

Input and labour requirements

All types of land degradation require some form of physical, chemical and biological inputs, as well as large inputs of human labour, to reverse the impacts and rehabilitate soil processes and ecosystem productivity (US EPA 2000). Reversal of chemical degradation through application of mineral and/or organic inputs is considered relatively easier, faster, and cheaper than the physical rehabilitation of soils. Last, but not least, infrastructure development in and around the areas where degraded lands are found may be poor (Sugrue 2008).

Human health and safety

Special care may be required for use and disposal of phytoremediative plants used in rehabilitation of degraded land due to contamination, while some form of phytoremediation may involve accumulation of organic contaminants. For example, the US EPA (2000) quoted a phytoremediation exercise using sunflower plants to extracted Cesium (Cs) and Strontium (Sr) from surface water, in which the plants were disposed of as radioactive waste. While metal accumulating plants need to be harvested and either recycled or disposed of in compliance with applicable regulations, further treatment or disposal are not required for most phytoremediative plants.

Awareness, education, and research and development

As technologies such as phytoremediation and bioremediation are relatively new, there is a wealth of opportunities for research and development on the subject. For example, further research is needed to study the effects that bioaccumulation and biomagnification can have on the food chain if insects and small rodents eat the plants that are collecting contaminants and are then eaten by larger mammals, as well as to establish whether contaminants can collect in the leaves and wood of trees used for phytoremediation and be released when the leaves fall or when firewood or mulch from these trees are used (UNEP undated).

Policies and institutions

Arresting and reversing current global trends in land degradation can be accomplished by promoting and supporting effective policies, legal and regulatory frameworks, capable institutions, knowledge sharing and monitoring mechanisms, together with good practices conducive to sustainable land management (SLM) (GEF undated).

Examples in bioenergy feedstock production

Region: South Asia
Country: India
Crop/Feedstock: Jatropha (*Jatropha curcas* L.)

Degraded land rehabilitation and biodiesel production using jatropha in Andhra Pradesh, India[83]

ICRISAT-India is an international agronomic research centre which aims to apply science to improve the livelihoods of those who live in disadvantaged regions of the semi-arid tropics. In 2005, ICRISAT-India, supported by the State Government of Andhra Pradesh and the National Oilseeds and Vegetable Oils Development Board (NOVOD), started promoting sustainable biofuel development in Andhra Pradesh, by providing land, financing and training to local Self-Help Groups (SHGs) for the cultivation of jatropha on marginal lands under rainfed conditions.

The project supported 10 SHGs of 8 people each, for a total of 80 members. It financed the groups until they were able to generate sufficient revenues from jatropha. As part of the scheme, a proportion of the income was allocated to a microsavings scheme. The project benefited from a Government buy-back policy, offering US$0.14 per kg of dry jatropha seeds.

ICRISAT established a 300 ha jatropha plantation (for biodiesel production) on common land in the villages of Velchal and Kothalapur in the Ranga Reddy District of Andha Pradesh. The area receives an average of 750 mm of rainfall per annum. The annual average temperature is 28-30 °C, however temperatures can range between 20-45 °C depending on the season. Soils are lateric, with shallow profiles and a high degree of degradation. The landscape is hilly, with small shrubs and sheet rocks. The shallowness of the soil, the low precipitations and the low organic matter content slow down the process of formation of soil and erosion takes place at a fast rate. Due to their very low productivity, these lands are unsuitable for traditional agriculture. For this reason, ICRISAT-India built nurseries where the most delicate phases of seedling's growth are monitored by the members of the SHGs.

The 300 ha plantation was solely rain fed, whereas in the nursery and during transplantation the SGHs used manual irrigation to favour seedling growth. Nutrients were applied in the form of farm yard manure to the young plants and oil press cake was applied to adult plants.

The return of organic matter to the soil, the erosion control operated by jatropha plants, and the lack of tillage in the plantation, led the formation of litter, and eventually of a layer of humus that greatly improved soil quality. Further, prior to the establishment of

83 The information included in this section was either adapted or excerpted from: GEXSI LLP (2008).

the jatropha plantation, the land used to be un productive, whereas from 2008 the jatropha plantation began to produce, with each plant yielding 1.3–1.7 kg of dry seeds, generating an annual income of US$160 000.00[84] (over the 300 ha plantation with a density of 2 500 plants/ha). The seeds were purchased from the Southern Online Biotechnologies (SBT), a biodiesel producer capable of compete on the local fuel market given average diesel prices at the pump in Andhra Pradesh of 0.81 US$/litre (as of 2008).

Region: West Africa
Country: Nigeria
Crops/Feedstock: Maize (*Zea mays*)

In situ bioremediation, using wild sunflower- and cassava-based compost, of heavy metal contaminated soil for maize production in Nigeria[85]

The dumpsite of an abandoned lead-acid battery manufacturing company in Ibadan, Nigeria was used to test a clean-up operation based on the use of wild sunflower (*Tithonia diversifolia*) and cassava (*Manihot esculenta*) compost for the degradation of lead (Pb) and other heavy metals, and for the simultaneous production of maize (*Zea mays*). The test was conducted in 2008 and 2009.

At the study site, Pb concentration in the soil (expressed in mg per kg of soil – mg/kg) was extremely high, around 500 times higher than the maximum permissible limit for potentially Toxic Elements (Pb = 300 mg/kg). This resulted in decreased soil microbial activities, soil poor fertility, and phytotoxicity.

In order to re-establish land fertility *in situ*, the researchers of the Department of Crop Protection and Environmental Biology of the University of Ibadan decided to restore soil biological, chemical, and physical balance through the addition of different blends of compost to the fields. Two solutions were tested: wild sunflower compost (WSC) and cassava waste compost (CWC) both with the addition of poultry manure. The mixtures of compost were prepared in ratio 3:1 of plant material to poultry manure. The compost was distributed in heaps along the field, well aerated through ventilation poles, and then thoroughly mixed and watered for a maturation period of 12 weeks.

The researchers tested two different rates of distribution for the mature compost: 20 tons/ha and 40 t/ha, for both WSC and CWC. Compost was spread one month prior to maize sowing; a portion of the site was left without compost for control.

Soil chemical analyses were performed before and after the test. The soil was acidic with pH of 4.2. Lead (Pb) and Cadmium (Cd) were present in greater concentrations than Zinc (Zn), Chromium (Cr), and Copper (Cu). In Ibadan, the concentrations of Pb and Cd in 2008 were extremely high: Pb was 146 000 mg/kg, while in uncontaminated soils Pb

84 ICRISAT-India ensured equal wages for men and women among the 80 SHG members.
85 The information included in this section was either adapted or excerpted from: Adejumo *et al.* (2011).

concentrations ranged from 2 to 300 mg/kg; Cd was found in concentrations of 41.3 mg/kg, compared to a 0.01-2.7 mg/kg range in uncontaminated soils.

The effectiveness of the different treatments was monitored through laboratory analysis throughout the whole growing season of maize. Leaf Area Index (LAI), development of vegetative characters in maize, as well as soil sample analysis, were conducted to track the heavy metal removal operated by soil micro-organisms colonizing the rhyzosphere.

The yield of maize grain grown in the contaminated field of Ibanda was 4.5 t/ha using 40 t/ha of WSC amendment/fertilizer (WSC_{40}), 2.6 t/ha for CWC_{40}, 1.09 t/ha for WSC_{20}, and 0.73 t/ha for CWC_{20}. In control areas of the site maize plants died off shortly after emergence and no grain yields were recorded, while Crop Growth Rate was 2.26 g/m^2/week in WSC_{40}. CWC and WSC at 40t/ha increased dry matter accumulation by 95 percent and plant height by 89 and 94 percent, respectively. Soil lead concentration was reduced by 72 and 69 percent in WSC and CWC at 40t/ha, respectively. Total lead concentrations in maize plant from compost treated soils were 0.02 percent (MSW) and 0.03 percent (CWC) of total grain mass.

Despite the low concentrations, the presence of Pb in grain suggests that the crop should be used for purposes other than food (e.g. bioethanol). The heavy metal removal action of maize plants in compost treated soils (MSW and CW composts applied at 40t/ha) ecologically restored the lead contaminated soil and, at the same time, allowed for the production of maize at high yields for uses other than food, such as bioethanol. Eventually, the land rehabilitation process could reduce contamination to an acceptable level for food production.

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3.12 SOIL COVER

Maizura Ismail

Key features

Soil cover is key for soil conservation. In agriculture, soil cover refers to the use of vegetation to cover the surface of soil either through cover crops, in which a type of annual or perennial crop is grown specifically for soil improvement purposes, or by leaving crop residue on the farm after harvest to shield the soil.

Soil cover may prevent loss of fertile topsoil and organic matter from erosion, formation of compaction and runoff. It may also suppress weeds, fix nitrogen, and increase nutrient cycling and soil biotic activities, thus improving soil structure and soil water infiltration. It may also contribute to maintenance of soil moisture.

Soil cover is an important element of Conservation agriculture[86], Organic Agriculture[87], Integrated Pest Management[88] (IPM), and Integrated Plant Nutrient Management[89] (IPNM).

Cover crops

Cover crops should be suitable for local conditions; compatible with the main crop(s); easy to establish; competitive compared to weeds, and able to either fix nitrogen or concentrate phosphorus (Bunch 2003). They should also be resistant to local insects, diseases and droughts, as well as be able to produce sufficient seeds for future plantings to avoid extra costs to farmers.

Cover crops are also known for their secondary functions. Certain cover crops, known as "green manure", can be killed while green or soon after flowering to add nitrogen or other nutrients into the soil. Some crops, known as "catch crops", prevent excess plant nitrogen from the previous harvest from leaching into the sensitive waterways by catching and absorbing the nitrogen, also known as catch crops (Wallace 2001). Other cover crops, known as "living mulch", are planted with the main crop and maintained longer as mulch mainly for weed suppression, and as livestock fodder and grazing, known as "forage crops" (Sullivan 2003).

Multiple species of cover crops may be simultaneously cultivated so as to exploit their various benefits. In order to do this, the complex relationships between species such as competition for light, water and nutrients, allelopathic effects and occurrence of pest and diseases, need to be understood and properly managed.

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86 For a description of *Conservation agriculture*, see section 1.1.
87 For a description of *Organic Agriculture*, see section 1.3.
88 For a description of *Integrated Pest Management (IPM)*, see section 3.5.
89 For a description of *Integrated Plant Nutrient Management (IPNM)*, see section 3.6.

Residue cover

Residue cover may consist of: crop residues from the previous harvest left in the fields; cover crops sown during the previous season and left in the fields after slashing, rolling or herbicide application; leaves and branches trimmed from trees in the cropping area, and mulches of grasses, shrubs, weeds, litter, husks and other organic waste materials (Shaxson and Barber 2003). In the case of mulch, residues may need to be collected from elsewhere and transported to the cropping area before field application. In all the other cases, the residue cover can be produced within the cropping area.

Potential benefits

Soil quality

Soil cover improves soil quality by fixing nitrogen in the soil; adding soil organic matter through decomposition of plant residues, and protecting soil surface from wind and water erosion. In the case of cover crops, the effectiveness in reducing erosion is determined, among others, by the amount of soil cover provided by growing plants, their height, structure, orientation, rooting characteristics and position (Johnson *et al.* 2010). As soil cover may increase soil organic matter, application of soil cover means that more food is available to soil biota, thus increasing their population and activities. These, in turn, lead to improved soil aggregation and porosity, to more soil macropores, and to higher soil infiltration rates.

When rain hits exposed soil, it breaks the soil aggregates, freeing the finer soil particles. These finer particles could settle in and block the soil surface pores, causing soil surface to seal over when it dries. This process is known as crusting. Soil cover reduces the area exposed to rain and the subsequent crusting and surface water runoff during rainy periods (USDA 2008). Cover crops also improve soil tilth by way of root penetration in compacted areas.

Soil cover provides a microclimate conducive to soil biota proliferation, which in turn improves the soil structure through increased soil biota activities including root penetration. As soil organisms consume organic matter and each other, nutrients and energy are exchanged through the food web and are made available to plants (USDA 2001). Soil cover also reduces soil temperatures, which can reach detrimental levels under dryland conditions (Aune and Doumbia 1998).

While some cover crops absorb residual nitrogen from the previous harvest and thus reduce nitrogen leaching into the waterways, some cover crops increase the available nitrogen in soil for plant uptake. Through symbiotic association with bacteria from the genus Rhizobium, cover crops such as legumes and pulses have the ability to biologically fix nitrogen from the atmosphere and contribute to soil nitrogen. The Rhizobium bacteria that live in the nodules, developed on the legumes' and pulses' roots, supply nitrogen to the host plant and through photosynthesis the host plant supplies the energy needed to biologically fix nitrogen to the bacteria (Danso and Eskew 1984).

Water availability and quality

Cover crops may absorb excess nitrogen from the previous harvest or manure application, thus reducing nitrogen leaching into the waterways. Cover crops and residues that shield soil surface from the onslaught of erosion mediums, such as wind, water and ice, may protect it from erosion and crusting. Soil cover may also reduce runoff and the resulting siltation, as well as enhance rainwater infiltration and availability of soil water for root uptake. The root system of cover crops may also improve soil water penetration.

More recent evidence also shows that some cover crops can conserve more soil water than open bare soil surfaces, especially in hot, dry and sunny environments with high evaporation.

Agrobiodiversity

The use of soil cover in a farm may be an effective means of enhancing both above-ground and below-ground biodiversity, which provides key ecosystem services back to the farm. For example, above-ground soil cover may provide a physical temporary habitat for several species of ground-nesting birds and small mammals (Scialabba and Williamson 2004). Plant residues may create a microclimate suitable as habitat for insects and other beneficial soil organisms. In the case of cover crops, they may also be the source of nectar and pollen. Below ground, after green manure is incorporated into the soil, a rapid multiplication of soil micro-organisms occurs to attack the freshly incorporated plant material to release nutrients for plant uptake (Sullivan 2003).

Availability of inputs

Cover crops that are grown to improve the nutrient content of the soil may also suppress weed growth by competing with weeds for space, nutrients and shade. In addition, soil cover can inhibit germination and growth of many weed species through the release of natural plant toxins by certain crops, also known as allelopathic effects. Residues that are left on the ground also act as physical barriers, preventing light and radiation from reaching the soil, hence retarding weed germination (Teasdale 1999). Thus, soil cover may be a cheaper alternative to herbicides.

Productivity/income

A direct economic benefit that may be derived from cover crops is the reduced cost for nitrogen fertilizers, which in most cases can offset the cost of establishing the cover crop. Indirect benefits include reduction in the costs incurred by the farmers for herbicides; insect and nematode control; water conservation, and water pollution control. In addition, longer-term benefits may be derived from the build-up of organic matter and the resulting increase in soil health (Sullivan 2003).

Income can also be generated from production of additional non-staple cover and forage crops for livestock production. Some cover crops, such as rapeseed, canola and sunflower, can also be used for bioenergy production, either to be used on-farm or for sale (Al Kurki *et al.* 2010).

Access to energy

As mentioned above, some cover crops have the potential to be used for bioenergy. Rapeseed, canola and sunflower, for instance, can be used to produce biodiesel. Bioenergy production from these crops can improve access to energy in rural areas.

Dietary diversity

Some cover crops may be used for food, and thus may contribute to the diversity of food in a certain area. Cover crops may also be used as forage and grazing for livestock production. For example, cowpea produces seeds that are rich in potassium, calcium, magnesium, phosphorus and vitamin A, that may be eaten fresh and/or dried for storage. At the same time, the cowpea leaves may also be eaten as vegetables or used for forage (Davis *et al*. 1991).

Challenges

Water and nutrient requirements

Cover crops may not be suitable in areas with low precipitation or short growing seasons (Steiner 2002; Bishop-Sambrook *et al*. 2004). In dry and arid areas, where growing seasons are shorter and dry seasons last 7-9 months, there may be fewer opportunities for growing cover crops and crop residues may serve as forage for livestock (Bishop-Sambrook *et al.* 2004). However, there is growing evidence that some cover crops can be grown in arid areas. By covering the soil surface and limiting water evaporation, while at the same time controlling transpiration, these crops use less soil water than bare open soil surfaces, and can thus be used (as an alternative to dead mulch) in hot dry environments to save soil moisture for the subsequent crops.

Land tenure

Maintenance of soil cover may be difficult on land that is collectively managed and is accessible to multiple users with conflicting interests in terms of land use, such as pastoralists and farmers (Benites *et al.* 2002). The land use right of the farmer may be limited to the growing seasons if they are cultivating communal land, whereby the fields are open for common grazing, making them unsuitable for cover cropping and for leaving plant residues on the field (Steiner 2002). For example, in sub-Saharan Africa farmers may not be able to restrict grazing even on their own land without challenging the traditional rights of others in the community (Evers and Agostini 2001).

Production costs

Soil cover also needs to be evaluated in terms of cash returns to the farm. For the immediate growing season, seed and establishment costs need to be weighed against reduced nitrogen fertilizer requirements and the effect on cash crop yields, on top of the additional management required when cover crops of any sort are added to a rotation. Turning green manure under or suppressing cover crops requires additional time and expense, compared to having no cover crop at all (Sullivan 2003).

Awareness, education, and research and development

Awareness raising activities on soil cover practices and the associated benefits should be carried out for farmers and extension workers.

Competing in residue use

Traditionally, residues are used for several purposes in addition to soil cover, including for feed and energy, as well as for fencing and building purposes (Thiombiano and Meshack 2009). If residues are used as soil cover, farmers may have to find alternative sources for the other uses. The opportunity cost of using residues as soil cover will depend on the aforementioned uses and the associated revenues.

Examples in bioenergy feedstock production

Region: East Africa
Country: Kenya
Crop/Feedstock: Maize (*Zea mays*)

Use of leguminous shrubs as soil cover to increase soil fertility in maize cultivations in the Busia and Vihiga districts, western Kenya[90]

The farmers of Busia and Vihiga in western Kenya used to grow maize in monoculture, with few inputs to fertilize the soil. As a result, the soils in the areas were compacted and became infertile. They were also eroding away. Maize yields were reduced to less than 1 ton per hectare.

In 1999, the World Agroforestry Centre (ICRAF) worked with the farmers to find solutions to these problems, under the IMPALA project. The project introduced no-tillage and incorporation of various leguminous shrubs, such as *Crotalaria* spp., *Tephrosia* spp., *Gliricidia sepium* and *Sesbania sesban*, into the cropping systems.

The farmers started intercropping maize and beans in the long rains, then planted the shrubs which were allowed to grow in the short rainy season. Towards the beginning of the long rains, the farmers slashed the shrubs and left them on the surface of the ground as mulch. Two weeks later they planted maize and beans again through the mulch. Thanks to both types of soil cover (i.e. cover crops and residue cover) the project aimed at raising maize yields through the increase of moisture and organic matter in the soil.

In 2001, only two years after the start of the project, one farmer harvested 1.9 tons of maize per hectare. In 2004, thanks to the aforementioned practices, the same farmer harvested 3.2 tons of maize per hectare. The shrubs and mulch controlled weeds and smothered the most aggressive grasses, and the incidence of *Striga*[91] decreased. The soil became darker and softer, as a consequence of a higher content of organic matter.

At the same time, farmers were able to produce enough fuelwood for their own use and sell bundles of wood at KSh 20 (US$0.32) each. The shrubs attracted bees and a farmer who collected honey was able to make KSh 18 000 (US$292.45) worth of honey. Another produced 90 kg of *Tephrosia* seeds, which he sold for KSh 15 000 (US$243.70).

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90 Unless otherwise stated, the information included in this section was either adapted or excerpted from: IIRR and ACT (2005).

91 *Striga* is a genus of the family Scrophulariaceae responsible for major weed infestations. It can be found in Africa, Asia, Australia and parts of North America. Infestations of this root-parasitic plant are favoured by poor soil conditions and infertility coupled with low crop's vigour (AATF 2011; Mohamed *et al.* 2001).

Region: South East Asia
Country: Philippines
Crop/Feedstock: Wild sunflower (*Tithonia diversifolia*)

Application of wild sunflower (*Tithonia diversifolia*) as green manure in the Bukidnon Province in Mindanao, the Philippines[92]

Traditional farmers in the Philippines have been exploiting the agronomic properties of wild sunflower as part of their farmer-generated innovations of improved fallows. Originally from Central America, wild sunflower was introduced to the Philippines as an ornamental plant. Now, sunflower has become naturalized in the upland areas throughout the country and is often used as a soil improver in a wide variety of ways.

Older farmers in Luzon, the Philippines, describe planting "fertilizer banks" of wild sunflower which would then be harvested and applied as an organic fertilizer to cultivated plots. In the Bukidnon Province of Mindanao, sunflower hedgerows are maintained around the swidden perimeter to facilitate rapid cultivation during the fallow period. Through rapid growth, efficient scavenging of soil nutrients, copious leaf litter and rapid decomposition, wild sunflower appears to accelerate nutrient cycling and enable soil rehabilitation during an abbreviated fallow period.

The large leaf area of sunflower intercepts most light and hard-to-control grasses are quickly choked out. A two-year fallow appears to be the norm, after which the sunflower biomass can easily be slashed and mulched. Some farmers interviewed claim that soil physical properties improve so dramatically during this period that ploughing is unnecessary and seeds can be dibbled directly – a big advantage in erosion-prone sloping uplands.

Other farmers in the area are manipulating wild sunflower as a biological tool to eradicate infesting weed cogongrass[93] (*Imperata cylindrica*) and rehabilitate degraded grasslands. In this case, stem cuttings may be planted at intervals throughout cogongrass swards or, alternately, seeds can be broadcasted. Farmers claim that at the end of the first year, the cogongrass is almost completely choked out and displaced by sunflower. By year two, the sunflower fallow can already be re-opened, sunflower seeds harvested, and a good crop grown without fertilizer inputs.

As a cover crop, fast growing sunflower foliage suppresses weeds, producing large amounts of organic matter, while covering a wide area and producing high oil content seeds. The highly extensive root system includes a strong taproot that can break deadpan and generate good tilth, tapping water and nutrients beyond the reach of other crops (NSA 1996). In terms of biological pest management services, nectar and pollen-rich sunflowers attract bees, butterflies and other pollinating insects, as well as beneficial insects which prey on pests such as aphids.

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92 Unless otherwise stated, the information included in this section was either adapted or excerpted from: Osei-Bonsu *et al.* (1996).

93 Cogongrass is considered the worst weed of southeastern Asia and the moist savanna of west Africa. It occurs in a wide range of habitats, including degraded forests, grasslands, arable land, and young plantations. Normally, the grass does not occur in closed forests but frequently appears within a few years once the forests are opened up for agriculture or lumbering (FAO 2003).

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3.13 SUSTAINABLE FOREST HARVEST

Marco Colangeli

Key features

"The key to sustainable forest harvesting is to apply the best knowledge available in six critical areas: harvest planning, forest roads, felling, extraction, long-distance transport, and post harvest assessment" (FAO, Forestry web site).

Harvesting does not refer only to the process of extracting the selected trees from the forest to the roadside, but also takes into account the importance of forests as a source of non-wood forest products and environmental services, as well as for the conservation of biological diversity and cultural values (FAO, Forestry web site).

Harvest planning begins with the selection of the harvest method. Two environmentally sound, economically feasible and socially acceptable harvest methods are Reduced Impact Logging (RIL) and Coppicing.

Compared to conventional logging, RIL practices significantly limit damages to the forest caused by logging activities, therefore maintaining biodiversity and functional habitats, while at the same time increasing the economic returns per hectare. RIL is referred to as "intensively planned and carefully controlled implementation of harvesting operations to minimize the impact on forest stands and soils, usually in individual tree selection cutting" (Killmann *et al.* 2001, page 186). RIL covers the harvesting process from planning to production, followed by post-harvest assessment. The main efforts in RIL are towards reduction of ecological disturbance through the use of appropriate felling and bucking techniques and sustainable winching techniques in order to move the logs to planned skidtrails and ensure that skidding machines remain on the skidtrails at all times (Dykstra 2001).

Another key sustainable forest harvest method is Coppicing, which refers to the practice of regularly cutting down trees near the ground to produce strong straight shoots for fuel or other uses. In some types of natural forests where fires are a considerable part of natural successions (savannah forests, miombo, etc.), coppicing is the main form of natural forest regeneration (FAO 2005).

Most broad-leaved plants have high sprouting capacity and are suitable for coppicing, whereas the majority of the conifers do not form coppice shoots when felled (Longman 1993). Among the broad-leaved plants, the best performances are offered by poplars (gen. *Populus*) and willows (gen. *Salix*) (FAO-IPC 2010). Poplars as well as high-productivity varieties of willows are being bred as a priority crop for the cellulosic ethanol industry in many countries (FAO 2008a). In developing countries, great performances for biomass production can also be obtained with fast growing and resistant species such as *Eucalyptus* spp., bamboo (*Bambusa* spp.), pepper tree (*Shinus* spp.), beechwood (*Gmelina* spp.), jumbie bean (*Leucaena* spp.) and others.

Coppice forests are usually harvested after 9-25 years depending upon the species, the environmental conditions and the use of the biomass harvested. In the case of biomass production exclusively for bioenergy, coppicing could even take place every two to five years as in the case of Short Rotation Coppice (SRC). These are high-density, sustainable plantations of fast-growing tree species that show potential for both bioenergy production and environmental services, such as phytoremediation[94]. Depending upon the environmental conditions, SRC can yield from 10 tonnes of dry matter per hectare (t_{dm}/ha) up to 40 t_{dm}/ha (FAO 2006a), with plantation density ranging from 10 000 to 30 000 cuttings/ha (FAO 2008a). Land that can be used for this type of plantation includes agricultural land that is not suitable or no longer needed for agriculture; clear-cut forest land in tropical and temperate areas, degraded land, and poor soils where food crop production is not optimal (FAO 2008a).

Biomass produced through sustainable forest harvest methods may replace wood from tropical forests and from protected forest areas and thus help conserve valuable natural forests for future generations (FAO 2006a).

Potential benefits

Soil quality

Both conventional logging and sustainable forest harvesting practices affect ground areas. Vehicular traffic during forest management, particularly where ground-based timber yarding methods are utilized, leads to soil compaction, increased bulk density, decreased pore space, decreased water infiltration rates, and increased runoff, limiting roots' nutrient uptake and growth rates (Putz 1996). However, as a proportion of total area, conventional logging causes about twice as much ground damages compared to RIL, with a particularly marked distinction in the area of skidtrails (Pereira Jr *et al.* 2002).

In a study by Lentini *et al.* (2009) conducted at the Roberto Bauch Forest Management Center in Brazil, heavy machinery was found to disturb about 10 percent of the ground in conventional logging, compared to about 5 percent in RIL, while 100 percent of skidtrails were found to be exposed to mineral soil in conventional logging compared to less than 10 percent in RIL.

Sustainable forest harvest methods can have a beneficial effect on soil's chemical composition. Since SRC biomass can be harvested using tracked machinery, capable of harvesting large amounts of material with a limited number of passes over the ground, the area disturbed by logging is substantially smaller than in conventional forestry. SRC plantations generally cause very little ground damage except in extremely wet conditions (BEC 1998).

Last, but not least, poplars and willows can be used for phytoremediation, to remove hazardous compounds such as heavy metals or organics from soils (IEA 2011).

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94 For a description of phytoremediation, see section 3.11 on *Rehabilitation of Degraded Lands*.

Water availability and quality

Well documented environmental benefits of sustainable forest harvest include reduced soil disturbance and erosion, as well as reduced logging impact on water quality and general hydrological functions of the forest stream system (Klassen 2001). A comparison of RIL and conventional logging in aast Kalimantan (Indonesia) found that areas logged with RIL were cooler due to less canopy openness; showed no inundated areas and were well drained thanks to the planned water ways; had no erosion proven, and provided good water catchment. In comparison, conventional logging areas were found to be hotter; were inundated with water and showed occurrence of gully erosion (Priyadi *et al*. 2006).

Biodiversity

Conventional logging usually employs selective harvesting, during which trees are identified by a timber cruiser, felled by a sawyer, searched for by tractors or skidders, and extracted on impromptu skidtrails to log decks or roadsides. Sustainable forest harvesting practices can reduce both canopy and ground damage compared to conventional logging, especially in the case of RIL. A review of case studies by Boltz *et al.* (2003) revealed that conventional logging may cause 90-129 percent greater canopy loss and up to four times as much ground area disturbance than RIL. The review listed several environmental externalities from conventional logging, including: heavy erosion and disruption of forest hydrologic cycles; changes in forest microclimate, plant community composition and structure that, in turn, may impact negatively on wildlife and forest ecological functions; modified forest microclimate that may render tropical forests more susceptible to fires, and decreased forest productivity that may result in higher opportunity costs for long-term forest management and greater incentive for forestland conversion (Boltz *et al.* 2003).

In terms of canopy damage and loss, RIL forests generally experience lower canopy damage and loss than conventionally logged forests. A study by Pereira Jr *et al.* (2002) showed that recently logged blocks using conventional logging had integrated canopy gap fractions of 21.6 percent of total area compared to RIL at 10.9 percent (Pereira Jr *et al*. 2002). Loss of canopy changes the light regime and forests microclimate, which may lead to nutrient cycling disruption, changes in recruitment of timber species, and in forest fauna diversity, and possibly long-term species composition, and an increase in the susceptibility of forest to fire. Compared to conventional logging, sustainable forest harvest methods such as RIL maintain a higher level of biodiversity and stock a greater amount of carbon (Mannan *et al*. 2008).

Conventional logging may cause more than twice the number of deaths of residual trees compared to sustainable forest harvest methods. For every 100 harvested trees, felling in conventional logging may cause the death of 34 remaining trees, compared to 16 in RIL (Lentini *et al*. 2009).

Apart from reducing damage to vegetation, RIL also reduces the duration of the entire logging operation. This may further reduce the impact on fauna by preventing concurrent logging operations executed over large continuous areas, therefore ensuring that the animals have a place where they can flee and from where they can return after logging has been completed (Jonkers 2001). The International Union for the Conservation of Nature (IUCN) recommends sustainable forest harvest methods to be promoted in all production forests harbouring great ape populations (Morgan and Sanz 2007).

Climate change mitigation

According to CIFOR (1997), 75 percent of the carbon stored in forests in southeast Asia is in biomass, and of this, 59 percent is in large trees (≥ 60 cm diameter). When logging damage is reduced thanks to sustainable forest harvest methods such as RIL, more carbon is retained in living trees.

Several studies described the potential of coppice forests to sequester large amounts of carbon in the soil and as underground biomass. A study performed by Cranfield University (2001) concluded that bioenergy tree coppice plantations provide the greatest potential amongst all feasible agricultural land-management strategies for soil carbon sequestration in Europe. In this study, poplar SRC plantations were found to store between 0.5 and 1.6 t/ha per year of carbon in underground stumps, with an average annual increase in below-ground biomass ranging from 1.17 percent to 2.15 percent.

Lastly, the rate at which coppice stands store carbon is higher than other silvicultural types both in the soil and as above-ground biomass (Forestry Commission of Great Britain 1989).

Productivity/income

Sustainable forest harvesting generally increases income for local populations over the long term.

Under RIL, both economic and environmental values may be realized, through the sustainable production of timber resources (DiNicola *et al.*1997). In Brazil and Bolivia, the primary factor driving the implementation of RIL is increased productivity, reduced harvesting costs, greater efficiency and/or reduced costs deriving from the ability to plan (Jonkers 2001). A study by Lentini *et al.* (2009) conducted at the Roberto Bauch Forest Management Center in Brazil demonstrated an increase of 19 percent in net income from RIL compared to conventional logging, mainly as a consequence of: higher productivity in skidding and log deck operations (39 percent); a greater reduction in all fixed and variable costs related to harvesting (12 percent), and a decrease in the timber wasted after logging (78 percent).

Stevens *et al.* (2009) cited a research in Brazilian Amazon that estimated that 68 percent more timber volume could be extracted over a 30-year period using RIL techniques compared to conventional logging, resulting in 35-40 percent higher estimates of net present value of the operation based on timber extraction cash flow.

Wood products and the related income obtained through coppicing are generated over shorter periods of time if compared to high stand forests. In the Philippines, charcoal making and biofuel trade and distribution provide seasonal income from coppice forests, particularly for farmers whose income comes primarily from the production and sale of mangoes (FAO 2002/4a). Moreover, the versatility of coppice forests allows the generation of income from a variety of wood products in addition to fuelwood and charcoal (e.g. woodchips, pellets, wood for veneer, feedstock for paper, etc.), depending upon the length of the cutting interval, species pool available, market demand and environmental conditions.

Access to energy

As already described above in the key features section, coppicing and especially SRC can be an important source of biomass for bioenergy production. In northern European countries, for instance, combined heat and power (CHP) production from biomass obtained from SRC represents a significant share of domestic energy consumption.

Human health and safety

In conventional logging operations, workers are exposed to substantial occupational health and safety hazards, including: physical hazards; noise and vibrations, and fire and chemical hazards (IFC 2007). Sustainable forest harvesting practices generally require provision of working conditions that meet internationally recognized standards and consider workers' occupational health and safety. In Sustainable Forest Harvest, these risks are significantly reduced through safety measures such as: escape routes; flexibility in felling direction; controlled felling practices, and personal safety equipment and appropriate hand tools, including wedges and sledge hammers (Hinrichs *et al*. 2001; TFF 2007).

Most operations in SRC plantations are managed using large machinery. The direct contact of workers with chainsaw and other tools is very limited; as a consequence, the risk of accidents and injuries is reduced if compared to conventional logging.

Challenges

Pest issues

Weeds, pests and diseases impact coppice forests more than high stand forests because of: often scarce genetic variability; frequent disturbance due to harvest[95] (cuts allow parasites to enter the plant), and, in SRC, strong competition at ground level with weeds. A completely weed-free site is required at planting and must be maintained until the crop foliage shades out the weeds (Forestry Commission Great Britain 2002). The best results against pathogens' attacks are obtained through the sound use of pest-resistant tree hybrids, clones or local varieties (FAO 2008a).

95 Depending upon the tree species and the environmental conditions, diseases and pests can have detrimental effects on biomass yields (Forestry Commission Great Britain 2002).

Input and labour requirements

Adoption of sustainable forest harvesting techniques can be a challenge in areas where professional foresters are rare, which is a common situation in many developing countries (Dykstra 2006). For instance, numerous studies identified in the lack of skilled logging personnel one of the most critical barriers to the wide-scale adoption of RIL. Without sufficient numbers of trained and skilled logging personnel who understand both why and how to carry out sustainable forest harvesting, there is little hope that timber concession holders will be able to effectively implement RIL and modern coppicing practices (Durst and Enters 2001). This is true for personnel at all levels. Well-trained loggers also need equally well-trained supervisors to ensure that their work is carried out properly and to provide feedback that will help them to improve their practices continually (Dykstra 2001). For example, aerial logging alternatives such as cable, skyline and helicopter harvesting systems that can substantially reduce direct impacts associated with ground disturbance require highly skilled crews and specialized knowledge (Dykstra 2001a). Moreover, the establishment of sustainable forest harvesting programmes is intensive in terms of labour requirements because operations in the field often require larger crews than in conventional forestry.

In SRC plantations, a high level of mechanization is required in order to reduce the production costs (FAO 2008a). In order to produce large amounts of biomass (>10 tons/ha) through SRC, indeed, it is important to create optimal water and nutrient conditions, eliminating competition by herbaceous plants and other tree species, and preventing biotic and abiotic damage (FAO 2006a).

Land tenure

As with many long-term sustainable practices in agriculture, one of the main barriers to the adoption of sustainable forest harvest methods is the lack of tenure security. As most of the benefits of these methods, such as better residual trees and less damage to trees for future harvests, may only be captured in the long term, forest managers have little incentive to log forests carefully if they anticipate the forest will be occupied, taken over, or damaged by others (Durst and Enters 2001). This is further exacerbated when there is a weak judiciary system in place to deal with and resolve land disputes and uphold the rights of concession holders or forest owners. For the successful implementation of RIL, for instance, long-term land tenure and use rights need to be clearly defined (FAO and ASEAN 2006).

Access to finance

There are numerous constraints that limit the financing of Sustainable Forest Harvest methods, which tend to be quite capital intensive. The most important is that many of the benefits of sustainable forest management do not generate revenue for forest owners and managers; further, these benefits tend to manifest themselves in the long term. A second constraint is the complexity and generally higher costs and perceived risks of sustainable forest management compared to other land uses, including unsustainable forest practices.

The most common constraint in developing countries as well as in developed countries is that sustainable forest harvest is a capital intensive and a long-term investment (FAO 2009).

According to FAO (2008b), access to finance from the private-sector in developing countries interested in sustainable forest harvest is often constrained for the following reasons:

- Need for long-term investments and, on the other hand, lack of short-term revenue generation.
- Forests are often not acceptable collateral for a loan (exceptions include Colombia and Uruguay).
- Land cannot be used as collateral without clear land tenure.
- Lending policies favour short-term loans with low risks, but a lack of information contributes to an inflated perception of risk in forestry.
- Interest rates are often higher than growth in the value of forests when wood products are the only marketed outputs.

These constraints affect especially small-scale forest owners and community based forest enterprises. In addition, administration costs are similar for large and small loans and this discourages lending to small enterprises. For this reason, several countries in South America have adopted policies to facilitate access to finance for sustainable forest harvest enterprises (FAO 2008b).

Awareness, education, and research and development

Despite extensive research and demonstration projects, there is still a great deal of unawareness, uncertainty, and skepticism regarding the potential benefits of sustainable forest harvest methods, particularly at the decision-making levels in governments and corporations (Durst and Enters 2001). In addition, there is also a lack of understanding of the specific requirements and methods of sustainable forest harvest, as well as of technical guidance on their implementation (Klassen 2001).

Examples in bioenergy feedstock production

Region: Northern Europe
Country: Sweden
Crop/Feedstock: Fuelwood

Short Rotation Coppice (SRC) willow for energy and phytoremediation in Sweden[96]

Approximately 16 000 ha of willows in SRC systems are currently grown in Sweden, consisting mainly of different clones and hybrids of *Salix viminalis*, *S. dasyclados* and *S. schwerinii*. Willow cultivation is fully mechanized from planting to harvest. In the initial phase, approximately 15 000 cuttings per hectare are planted in double rows, to facilitate future weeding, fertilization and harvesting. The willows are harvested every three to five years, during winter when the soil is frozen, using specially designed machines. The above-ground biomass is chipped on-site, then stored or directly burned in combined heat and power (CHP) plants. After harvest, the plants coppice vigorously, and replanting is therefore not necessary. The estimated economic lifespan of a short-rotation willow coppice stand is 20 to 25 years.

During the 1990s, large willow plantations equipped with irrigation systems were established adjacent to wastewater treatment plants to improve the efficiency of nitrogen treatment while producing biomass irrigated with wastewater. Research has shown that nitrogen retention in short-rotation willow coppice can exceed 200 kg per hectare per year. In Enköping, a town of about 20 000 inhabitants in central Sweden, a novel system has been introduced. The nitrogen-rich wastewater from dewatering of sludge, which formerly was treated in the wastewater plant, is now distributed to an adjacent 75 ha willow plantation during the growing season. The water is pumped into lined storage ponds during the winter and used for irrigating short-rotation willow coppice during the summer (May to September).

The system treats about 11 tonnes of nitrogen and 0.2 tonnes of phosphorus per year in an irrigation volume of 200 000 m^3 of wastewater, of which 20 000 m^3 is water derived from dewatering of sludge after sedimentation and centrifugation.

Possible environmental hazards associated with such applications, e.g. nitrogen leaching and nitrous oxide (N_2O) emissions into the atmosphere, are monitored; the results indicate minimal risks after wastewater application. Today, biomass production of willow grown commercially in Sweden is, depending on site conditions, about 6 to 12 tonnes per hectare per year.

Given an average international price for wood chips of US$150 per tonne and an average international price for wood pellet of US$250 per tonne (USDA 2004; BEC 2011; FOEX 2011), the estimated revenue generated by the 75 ha SRC plantation in Enköping is

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96 The information included in this section was either adapted or excerpted from: FAO (2006b).

between US$100 000 and US$170 000 per year. In addition to this estimate, environmental benefits and monetary savings deriving from the implementation of wastewater disposal within the SRC plantation represent an additional source of income for the municipality.

Region: South East Asia
Country: Philippines
Crop/Feedstock: Fuelwood

Sustainable wood energy from Coppicing in the Philippines[97]

In the Philippines, fuelwood, charcoal and other forms of bioenergy provide a major contribution to the energy requirements of the population. The collection, distribution and trade of these fuels also provide income and employment to millions of people.

The island province of Cebu is situated in the central Philippines, about 550 km southeast of Manila. It is a narrow strip of land about 5 088 km^2 in area, stretching 220 km from north to south and only 40 km in breadth at its widest point. It has a total population of approximately 3.4 million, consisting of about 676 000 households with an average household size of five people. Cebu has suffered from major deforestation during the past decades. Despite this, thanks to coppicing, the fuelwood industry appears to be thriving and fuelwood is a major source of energy in the province, particularly for cooking.

Most of the fuelwood production in Cebu originates from a handful of species: *Leucaena leucocephala, Leucaena glauca, Gliricidia sepium, Gmelina arborea* and *Swietenia macrophylla* managed with the practice of coppicing. The practice of coppicing is found among many fuelwood producers in Cebu. Fuelwood coppice lands are normally harvested in rotational patches every two to five years. Trees are cut and carried or transported to leveled areas where they can be split, and bundled according to size of fuelwood or converted into charcoal.

In Cebu, trade in fuelwood has been a thriving and sustainable industry since the 1950s. Fuelwood trade in the province provides income and employment to an estimated 45 000 to 65 000 people. In general, the fuelwood marketing system in Cebu appears to be competitive and efficient. Roughly 150 000 to 200 000 tonnes of fuelwood (including coconut fronds), and 40 000 to 50 000 tonnes of charcoal are sold every year. From 1992 to 2002, the value of commercial biofuel trade in the province of Cebu was estimated between US$9.3 million and US$12 million per year.

97 The information included in this section was either adapted or excerpted from: FAO (2002/4a).

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3.14 SUSTAINABLE IRRIGATION

Amir Kassam, Maizura Ismail, Marco Colangeli[98]

Key features

Irrigation involving excessive water application and insufficient drainage leads to land degradation caused by waterlogging, rising groundwater level and salinization, especially in arid and semi-arid zones where evaporation rates are high. Most crops do not grow well on saline soils as the salts cause a reduction in water uptake by plant roots, while some salts are toxic to plants when present in high concentration (Brouwer *et al.* 1988; Pereira *et al.* 2002). If more agricultural land becomes unsuitable to cultivate due to waterlogging, rising groundwater level and salinization, more rural poor will lose their agricultural resource base upon which their livelihoods depend. Rehabilitation of degraded irrigated land is possible by improving the drainage systems. However, this may involve high and often unavailable investment capital. Therefore, it is necessary to improve the sustainability of existing irrigation systems, taking into consideration crop water requirements and limited water availability. In addition, the agronomic and production system measures such as minimum soil disturbance and soil mulch cover can reduce soil evaporation and irrigation water requirement, and improve water use efficiency as well as crop water productivity (Molden 2007; Kassam *et al.* 2007; Basch *et al.* 2012).

Farmers may increase plant water availability in irrigated agriculture by minimizing water losses from irrigation systems; increasing the effectiveness and efficiency of water application; increasing aquifer and groundwater recharge, and improving water collection during rainy season for off-season irrigation (Liniger *et al.* 2011). Water losses from irrigation systems may be minimized by using deep and narrow canals, lining the canals and maintaining them in good condition, while aquifer recharge may be increased by increasing water filtration into the soil. Reducing evaporation while increasing productive transpiration can enhance water productivity if there is adequate plant nutrition (Burt *et al.* 2005). The amount of evaporation depends on the climate, soils, and the extent of mulch cover and of the crop canopy which shades the soil, with evaporation claiming a very high share of evapotranspiration with low plant densities. Similar to rainfed systems, soil evaporation losses under irrigation production can be drastically reduced by using no-till practice with soil surface mulch cover as in Conservation agriculture systems (Basch *et al.* 2012).

Application of water in the field may be improved through knowledge-based precision irrigation approaches/systems (FAO 2011), such as:

- deficit irrigation;
- supplemental irrigation, and
- wastewater harvesting for irrigation,

98 Marco Colangeli is the author of the second example.

and through irrigation technologies, such as:

- drip irrigation;
- microsprinklers, and
- spate irrigation.

Deficit irrigation

Deficit irrigation practices differ from traditional water supplying practices as the main objective is to increase the water use efficiency of a crop by eliminating irrigations that have little impact on yield. The resulting yield reduction may be small compared to the benefits gained through diverting the saved water to irrigate other crops, for which water would normally be insufficient under traditional irrigation practices (Kirda 2002; FAO 2002). Under deficit irrigation all of the applied water remains in the root zone and may be used in evapotranspiration (Fereres and Soriano 2007; Gottlieb *et al*. 2012).

According to Kirda (2002), before implementing deficit irrigation, farmers need to know crop yield responses to water stress and the level of reduced irrigation allowable without significant reduction in crop yields. This varies from crop to crop (Doorenbos and Kassam 1979), with the high-yielding varieties more sensitive to water stress than low-yielding varieties. Also important is information on soil water retention capacity, with deficit irrigation more suitable to soil with fine texture than to sandy soils. Among field crops, groundnut (*Arachis hypogaea*), soybean (*Glycine max*), common bean (*Phaseolus vulgares*) and sugar cane (*Saccharum officinarum*) show proportionately less yield reduction than the relative evapotranspiration deficit imposed at certain growth stages.

There are two main types of deficit irrigation: sustained deficit irrigation (SDI) and regulated deficit irrigation (RDI) (Santos *et al*. 2007; Shatanawi 2007; Fereres and Soriano 2007; Ramos and Santos 2009 and 2010). In SDI, the irrigation is reduced during the whole season, while RDI starts with normal irrigation and then gradually irrigation is reduced. In RDI, the deficit irrigation strategy is based on limiting non-beneficial water losses by reducing the amount of water for the crop during non-critical phenological stages. The deficit irrigation is controlled during times when the adverse effects on productivity are minimized.

As summarized in Aboukeira (2010), Geerts and Raes (2009) and Fereres and Soriano (2007), field results from both these practices in annual crops and fruit trees and vines show that deficit irrigation can reduce irrigation water use and raise crop water productivity in a number of crops. Globally, the potential benefits of deficit irrigation derive from three factors: reduced costs to production, greater irrigation water use efficiency, and the opportunity costs of water (Aboukeira 2010).

Supplemental irrigation

Supplemental irrigation is an irrigation system that provides small amounts of water to rainfed crops during times when there is a shortage of rainfall and soil moisture during the most sensitive growth stages, such as flowering and grain filling, in order to improve and stabilize yields (Oweis and Hachum 2005). One of the key benefits of supplementary irrigation is that it permits early planting. While the planting date in rainfed agriculture is determined by the onset of rains, supplemental irrigation allows the date to be chosen precisely, which can improve yield and water productivity significantly (Oweis *et al*. 1999; FAO 2011). Supplemental irrigation usually comes from surface sources and groundwater. Non-conventional water resources, such as treated wastewater, may also be used (FAO 2002).

Wastewater harvesting for irrigation

According to FAO RNE (2003), whenever good quality water is scarce, water of marginal quality may be considered for irrigation purposes, although it may require more complex management practices and more stringent monitoring procedures. For practical purposes, water of marginal quality can be defined as "water that possesses certain characteristics which have the potential to cause problems when it is used for an intended purpose" (Pescod 1992). The municipal wastewater is an example of marginal quality water, due to the associated health hazards. Another example is the brackish water, with potential problem rising from its high dissolved salt content.

Treatment of wastewater and its use for irrigation may be an option, particularly in arid and semi-arid areas, as it represents an additional, renewable, reliable source of water that may also include fertilizer for the crops. However, due to the different nature of this wastewater in terms of its mineral load and organic and biological constituents, its reuse should be carefully administered and professionally monitored and managed to ensure limited potential risks and threats to the soil, water, crops irrigated, as well as to the whole environment. The constituents of the wastewater must be taken into consideration for better management practices, including: suspended solids; nutrients; salinity, and pathogens.

Wastewater needs to be treated prior to distribution on the farms, to produce treated effluents of suitable and acceptable level of risk for human health and the environment. The most widely used natural biological treatment is the "Wastewater Stabilization Ponds[99]", which may be designed to achieve different degrees of wastewater purification.

Drip irrigation

According to Brower *et al*. (1988), drip irrigation, also known as trickle irrigation, involves dripping water onto the soil at very low rates (2-20 litres/hour) from a system of small diameter plastic pipes fitted with outlets called emitters or drippers. Unlike surface and sprinkler irrigation that wet the whole soil profile, in drip irrigation water is applied close to plants so that only part of the soil in which the roots grow is wetted, therefore this can be a very efficient method of irrigation. To provide favourable high moisture level in

99 The system consists of three phases, namely: anaerobic ponds, normally having earth embankments with depth between 2 and 5 m and functioning as open septic tanks with gas release to the atmosphere; facultative ponds also formed by earth embankments, where aerobic biological reactions could proceed in the middle layer through facultative bacteria; and maturation ponds providing tertiary treatment and further pathogen reduction.

the soil in which plants can flourish, water is applied frequently (usually every 1-3 days), conveyed under pressure through a pipe system to the fields.

Drip irrigation is most suitable for row crops (vegetables, soft fruit), tree and vine crops where one or more emitters can be provided for each plant[100]. Generally only high value crops are considered because of the high capital costs of installing a drip system.

Microsprinklers

Sprinkler irrigation applies irrigation water in ways similar to natural rainfall. Water is distributed through a pipe and sprayed into the air through sprinklers, where the water breaks up into small drops and fall to the ground. Microsprinklers, also known as mini-sprays, microsprays, jets, or spinners depending on the water throw patterns, have emitters with flow rates that vary depending on the orifice size and line pressure (Hla and Scherer 2003) Sprinkler irrigation is suited for most row, field and tree crops and water can be sprayed over or under the crop canopy. A good clean supply of water, free of suspended sediments, is required to avoid problems of sprinkler nozzle blockage and spoiling the crop by coating it with sediment (Brouwer *et al.* 1988).

Spate irrigation

According to van Steenberg *et al.* (2010), spate irrigation is an ancient practice by which floodwater is diverted from its river bed and channeled to basins where it is used to irrigate crops and feed drinking-water ponds, serve forest and grazing land and recharge local aquifers. Common features of spate irrigation schemes include:

- *ingenious diversion systems*: built to capture short floods, as well as designed to keep out the larger and most destructive water flows;
- *sediment management*: as the flood water has high sediment loads that would otherwise fill reservoirs and clog intake structures and distribution canals, the sediments are manipulated and used to build up soil and level the land;
- *soil moisture conservation*: to store spate irrigation water in the soil for use by crop plants, and
- *social organization*: to manage the sometimes complex system, ensure timely maintenance of the structures and channels, and oversee the fair distribution of the flood water.

Spate irrigation is as much about sediment management as it is about water management. It relies on the high sediment loads that also bring along nutrients from upstream catchments, to maintain soil fertility.

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100 Accomplishments in the irrigation of fruit trees and vines with an innovative technique of imposing deficit irrigation by alternating drip irrigation on either side of the fruit tree and vine row (partial root zone drying, PRD) are summarized in Fereres and Soriano (2007), dos Santos *et al.* (2003) and Goldhamer *et al.* (2002).

Potential benefits

Soil quality

The sustainability of irrigated production depends on minimizing negative externalities such as salinization and export of pollutants, but also on enhancing and maintaining soil health and quality, and its productive capacity (FAO 2011). Soil health is not only a matter of applying mineral fertilizer but depends on maintaining good soil structure and porosity, as well as a high level of soil organic matter and biological activities. This requires that the irrigated production systems are promoted based on Conservation agriculture principles so that factor productivities can be optimized and high soil quality sustained.

With regard to the use of wastewater for irrigation, in addition to direct economic and social benefits that rise from conserving natural resources, farmers may take advantage of the fertilizing value of wastewaters. Pescod (1992) estimated that typical wastewater effluent from domestic sources could supply all of the nitrogen and much of the phosphorus and potassium that are normally required for agricultural crop production. In addition, micronutrients and organic matter also provide additional benefits.

Water availability and quality

Proper application of deficit irrigation may reduce overall water requirement without significantly affecting yields (Kirda 2002; Fereres and Soriano 2007). According to Kirda (2002), deficit irrigation may provide acceptable and feasible irrigation options for minimal yield reductions with limited supplies of irrigation water for a number of crops, including: soybean (during vegetative growth); wheat (during flowering and grain filling stages), and sunflower and sugar beet (during vegetative and yielding stages). Thus, the productivity of the applied irrigation water under deficit irrigation (i.e. the application of water below the full crop-water requirement), is higher than under “full” irrigation (i.e. the application of water to meet the full crop-water requirement) (Fereres and Soriano 2007).

Use of wastewater for irrigation as well as drip irrigation may also increase water availability or release water with better quality for domestic needs. In areas where water is limited, the same amount of water that would not be sufficient to conventionally irrigate a plot may be enough to provide minimum irrigation to all the plants for them to survive through the summer months through drip irrigation, and leaving also some water for domestic needs (ITC *et al.* 2003). At the same time, use of wastewater may also help partially solve the problem of coping with the pressing environmental problem of wastewater disposal (FAO RNE 2003).

Human health and safety

Overall, as water application and use efficiency improves, and productivity is optimized, there should be a decrease in wastage of water and health hazards created by waterlogging and water pollution from agrochemicals. Although primarily for cropping, water collected through spate irrigation may also be used by farmers and surrounding communities as drinking water. At the same time, spate irrigation may also recharge groundwater supplies and provide more water for human use (van Steenberg *et al.* 2010).

Challenges

Pest issues

The primary constraint to harvesting wastewater for irrigation is public health as wastewater, especially from domestic sources, may contain pathogens such as bacteria, viruses, protozoa and helminthes, which can cause disease spread when not managed properly (Westcot 1997). These pathogens may be able to survive for days, weeks or months in the soil and on crops that come in contact with wastewater. Use of wastewater irrigation through overhead irrigation such as sprinklers, for example, may contaminate ground crops, fruit trees and farm workers (Pescod 1992). Therefore, the primary objective of any project reusing wastewater must be to minimize or eliminate potential health risks.

Input and labour requirements

One of the main problems with micro-irrigation systems is blockage of the emitters if the water is not clean, due to the very small waterways used (Brouwer *et al*. 1988). Water used in drip irrigations needs to be free of sediments, algae, fertilizer deposits and dissolved chemicals, or filtration may be used otherwise. At the same time, animals, rodents and insects, even frost, may cause damage to some components (Hla and Sherer 2003). Due to this complication, micro-irrigation systems, such as the drip irrigation and microsprinkler, normally have greater maintenance requirements and may require an experienced engineer or consultation with the equipment dealer.

Spate irrigation systems may be vulnerable to disuse as more landowners install their own wells. As more farmers become less dependent on spate water for irrigation and less labour is available to maintain the system, the remaining spate farmers may be unable to mobilize sufficient labour and draught animals for the timely reconstruction of the diversion structure, as well as for the cleaning of the flood canals. As a result, the diversion of spate water to their fields may become more difficult and more landowners may have to give up spate-irrigated agriculture, making the spate irrigation system non-functioning as the capacity to maintain the irrigation infrastructure is no longer available (van Steenberg *et al.* 2010).

Access to finance

Micro-irrigation systems are ideal for high value installations such as orchards, vineyards, greenhouses, and nurseries where traditional irrigation methods may not be practical, however the initial investment may be high (Hla and Sherer 2003). Thus, micro-irrigation systems might not be affordable to subsistence or poor farmers.

Awareness, education, and research and development

The application of sustainable irrigation practices and technologies requires farmers to be aware of crop yield responses and of the technologies involved. For example, deficit irrigation requires significant knowledge of crop yield responses to deficit irrigation at certain growth stages; use of wastewater requires knowledge of pathogens and of their ability to survive on soil and crops; while microsprinklers require knowledgeable farmers to regularly maintain the systems.

Overall, knowledge-based precision irrigation will become increasingly a basis for sustainable crop production intensification, as more investments are made to improve irrigation management and water productivity with new production systems such as CA (FAO 2011), and System of Rice Intensification (SRI) methods in which irrigated rice is produced under aerobic soil conditions using resource-saving agronomic management (Uphoff *et al.* 2011; Kassam *et al.* 2011). This will require greater awareness of the changing paradigm and knowledge base and the need for this to be reflected in agricultural education, research and technology development.

Policies and institutions

Certain irrigation and water management schemes involve groups of farmers rather than individuals as they cover a large area. Therefore high levels of cooperation are required. In spate irrigation, for example, farmers and the community need to work closely together to divert and distribute flood waters and maintain their intakes and canals. Spate irrigation also involves a certain level of uncertainty that stems from the unpredictable numbers, timing and volumes of floods, the occasional very large floods that wash out diversion structures, and the frequent changes to the wadi channels from which the water is diverted (van Steenberg *et al.* 2010). These issues call for substantial local wisdom in setting up and constructing intakes, organizing water distribution and managing the flood waters and their heavy sediment loads.

Policy and institutional support is also needed to transform rainfed and irrigated agriculture towards greater sustainability. Irrigated CA and SRI require longer-term policy and institutional support to enable farmers to accelerate their adoption of these production systems which not only save water but also offer higher water productivity than conventional production systems. In this regard, a change in mind-set is involved on the part of the producers and their supply chain service providers. In addition, there is a need to reduce the risks for farmers who are willing to adopt sustainable irrigation technologies and crop production systems that can also address issues related to increasingly greater resource degradation and scarcity, rising costs of agriculture inputs including energy and water, and climate change.

Examples in bioenergy feedstock production

Region: East Africa
Country: Eritrea
Crops/Feedstocks: Maize (*Zea mays*); sorghum (*Sorghum bicolor*)

Spate irrigation for maize and sorghum production in Eritrea[101]

Spate irrigation has a long history in Eritrea and still forms the livelihood base for rural communities in arid lowlands of the country. With this technique, seasonal floods of short duration springing from the rainfall-rich highlands are diverted from ephemeral rivers (wadis) to irrigate cascades of leveled and bunded fields in the arid coastal plains. The main crops grown in spate irrigated areas in Eritrea are sorghum and maize.

Relatively high yields are obtained in the eastern lowlands of Eritrea using spate irrigation. The water management practice there consists in diverting as many spate flows as possible to a given area; through this system, up to two or three irrigations may take place before planting. The result of this approach is that in a good year, harvests in Sheeb region of Eritrea yield up to 3 800 kg/ha of sorghum on the first cutting and around 1 500 Kg/ha as a ratoon[102] crop. In nearby locations, where spate irrigation is not adopted or poorly managed, sorghum yields are as low as 800 kg/ha on the first cutting.

In Sheeb, under well managed spate irrigation and favourable floods regimes, maize yields up to 2 000 kg/ha, whereas without spate irrigation, Eritrean farmers produce on average 500 kg of grain per hectare (FAO 2010).

Region: South Asia
Country: India
Crop/Feedstock: Sugar cane (*Saccharum officinarum*)

Sustainable irrigation in a sugar-cane farm in Belgaum, India[103]

Suresh Desai is a farmer in the Belgaum District of Karnataka, India, where he owns a 4.5 hectares farm. For nearly a decade, Suresh followed conventional practices, relying on external inputs in the form of chemical fertilizers and pesticides, and flooding the fields. In this area of India, sugar cane is grown in three-year cycles. After cutting the cane, the sugar-cane trash is generally burned, in order to improve initial re-growth of the ratoon crop, and as a pest control strategy. Irrigation in this area of India is done by flooding the fields, and most of the nutrients contained in the ashes are leached out with the first irrigation.

101 The information included in this section was either adapted or excerpted from: Liniger *et al.* (2011).
102 Ratoon cropping is defined as producing a new crop without replanting (Stinson *et al.* 1981).
103 The information included in this section was either adapted or excerpted from: FAO (2002a).

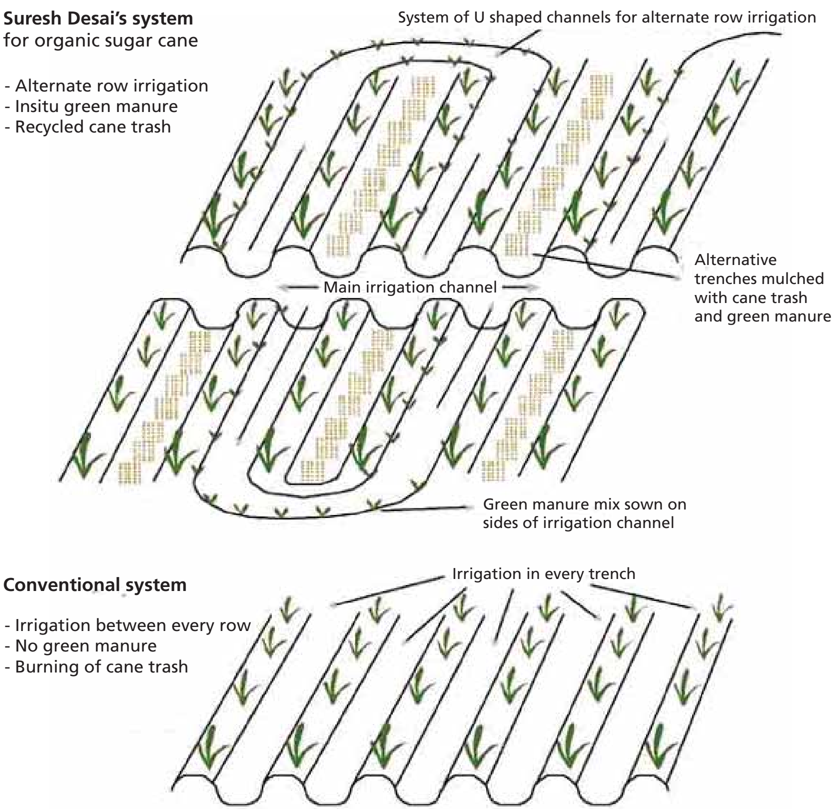
Suresh's sugar-cane yields used to be around 100 tonnes/ha, in line with those of his neighbours. However, Suresh noticed a process of degradation unfolding in his fields. The crops became increasingly affected by pests and diseases, the soil gradually lost its fertility and structure, and water supplies were dwindling. With the escalating prices of external inputs, Suresh began thinking he needed a drastic change in the methods of cultivation of his sugar-cane fields.

Suresh began to compost sugar-cane residues *in situ*, i.e. in the fields used for the production of this crop during the previous growing season. With this method, Suresh was able to reduce the application of chemical fertilizers by 50 percent. However, problems related to irrigation started to appear: groundwater levels declined drastically, and the fields became slowly gorged with water and laden with salts. Suresh came to understand that irrigation itself was responsible for the spoilage of his soils.

He then decided to use the trash obtained after the cutting of the canes as mulch, so that evaporation losses would be significantly reduced, the need for irrigation would diminish, and the salinization problem would eventually be overcome. In order to increase watering efficiency, Suresh disposed the sugar-cane trash in one row and the water was provided in the next row (see figure 5). Further, by connecting two parallel irrigation rows with a perpendicular trench at the ends, he made watering the fields much easier.

Figure 5

Diagram of the sustainable irrigation system used by farmer Suresh Densai in his sugar-cane farm in Belgaum, India



Source: edited from: FAO (2002b)

Thanks to this system, Suresh Desai was able to reduce his irrigation requirements by 50 percent; after harvesting the cane, the remaining trash was gathered in the row that was used previously as the irrigation channel.

After three years, Suresh observed a significant improvement in soil quality and a remarkable increase in soil life. He also started introducing green manure between the rows of cane and found that using chemical fertilizers became unnecessary. In addition, he saw that his crops were healthy and that there was no more need for chemicals to combat pests and diseases. As of 2002, his fields had not been ploughed or turned up for five years. Ever since ploughing stopped, the water-retention capacity of the soil improved further. Consequently, irrigation frequency was reduced from once every 10 or 12 days to 20 or 25 days, thereby achieving a further reduction in water requirements. Overall, the system implemented by Suresh enabled a 75-80 percent reduction in water use compared to conventional methods.

On Suresh's farm, the input cost per hectare was 3 700 Rs (US$74 as of 2002), compared to an average of 15 000 Rs (US$300 as of 2002) per hectare for farmers not using his sustainable irrigation system. Yields in Suresh's farm were 100 t/ha, around 10 percent lower than those of his neighbours. However, Suresh's net profit (US$1 126 as of 2002) was higher than that of the other farmers in the area (US$1 020 as of 2002), as a result of the lower input costs.

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3.15 WILD BIODIVERSITY MANAGEMENT AT FARM LEVEL

Maizura Ismail, Romina Cavatassi, Marco Colangeli[104]

Key features

The Millennium Ecosystem Assessment (2005) has identified the intensification of agricultural production systems including the conversion of forested areas into agriculture among the key drivers of biodiversity loss in the last 50 years. On one hand, agricultural intensification has led to a significant increase in the supply of food, feed, fibre and fuels. On the other hand, this process has significantly affected biodiversity and ecosystems (FAO 2007), mainly through land use change leading to habitat loss, increases in nutrient-associated pollutants, and the spread of invasive alien species and disease organisms (MEA 2005).

Whereas agricultural intensification has initially led to a tremendous increase of agricultural production, in the long run excessive intensification can lead to a decline in productivity due to over-exploitation of ecosystem services[105] including plant genetic diversity, soil micro-organisms, pollinators, and biological predators of pests (WBCSD and IUCN 2008).

Nevertheless, farmers may conserve, enhance and manage biodiversity and related ecosystem services through good agricultural practices which utilize ecosystem-based approaches[106] designed to improve the sustainability of production systems.

Examples of measures to conserve wild biodiversity in an agricultural landscape include (McNeely and Scherr 2002 in FAO 2007):

- enhancement of wildlife habitat on farms and establishment of farmland corridors that link uncultivated spaces;
- mimicking of natural habitats by integrating productive perennial plants;
- use of farming systems that reduce pollution, and
- modification of resource management practices to enhance habitat quality in and around farmlands.

Enhancement of wildlife habitat on farms and establishment of farmland corridors that link uncultivated spaces

through good practices such as:

- Set aside land/conservation reserves: selected land areas should be set aside and not used for agricultural purposes, so increasing the complexity of vegetation in

104 Marco Colangeli is the author of the first example.

105 Ecosystem services are natural processes and functions within the ecosystem, resulting from the interactions among an assemblage of living organisms and the chemical and physical environment, that give rise to a range of goods and services fundamental to sustain and improve human well being (POST 2006).

106 For a description of the *Ecosystem Approach*, see section 1.2.

agricultural landscapes, providing diverse pollen, nectar and microhabitat for native species of insects, birds and small mammals107.

- Field margins/vegetative buffer strips: a field margin/buffer strip is a strip/margin of vegetation along contours or boundaries that is left unmanaged or is managed to reduce the impact of intensive agriculture of one area on an adjacent area. They are usually located between fields or between agricultural areas and sensitive native habitats, and may serve both to protect the environment and enhance biodiversity. When located along waterways and water bodies, the margins/strips are known as riparian buffer strips or stream filter strips, and may contribute towards maintaining pure water sources, as well as enhancing the area for wildlife habitat and movement.
- Windbreaks/shelterbelts/hedgerows: windbreaks/shelterbelts/hedgerows are barrier of trees or shrubs that are used as demarcation between fields and roads or between two fields mainly to prevent wind erosion, reduce evapotranspiration, and provide a shelter for animals. They may also provide habitat for wildlife, serve as biological corridors, and reduce water runoffs. The effectiveness of windbreaks and shelterbelt depend on their permeability, shape and height.

Mimicking natural habitats by integrating productive perennial plants

Mimicking natural ecosystems on the farm includes application of agroforestry systems, such as planting woody perennials or trees in combination with crops; planting patches of different native vegetation on farm, and ensuring crop and plant species in multistrata mixture.

Use farming systems that reduce pollution

The negative impacts of agricultural intensification on wildlife generated by the utilization of agrochemicals may be reduced if quantities, methods and timing of agrochemical applications are adapted to specific agronomic requirements and handled by agrochemical experts (Poisot *et al.* 2007).

Modify resource management practices to enhance habitat quality in and around farmlands

Improvements in farm's management and resource utilization may allow wild species to thrive, while maintaining or increasing farm profitability.

For example, reduced tillage may encourage below-ground biodiversity, thus increasing soil water infiltration and reducing the farm's irrigation requirements and costs. Application of diverse cropping patterns such as intercropping and crop rotation, including cultivation of legumes to provide a biological source of nitrogen may reduce the costs of farm's inputs, while at the same time creating an environment more conducive to biodiversity proliferation.

107 In the United States, for instance, conservation reserves are set aside for biodiversity conservation, with incentives in the form of payment for environmental services.

Potential benefits

Soil quality

Biodiversity-friendly farming practices encourage the proliferation of both surface and underground biodiversity, including fungi and bacteria that carry out important functions related, among other things, to: soil water dynamics; nutrient cycling; decomposition of pesticides and pollutants; soil organic matter accumulation, and trapping and parasitizing of disease-causing nematodes (Inghams 2000).

Shelterbelts and windbreaks also act as wind erosion control and shield against sand encroachment in desertified areas (Lu and Lu 1997).

Water availability and quality

Riparian buffer strips play an important role in providing habitat to wildlife. Maintenance of native grass species in riparian buffer strips has positive effects on water quality, as these species often have extensive root systems that may serve to prevent erosion and catch sediment and nutrients, thereby filtering runoff and improving water quality (Scialabba and Williamson 2004).

Biodiversity

For a description of the positive effects on biodiversity of good agricultural practices, please refer to the key features section above.

Agrobiodiversity

Biodiversity is key to agricultural development (Serrano 2008). Breeding of new varieties can largely benefit from the genetic material of their wild relatives to obtain new varieties that produce higher yields or are more resistant to drought, pests and diseases as well as to increase the nutritional content.

Productivity/income

The biodiversity-friendly practices described above may reduce the risk of habitat loss and fragmentation, which can break the balance between different wildlife population species, and affect ecosystem functioning (Steinfeld *et al*. 2006) and, possibly, crop production.

Another positive aspect of adopting good agricultural practices such as the ones described above is the possibility, where they exist, of getting compensated through payments for environmental services (PES) schemes. These are offered in a number of countries, mostly developed, where public funds (although some private initiatives are also in place) are increasingly being used to provide incentives for producers to take greater account of the negative externalities of production and to implement biodiversity-friendly practices. In addition, there are government programmes that explicitly compensate farmers for delivering ecosystem services (Cassman *et al.* 2005). Compensation schemes based on market mechanisms include: land markets for high-biodiversity-value habitat; payments for private, non-consumptive uses such as ecotourism; tradable rights and credits within a regulatory cap on habitat conversion, and ecolabelled products such as shade-grown coffee, herbal medicines and other botanicals from natural forests (Scherr *et al.* 2004).

Last but not least, some of the agricultural practices above described may also have other positive benefits. Windbreaks, for instance, can be designed for sheltering livestock, protecting them from windchill, which is a major stress on animals living outside in winter, thus generating positive effects on animal welfare and productivity (Beetz 2002).

Availability of inputs

Planting complexes of regionally specific native perennial grasses and other herbaceous and wood perennial species in buffer strips can be an effective and inexpensive way to address the common management problem of weed control (Scialabba and Williamson 2004).

Access to energy

Proper selection of trees for shelterbelt and hedges by farmers can have a number of benefits, including: enhanced biodiversity; production of additional food and fodder; erosion control, and protective shields from sand encroachment and chemical drift. In addition, farmers could also collect fuelwood and timber (FAO 2002; Musnad and Nasr 2004).

Food security

Wild edible plants, fruits and insects largely widespread in Africa, Asia and Australia can also represent important sources of food in emergency situations (FAO 1995; Mbabazi 2010).

Challenges

Pest issues

Several species, such as peccaries, single-antler deer, pacas, agoutis and some monkeys are in the habit of raiding cultivated patches amid the forest, and can do considerable damage and even become farm pests (Ojasti 1996). Leaving an unharvested strip of crop can also unintentionally attract animals to production areas, leading to crop losses (Scialabba and Williamson 2004).

As conservation programmes expand and contact between humans, domestic animals and wildlife increases, conflicts between biodiversity conservation, public health and domestic animal health may intensify (POST 2008). Movements of animals provide a route for the transfer of pathogens between animals and the spread of diseases to new areas.

Land tenure

Conflicting or poorly defined property rights to land, water and other natural resources represent a key barrier to on-farm application of conservation and biodiversity-friendly farming practices (FAO 2007).

Opportunity and production costs

When land is set aside for conservation purposes as well as when new farming practices are adopted, there are opportunity costs associated with the agricultural production that is foregone. Whilst the foregone income or the high investments costs required might be compensated by financial compensation programmes, these are still too few and scant to provide a possible solution that would lead to widespread adoption of conservation practices that do not hurt farmers.

Access to finance

The value of ecosystem services is often underestimated, due mainly to the difficulty of attributing a value to goods and services for which a market does not exist, such as those provided by the ecosystem. This is one of the reasons why PES is still not widespread and why the willingness of financial institutions to provide credit to farmers in order to implement biodiversity-friendly practices remains low. The inability to afford investments requiring financial expenditures in the short run in order to obtain benefits in the long run, coupled with the risk connected to long-term investments is one of the main reasons why farmers sometimes fail to adopt practices that promise to offer higher returns (FAO 2007).

Awareness, education, and research and development

Lack of information on and the learning process required to adopt biodiversity-friendly products and good agricultural approaches is a key barrier to on-farm application of conservation and biodiversity-friendly farming practices (FAO 2007).

Examples in bioenergy feedstock production

Region: South Asia
Country: India
Crop/Feedstock: Sugar cane (*Saccharum officinarum*)

Control of planthopper *Pyrilla perpusilla* in large scale sugar-cane plantations in Uttar Pradesh, India, through management of ecto-parasitoid *Epiricania melanoleuca*[108]

The sugar-cane lophopid planthopper *Pyrilla perpusilla* is a major pest affecting sugar cane in India (as well as other parts of Asia), but it has also been reported to affect other crops such as wheat, maize, and millet. *Pyrilla perpusilla* sucks phloem sap from leaves and excretes honeydew onto foliage, leading to fungal diseases. This direct and indirect damage affects sugar yield and quality, with reported losses in sucrose content ranging from 2 to 34 percent. On average, this pest reduces sugar-cane yields by 28 percent, and difficulties in milling cane from affected plants have also been recorded.

Initial attempts to identify the parasitoids of *P. perpusilla* were carried out between the 1920s and the 1940s. Recently, further research has been conducted, with the aim of developing integrated pest management programmes. Sixteen species of natural enemies of *P. perpusilla* were identified in India through this research.

Epiricania melanoleuca[109] (Lepidoptera: Epipyropidae) was found to be particularly effective in reducing pest populations by as much as 90-100 percent. In 2007, in Uttar Pradesh, India, a mild winter contributed to an epidemic of *Pyrilla perpusilla*. In order to control this epidemic, three sugar mills of Uttar Pradesh covering an area of approximately 40 000 ha introduced a management programme for the ecto-parasitoid *Epiricania melanoleuca*. This larva was so effective in controlling the *Pyrilla* population that the use of pesticides became unnecessary. Sugar-cane production was not significantly affected, and spraying was not performed, resulting in a saving of Rs.1600/ha (USD39.75/ha), in addition to avoided environmental pollution. Since 2007, in sugar mills in Uttar Pradesh, when *Epiricania melanoleuca* cocoon is present in field at a rate of one to five individuals/leaf, and *Pyrilla* population level ranges from 20 to 150 individuals/leaf, insecticides are not used at all.

As this example shows, using non-lethal pest control practices by relying on natural control methods can be effective in copying with pests, including major epidemics. The conservation and management of natural enemies is therefore essential.

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108 The information included in this section was either adapted or excerpted from: Kumarasinghe and Wratten (1996) and Gangwar *et al.* (2008).

109 This larva feeds through the host cuticle by penetrating it with sharp mandibles, allowing the parasitoid to suck the host's body fluids.

Region: East Asia
Country: China
Crop/Feedstock: Wheat (*Triticum spp.*)

High diversity shelterbelts for fuelwood production, and for the control of wind erosion, salinization and desertification, increase wheat yields in Xinjiang, China[110]

The Xinjiang Autonomous Region is located in the western part of China and is home to the biggest desert in the hinterland of Eurasia. Located far from the sea, this region is surrounded by mountains, with 3.53 percent of the total land area consisting of scattered forested lands, called "*oases*". Mostly desert, with high radiation, limited water resource and a growing population, the Xinjiang oases are increasingly being affected by sandstorm events, desertification and salinization. These processes, which are due to over-grazing, unsustainable forest harvest and unsustainable irrigation, in addition to the adverse climatic conditions of the area, have led to a reduction in wheat yields.

To counter these problems, an oasis forestry development model suitable to Xinjiang was developed, consisting in the establishment of a protective, high diversity forest system composed of grasses, shrubs and trees. Under this system, a shrub-grass barrier was built around the periphery of the oasis; large scale windbreaks and sand-fixing forests were planted around it, and a shelterbelt forest network was established in the inner oasis area, under intercropping or other agroforestry systems. These forests provide timber, fuelwood and fodder.

The shrub-grass barrier[111], 50-60 cm in height, resulted in less top soil movement, reducing soil erosion by wind. In particular, shrub-grass barriers with a width of 250 cm were found to intercept up to 90 percent of the blowing sand, with this percentage increasing to 97 percent with a barrier with a width of 570 cm. In addition, each hectare of shrub-grass produced enough fodder for 5-12 sheep.

A further protective barrier is provided by the windbreaks and shelterbelts around the oasis. In irrigated areas, sandstorm resistant tree species such as *Populus euphratica*, *P. balleana*, *Ulmus pumila*, *Elaeagnns* spp., *Salix alba*, *Calligonum mongolicum*, and *Hippophae rhamnoides,* were planted as protective forest belts. In areas with no irrigation, salt cedar and saxaul were planted. Inside oases used for intercropping trees and crops, "narrow belts" were established. Plants with high economic value such as *Amygdalus communes*, *Zizyphus* spp., *Juglans regia* and *Morus alba* were introduced as well. Shelterbelts contributed to a significant decrease in soil erosion by wind, with positive effects on crop yields in the Xinjiang region. In addition, shelterbelts provided a large amount of biomass in the form of fuelwood and timber.

The shrub-grass barriers, windbreaks and shelterbelts established in Xinjiang

110 The information included in this section was either adapted or excerpted from: Lu and Lu (1997).
111 The shrub-grass barriers comprises the following species: *Alhagi sparsifolia; Medicago saliva; Haloxylon ammodendron; Magi sparsifolia; Tamarix spp.; Caragana spp.;* and *Astragalus adsurgen.*

contributed to modify the microclimate and to increase agricultural productivity. In particular, wind velocity was reduced by 80 percent at 1.5 m height, and evaporation reduced by 22.2 percent. Salt content up to 100 cm below the surface was reduced by 79.3 percent in seven-year-old forests when compared to open fields. Last, but not least, wheat yield increased by 193 percent compared with non-protected fields in the Xinjiang region.

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ENVIRONMENT – CLIMATE CHANGE – BIOENERGY – MONITORING AND ASSESSMENT

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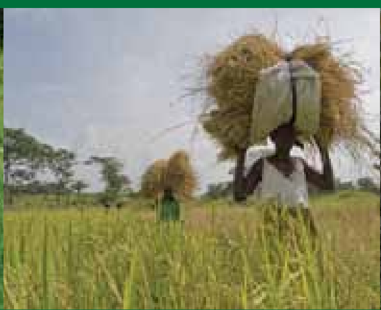
In order to ensure that modern bioenergy development is sustainable and that it safeguards food security, a number of good practices can be implemented throughout the bioenergy supply chain.

Building on FAO's work on good practices in agriculture and forestry, the FAO's Bioenergy and Food Security Criteria and Indicators (BEFSCI) project has compiled a set of good environmental practices that can be implemented by bioenergy feedstock producers so as to minimize the risk of negative environmental impacts from their operations, and to ensure that modern bioenergy delivers on its climate change mitigation potential.

These practices can improve both the efficiency and sustainability in the use of land, water and agricultural inputs for bioenergy production, with positive environmental and socio-economic effects, including a reduction in the potential competition with food production. These practices can also minimize the impacts of bioenergy feedstock production on biodiversity and ecosystems, which provide a range of goods and services that are key for food security.

The good practices compiled in the BEFSCI report are divided into three main groups. The first group is comprised of agricultural management approaches (namely Ecosystem Approach, Conservation Agriculture and Organic Agriculture), which provide comprehensive and holistic frameworks and principles of sustainable agriculture. The second group consists of integrated, sustainable agricultural and forestry management systems, namely Agroforestry, Integrated Food-Energy Systems, and Multiple Cropping Systems and Crop Rotation. The third and last group includes a broad range of field-level agricultural and forestry practices that can be implemented on the ground by bioenergy feedstock producers, such as No- or Minimum Tillage, Integrated Pest Management, and Integrated Plant Nutrient Management.



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