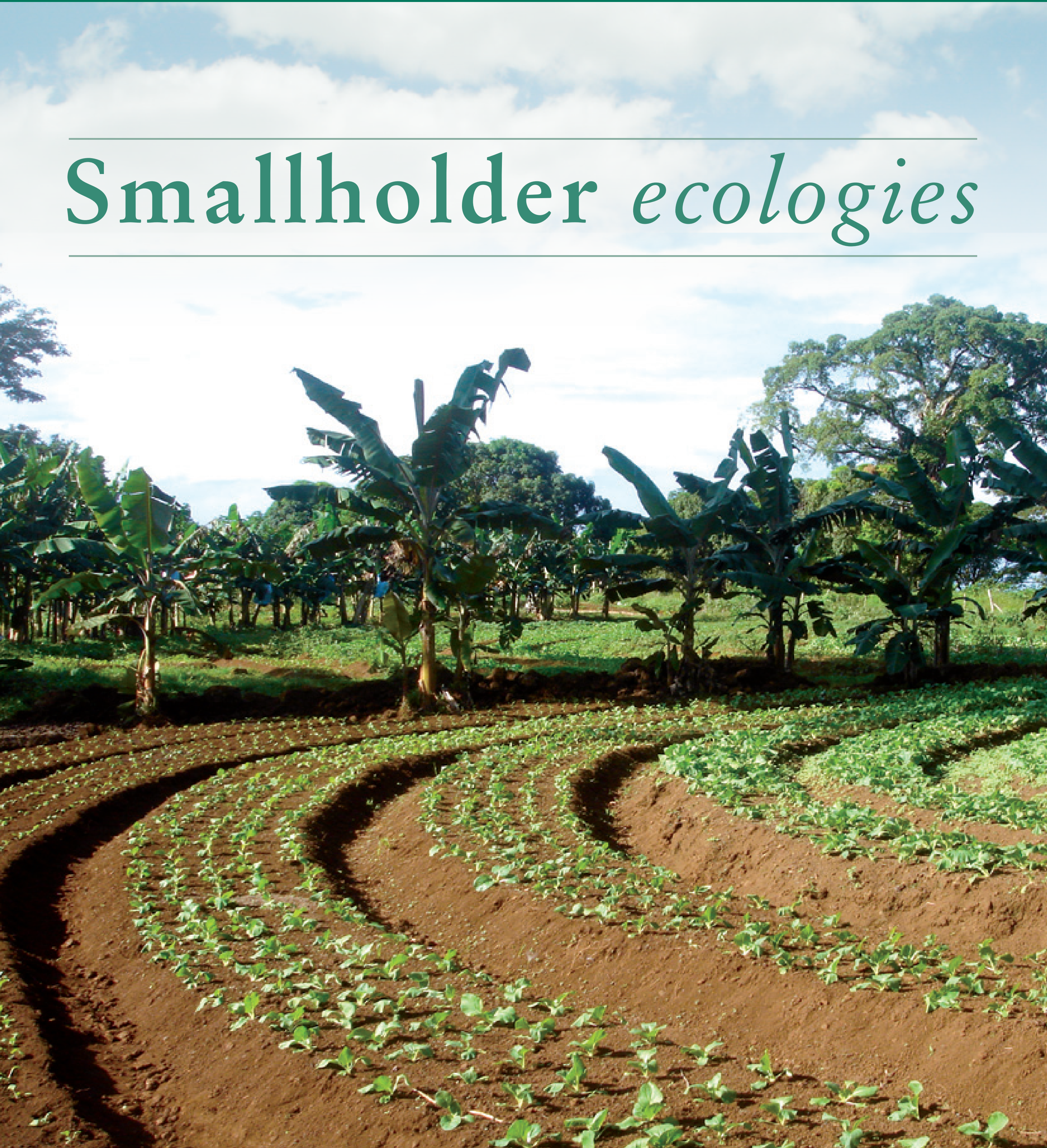
Food and Agriculture Organization of the United Nations

Smallholder *ecologies*



Smallholder *ecologies*

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Abstract

Global food and agriculture systems face a series of inter-related challenges; to assure food security for a growing world population while supporting decent livelihoods and reducing the environmental footprint of agriculture. Agroecological approaches can address these challenges by contributing to a greener economy. Agroecological systems are diverse, highly inter-connected and perform multiple functions that benefit society. They place a strong emphasis on environmental integrity and social well-being. Moreover, the agroecological mode of production is highly efficient and resilient to disturbances. This document provides a review of the scientific literature on agreocology, including global, regional, national and local studies. In the Annex, the performance of various agroecological management systems are described and compared. Based on these findings, key steps towards an agroecological transition are outlined.

Introduction

Agroecology is the science of applying ecological concepts and principles to the design and management of sustainable food systems (Gliessman, 1998). In addition, agroecology is simultaneously a set of management practices (often based on local, traditional or indigenous knowledge) and a social movement.

Rather than a one-size-fits-all blueprint, agroecological approaches can be seen as a series of principles and methods that have guided farming for millennia, refined and adapted to fit contemporary needs and resources. Agroecological systems perform multiple functions that benefit humanity: they produce food, fuel and fibre, while supporting environmental integrity. Agroecological approaches place a strong emphasis on re-establishing connections between the farm and wider communities. In this way, they build social capital and strengthen social cohesion.

Although the boundaries of what constitutes an agroecological system are not absolute, a diverse range of management systems incorporate agroecological principles. A number of these management systems are described in the *Annex: Performance of different agroecological management options*, including conservation agriculture, integrated pest management, mixed rice-fish systems, mixed crop-livestock systems, organic agriculture, grasslands and forage crops, traditional polycultures, agroforestry systems, perennial grain polycultures, biodynamic agriculture, and permaculture. While agroecological methods could also include ecological intensification through moderate input systems, most agroecological systems are operated by networks of smallholders. This document focuses on these networks and the ways in which smallholders could be assisted to help achieve an agroecological transition.

This document aims to demonstrate why agroecology is important, now and for a sustainable future. Firstly, a brief snapshot is presented, outlining the demographic, food security and environmental challenges facing humanity. In the context of these inter-related global challenges, including Earth system boundaries, it is argued that a new approach to agriculture is desperately needed. Based on a review of the scientific literature, agroecological practices and management systems are evaluated in terms of their potential to contribute to a greener economy by improving productive efficiency and resilience, environmental integrity and social well-being. To conclude, some key steps are outlined towards an agroecological transition that is able to deliver positive impacts on a large-scale.

A perfect storm on the horizon: inter-related global crises

The phrase "perfect storm" has been used to describe the future coincidence of food, water and energy insecurity (Godfray *et al*., 2009). The food component of the coming storm is unavoidably global. Through globalized food markets, countries are highly inter-dependent on each other for their food supplies and the impacts of future food insecurity will spill across national borders (Davies *et al*., 2009).

Driven by population increases, economic growth and changes in dietary patterns, the FAO's modelling scenarios for 2050 predict that demand for food and agricultural products will increase by 1.1 percent per year, a 60 percent increase from 2005-07. This includes a 76 percent increase in demand for meat, which has a high environmental footprint (Alexandratos and Bruinsma, 2012). The challenge of assuring future food security is compounded by a growing demand for biofuels (occupying land that could be used to grow human edible food), increasing water and land scarcity, adverse impacts of climate change and slowing increases in agricultural productivity (Conway and Pretty, 2009; Davies *et al*., 2009).

To meet future food security demands, the orthodox solution is to increase yields by further intensifying agricultural production. However, industrialized agriculture is already associated with a series of negative environmental impacts. High external input agricultural systems cause significant environmental impacts on soil quality and erosion, air and water pollution, eutrophication, pesticide impacts and destruction of biodiversity. Moreover, through nitrous oxide (N_2O) and methane (CH_4) emissions, agriculture is a major contributor to climate change (IPCC, 2014). Pretty *et al*. (2001) conservatively estimated that the external costs of UK agriculture amounted to at least USD 3.8 billion each year. Using a similar framework, the external costs in the US reached nearly USD 34.7 billion per year. Recent research suggests that the full cost of food, including the environmental and social externalities associated with agricultural production, is at least two to three times higher than the financial cost (FAO, 2014).

Our current patterns of production and consumption are placing increasing strain on natural resources. The Global Footprint Network estimates that it would take the equivalent biocapacity of 1.5 planets to match humanity's current ecological footprint (GFN, 2012). Living in ecological deficit is only possible in the short-term because we are depleting the finite stocks of Earth's natural capital. This ecological overshoot will affect future generations who face a permanent reduction in welfare and constrained options to deal with environmental problems. In the long-term, ecological overshoot increases the risk of environmental catastrophe.

Continuing with business as usual will continue to degrade the environment and undermines the natural resource base that all agricultural production depends on, as well as livelihoods. The following section gathers the scientific data on agroecological systems to demonstrate that these can be a viable alternative for efficient and resilient food systems that can contribute to food security and promote sustainability.

Scientific review of agroecological practices

Agroecological practices that aim to increase productivity, while regenerating ecosystems and reducing environmental externalities, have been applied in various countries with significant results in the majority of cases. The following section reviews the scientific literature from agroecology field studies at global, regional, national and local levels.

Increasing productivity while improving ecosystem services

Pretty *et al.* (2006) undertook a global meta-review of regenerative agriculture covering three percent of the total cultivated area in developing countries. In a collaborative project, 286 interventions across 57 developing countries were analyzed. Their research focused on low cost and locally available technologies and inputs, including: integrated pest management, integrated nutrient management[1], conservation agriculture, agroforestry, aquaculture, water harvesting in dryland areas and livestock integration into farming systems.

Through the application of agroecological practices, productivity increased on 12.6 million farms, covering 37 million ha. The average crop yield increase was 79 percent. In addition to productivity gains, the interventions helped to restore and enhance the provision of ecosystem services. In particular, all crops showed water use efficiency gains, with the greatest improvements in rain fed crops. Potential carbon sequestration

1 Integrated nutrient management seeks to balance nitrogen demand, while importing inorganic and organic nutrients, and reducing nutrient losses from erosion.

also increased substantially, by 0.35 t C/ha/year on average. For projects with pesticide data, 77 percent decreased their pesticide use by applying practices such as integrated pest management. The average reduction in pesticide use was by 71 percent. At the same time, yields grew by an average of 42 percent. This illustrates the mutual benefits of agroecological practices, increasing productivity while reducing environmental harm and health risks associated with pesticide exposure.

As part of the UK Government's Foresight project, looking at the increasing pressures on the global food system, Pretty *et al.* (2011) evaluated agroecological practices for the ecological intensification of African agriculture. Forty ongoing projects based in 20 African countries were selected to investigate in detail the processes of developing productive and sustainable agricultural systems on a sufficiently large-scale.

By early 2010, these projects had demonstrated benefits for 10.4 million farmers and their families with improvements on 12.8 million ha of land. Farmers have been able to increase food outputs in two ways. Multiplicative improvements involved adopting new varieties in combination with changes to agroecological management. Using these strategies, crop yields increased by a factor of 2.13 (i.e. slightly more than doubled), over a time period of 3 to 10 years. This has resulted in an estimated increase in aggregate food production of 5.79 million tonnes per year, equivalent to 557 kg for each farming household across all projects. Many projects also improved food outputs by additive means; diversifying production by adding a range of new crops, livestock or fish (in mixed systems), in parallel with existing staple or vegetable cultivation.

Increases in productivity and food outputs (i.e. provisioning ecosystem services) were closely tied to the rehabilitation of critical ecosystem processes (i.e. regulating ecosystem services), including water quantity and quality, soil conservation and quality, and carbon sequestration, while enhancing and conserving biodiversity. Some key examples from the projects are highlighted in Box 1. Many of these environmental processes and cycles are inter-connected. Through a holistic approach to land management, agroecological systems were able to take advantage of these synergies. For example, practices to improve soil conservation and fertility also had positive effects on water quality and storage, soil carbon sequestration and greenhouse gas (GHG) mitigation.

Box 1. **Successful regeneration of ecosystem services in African agroecological projects**

Water quality and quantity. Introducing a greater diversity of trees, crops (e.g. beans, fodder shrubs and grasses) and non-cropped habitats helped to prevent run-off and soil erosion which has contributed to increased groundwater reserves. In some parts of Burkina Faso, the water table has risen 5 meters through rainwater harvesting and measures to prevent soil erosion.

Soil conservation. A key constraint in Africa is the poor quality and lack of nutrient supply of many soils. Many different approaches were applied in the projects, including inorganic fertilizers, organic practices, composting, and adding legumes, fertilizer trees and shrubs.

Agroforestry systems in Malawi, Tanzania, Mozambique, Zambia and Cameroon have introduced 'fertilizer trees' to maize production. Compared to continuous maize cultivation, projects with two out of five years devoted to fast growing and N-fixing shrubs (e.g. Calliandra and Tephrosia) have improved soil quality and fertility, which has contributed to a 60 percent increase in total maize production over the five year period.

GHG mitigation. Improving soil quality has also resulted in greater carbon sequestration and a reduction in GHG emissions from agriculture. The use of legumes and shrubs has improved the C content of soils, while legumes also help to fix N in soils, reducing the need for inorganic fertilizer (and associated N_2O emissions) on subsequent crops.

Biodiversity. A wide range of projects demonstrated that developing local plant and animal materials was highly effective. 'Orphan crops' that have been previously neglected (e.g. new varieties of cassava, plantain, orange-fleshed sweet potatoes, tef, pigeonpea and soyabean) benefited many poor families who had not previously been able to access better genetic material. New varieties, such as orange sweet potato, have improved the health of people with vitamin A deficiency (affecting 60 per cent of women and 28 per cent of children across Africa). In Uganda, the development of 19 new varieties of sweet potatoes has resulted in yield increases from 4.4 to 10 t/ha.

Local breeds. In combination with better disease management and the use of fodder shrubs, the development of local breeds has significantly improved livestock management. As an example, the Rakai chicken project in Uganda featured the development of an improved chicken breed based on local stocks. Local birds may hatch up to seven times per year compared with two to three times for unprogrammed birds. Chicks are produced at lower cost since farmers do not need to transport them from distant towns, as was the case with commercial chicks.

(Pretty *et al.*, 2011)

Social capital and connections

Social capital describes the importance of social relationships in cultural and economic life. It involves norms of trust, solidarity, reciprocity and exchange that exist between members of groups and networks. Where social capital is high, people have the confidence to invest in collective activities, knowing that others are likely to do the same. Almost all the 40 projects analyzed by Pretty *et al.* (2011) were engaged in the development and formation of new forms of social capital. For example, integrated pest management programmes in West Africa have used farmer field schools (FFS) to increase farmers' engagement and understanding of the use of biological controls to combat pests, such as the pearl millet head miner. In 2009, FFS had been run for 700 farmers in 395 villages. Through the farmers' coordinated action, a parasitic wasp (*Habrobracon hebetor*) was introduced, killing 72 percent of the pest larvae, increasing yields by 40 percent and bringing benefits that extended to 700 000 farmers. FFS were important, not only for developing farmers' skills and knowledge (human capital), but also to build trust and encourage collective action (social capital).

National and local level case studies further demonstrate the importance of social connections in agroecological systems. Cuba is a prime example of a successful agricultural transition. During the late 1980s, Cuba was considered an example of the success of modern agriculture through the adoption of the Green Revolution. However, agricultural production was heavily reliant on a single export crop, sugarcane, which occupied 30 percent of agricultural land and generated 75 percent of export revenues. There was a high external dependency on food, machinery and agricultural inputs. After external conditions changed as the result of the trade embargo in the early 1990s, agricultural production collapsed. In response, a radical shift in farming approach took place. Smallholder peasant cooperatives were encouraged and the spread of alternative agroecological practices was facilitated through the National Association of Small Farmers (ANAP). Having re-oriented its agriculture to depend less on imported chemical inputs, food production rebounded to grow at a remarkable rate of 4.2 percent annually, from 1996 to 2005 (Rosset *et al.*, 2011).

Rosset *et al.* (2011) argue that the success of Cuba's agricultural transition was not only due to technical changes in farming methods. The development of the necessary social dynamics for widespread adoption was also a critical component. Through the Campesino-a-Campesino (CAC) social process methodology, ANAP was able to build a grassroots agroecology movement that promoted farmer innovation and the rediscovery of traditional solutions. Significantly, the CAC provided a network for horizontal sharing and learning.

Similarly, in Andhra Pradesh State, India, community managed institutions have helped to drive an agroecological transition. Many smallholders who had been using chemical fertilizers and pesticides were caught in a debt trap due to the high cost of inputs, lack of credit, poor access to markets, and lack of investible surplus. During 2002-03, the estimated prevalence of indebtedness was very high at 82 percent and the average outstanding loan for smallholders was more than twice the national average. With the support of the Society for Elimination of Rural Poverty (SERP), an alternative approach of Community Managed Sustainable Agriculture (CMSA) has been adopted by over 300 000 farmers, covering an area of 0.5 million ha, in just four years (World Bank, 2009).

CMSA involves a combination of scientifically proven methods, indigenous knowledge and traditional wisdom. The CMSA approach promotes a number of agroecological principles; chemical pesticides are replaced by a combination of physical and biological measures, while biological and agronomic measures improve soil fertility and lead to a reduction in the use of chemical fertilizers. This has dramatically reduced the cost of cultivation, without a significant reduction in yields. As a result, farmers' net incomes have increased in addition to significant health and ecological benefits.

CMSA is based on community institutions that form a federation of self-help groups, consisting of ten million members, with a body corpus of USD 1.5 billion. These community organizations help to plan, implement, manage and monitor CMSA programmes. They also provide a series of financial and other livelihood improvement services to which smallholders would not normally be able to access. Following the success of CMSA, the National Mission on Sustainable Agriculture in India is considering adopting this approach as one of the key national strategies. There is a potential of scaling up this approach to the whole of India as CMSA is showing trends of being economically viable and ecologically friendly.

In the Netherlands, new forms of co-operation have been established to transfer responsibilities for managing landscapes and improve rural governance, which has suffered from strained relationships between the state and farmers. The creation of territorial cooperatives has introduced new forms of self-regulation and strategies of negotiated development. These new forms of rural governance are based on principles of responsibility, accountability, transparency, representation and accessibility. Ploeg (2009) found that territorial cooperatives can facilitate a reduction in transaction costs while enhancing reach, impact and efficiency. Territorial cooperatives encourage the innovative abilities and experimentation of smallholders, who are linked together through the new institution that strengthens social capital and provides a network of inter-relations with other regional, national and supranational institutions.

Organic agriculture implements precise agroecological practices, as well as detailed requirements that preserve the ecological claim throughout post-harvest handling, processing, distribution and marketing. The "organic" link from the farm to the consumer adds value to the environment, people and the economy. In Uganda, the Export Promotion of Organic Products from Africa (EPOPA) project has delivered positive socio-economic impacts through improved livelihoods, poverty alleviation, and support for local economic growth. EPOPA took place over two phases from 1995 to 2008, supported by the Swedish International Development Agency (Sida), in close co-operation with existing export companies and smallholder farmers. The scheme focused on achieving a higher price and increased market opportunities by promoting and selling certified organic products. In particular, the organic premium was seen as a means to reduce poverty amongst smallholder producers. Through improvements in soil fertility management, water conservation and other good agricultural practices, organic coffee farmers were also able to improve the grade and quantity of their produce. The project assisted with the costs of the organic conversion process and provided technical support along the supply chain from production to certification, processing and end marketing. This financial and technical support helped to minimize some of the risks as companies embarked on organic marketing involving new products in a new market with uncertain expectations (FAO, 2011b).

Through the EPOPA project, the number of certified organic producers in Uganda increased to over 200 000, with a total export trade of more than USD 22 million in 2008. This has since risen to USD 35 million in 2010 (FAO, 2013). A particular strength of the project was the market oriented approach. Market linkages were developed and farmer institutions were supported at a remarkably low cost, with extremely efficient results. In the second phase of the project (2003-2007), Sida's total investment was USD 8.5 million. This investment was able to assist over 200 000 households (one million people) to produce commercial exports of USD 20 to 25 million per year; the investment per person affected was less than USD 2 per person per year. With a commercial foundation, the socio-economic benefits have continued after donor funding ended. In 2009, at least 14 of the

19 companies assisted by EPOPA continue to be involved in organic trade with premium incomes continuing to flow to contracted farmers. The long period of commitment from Sida also helped to improve the quality of impact as there was time to learn from mistakes and adjust accordingly (FAO, 2011b).

Common characteristics of agroecological approaches

In the context of the inter-related global challenges facing humanity, agroecological approaches have the capacity to contribute to a greener economy that is capable of assuring food security for present and future generations while providing decent livelihoods and respecting critical planetary boundaries (FAO, 2012). This capacity is based on a number of common characteristics of agroecological systems. As demonstrated by the reviews and case studies outlined above, agroecological systems are typically multi-functional, diverse and inter-connected. Furthermore, they place a strong emphasis on environmental integrity and social well-being. These characteristics lead to two further properties: high efficiency of production and strong resilience to environmental and socio-economic disturbances. The key characteristics of agroecological systems are described in this section.

Agroecological farming, mostly practiced by smallholders, is inherently multi-functional. Smallholder agroecological farmers not only produce food (crops, livestock and derived products, fish and wild food); they also produce fuel (biomass, wood), fibre (cotton, hemp, silk) and biochemicals (natural medicines, pharmaceuticals). As natural resource managers, agroecological farmers support the regulation of water quantity and quality, soil conservation and fertility, air quality, climate regulation and biodiversity conservation. And as guardians of social cohesion, smallholder agroecological farmers create new labour opportunities for local communities, protect landscape aesthetics, and maintain local languages, cultural heritages, and spiritual and religious values. As good environmental stewards, agroecological farmers contribute to provisioning, regulating and cultural ecosystem services that provide multiple benefits to rural and urban populations.

Agroecological systems place a strong emphasis on maintaining environmental integrity. Methods are often based on low cost, locally available technology and inputs that mimic natural ecologies. Compared to high external input systems, that are often associated with negative external costs to the environment, agroecological approaches operate as closed, circular systems. Through the provision of regulating ecosystem services, agroecological methods provide 'spill-over' benefits to neighbouring farms (e.g. through pest/disease control and maintaining healthy functioning water/nutrient cycles) and wider national and global populations (e.g. through carbon sequestration and mitigation of GHG emissions).

Agroecological systems are characterized by diversity. Using a variety of methods and sources of knowledge, they produce a wide range of commodities. For example, (agroecological) smallholders around the world grow over 5 000 crops and raise 8 000 breeds from 40 different livestock species. These include orphan crops and local breeds that are neglected by conventional agriculture. In contrast to highly industrialized monocultures, agroecological methods typically feature polycultures and integrate trees, fodder shrubs, legumes, fish and livestock.

Box 2. **Essential agro-ecosystem properties**

Capacity: average food productivity performance of a management system for present and future generations. Capacity is evaluated in terms of efficiency and resilience.

Efficiency: quantity of production of foods, biofuels, fibres, timber and other ecosystem goods and services that can be obtained from a unit of inputs (water, land, biodiversity, energy, nutrients and labour). To be efficient, production systems must optimize environmental, economic and social input/output ratios.

Resilience: efficiency under disturbed conditions. This indicates that resilience has a time horizon that considers the aptitude of the system to maintain its performance after a disturbance or long-term or permanent changes in its environment or internal conditions, including both environmental and macro-economic risks.

Diversity: the biodiversity of genes, species and ecosystems, as well as the diversity of income sources and knowledge, traditional and scientific.

Coherence: the consistency of interactions within a production system. It considers ecological balance, economic integration and household labour, and seeks to minimize trade-offs and maximize synergies.

Connectedness: refers to coherence in the broader ecological and human landscape. It includes: trans-boundary pollution and the production system connectivity with external waterways and habitats; integration of farm business in the supply chain and independence from exogenous factors; and the participation of producers in social networks and institutions.

Note: terms are defined according to how they are referred to in this paper.

A central hallmark of agroecological systems is their high degree of inter-connectedness. Agroecological methods focus on the interactions between different environmental cycles and processes on the farm. Based on a holistic approach to environmental management, smallholder agroecological farmers are constantly fine-tuning their practices in relation to living nature, evolving and adjusting according to fluctuations in systems. In contrast, the development of modern agriculture has involved a separation of various components into highly specialized entities. In an effort to improve efficiency, these components have become increasingly fragmented. This has led to a loss of the subtle webs and connections that allow adjustments to the surrounding environment through feed-back and loop systems. Agroecological management systems also pay close attention to environmental interactions beyond the limits of the farm, aiming to prevent the spill-over of any negative environmental externalities.

As a driving engine of rural economies, while also contributing valuable cultural ecosystem services, smallholder agroecology is a cornerstone of societal cohesion for many local communities. Agroecological methods typically require more labour than conventional methods (see Table 1, Annex). For example, organic farms employ 30 percent more workers than non-organic farms (Scialabba, 2007). In areas where there is high unemployment or underemployment, agroecology can create new jobs, contributing to decent rural livelihoods.

Smallholders also engage in a number of other non-farm activities that are embedded in patterns of co-operation and inter-relations. In this sense, agroecology is about reweaving social connections between the farm, local and more distant communities. A particular strength of agroecological systems is the central role of skill-based innovation, combined with networks that enhance learning and sharing. Networks of smallholders, such as the CAC or CMSA, are built on solidarity and strong social capital.

Agroecological systems are highly efficient because they optimize the ratio of inputs (water, land, biodiversity, energy, nutrients and labour) to outputs. The multi-functionality of agroecological systems contributes to their efficiency through the production of food, fuel, fibre and biochemicals, as well as the provision of regulating and cultural ecosystem services that are valuable to humanity. In addition, the emphasis of agroecological approaches on environmental integrity prioritizes the use of low cost, locally available technologies, based on natural inputs where possible, to minimize the occurrence of negative external costs to the environment.

Agroecological systems have a high degree of resilience based on their properties of diversity and connectivity. Maintaining a diversity of crops, livestock and other income generating activities improves economic resilience by providing some insurance should any one source of income fail due to market fluctuations, extreme weather events, pests and disease, or other external shocks. Evidence suggests that agroecological systems may be more resilient to environmental disturbances caused by climate change, compared to conventional farming systems (Rosset *et al.*, 2011). In Cuba and Central America, agroecological systems have suffered less erosion, fewer landslides and fewer damages to crops in the aftermath of hurricanes. From an ecological perspective, the polycultures and mixed systems that are common amongst agroecological management systems are characterized by greater levels of biodiversity, compared to highly industrialized agricultural systems, and particularly monocultures. In turn, greater agricultural biodiversity enhances resilience (Fischer *et al.*, 2006).

The inter-connections amongst agroecological systems further strengthen their resilience. Agroecological farming methods are closely tuned in to environmental fluctuations and are constantly evolving in response to feed-back from different processes and cycles. As conditions change, agroecological systems are more flexible and better equipped to adapt their practices. This adaptability is enhanced through the various grassroots networks of agroecological smallholders. Through these mechanisms, successful innovations (often from farmers experimenting in the field) can be exchanged, and best practices to cope with new disturbances can spread amongst practitioners.

The concepts of capacity, efficiency and resilience are further explored in the Annex, which provides an overview of different agroecological management practices. A comparison of each management practice in terms of relevance to current world food supply and impacts on agro-ecosystem properties, rural labour and ecosystem services is provided in Table 1.

The way ahead for an agroecological transition

The case studies and meta-reviews analyzed in this document provide proof of concept that agroecological management systems can increase productivity, while reducing the environmental footprint of agriculture, enhancing the flow of beneficial ecosystem services, strengthening social cohesion and improving the economic and ecological resilience of smallholder farmers. The flow-on effects contribute to national food budgets, local economic growth, and ultimately improved well-being of both rural and urban populations (Pretty *et al.*, 2011). National and local experiences in Cuba and Andhra Pradesh State, India, demonstrate that an agricultural transition is possible, away from high external input systems based on the agricultural modernization paradigm, towards locally adapted solutions based on agroecological principles. However, many successes are still localized, often because favourable policy environments are missing. In order to scale-up impacts, this final section provides a sketched outline of what an agroecological transition might look like.

Fundamentally, an agroecological transition is about recognizing the critical role that smallholders play in modern societies. This means drawing attention to, and properly valuing, the multiple functions that agroecological smallholders perform to benefit society, the environment and future generations. To achieve this, new tools are required, including technical, legal and financial mechanisms that are capable of serving the diverse needs of smallholders. Based on these tools, a policy framework should aim to create the preconditions for a transition and open up dynamic spaces for local communities to craft their own development process. With these objectives in mind, three areas are identified where public policy could help to enable an agroecological transition: recognition of the rights and autonomy of smallholders; creating the right markets and incentives to allow agroecology to flourish; and investing in agroecology for future food security and environmental integrity.

Recognition of smallholder communities starts with the affirmation and protection of basic rights, local autonomy and self-determination. Key areas include access to natural resources, food sovereignty, social and labour rights. This means a halt on land grabbing and a review of tenure rights for women and men. It implies the negotiation at local level of protected open spaces, for innovation and the remodeling of landscapes. An agroecological transition is about facilitating a stronger decision-making role for smallholder communities. In many places, farmers feel that they could contribute more, but they are not given a voice or sufficient recognition.

Properly valuing smallholders, the environment and social cohesion means providing markets and incentives that remunerate agroecological farmers for the range of societal and ecosystem services that they provide. Options include certification and labelling schemes (such as for organics or products of origin to promote regional food cultures and difference), and creating new markets to support locally produced food through public procurement policies. Ensuring farmers get a decent price also requires governments to prevent dumping of cheap, subsidized foods and the prohibition of food speculation. Payments for ecosystem services (PES) schemes are another option for co-financing sustainability. Bundled PES schemes cover a range of services provided by agroecological farmers, including contributions to food security, climate change adaptation and mitigation, environmental stewardship and social cohesion. PES schemes are a promising development to access public and private investments.

Investments need to be re-oriented towards more holistic and inclusive forms of agriculture where local communities are recognized and play a key role in decision-making. Most policies still actively encourage farming that is dependent on fossil fuel based inputs and causes negative environmental externalities. This is a significant barrier to the adoption of more sustainable ways of farming. In particular, investments are required to assist the adoption of agroecological methods (e.g. by providing micro-credit for land preparation, soil rehabilitation, or adapted irrigation systems), to establish markets for diverse, local and regional food, to develop PES schemes for bundled environmental and social services, support farmer-led research and local adaptive knowledge and provide training for local extension services. Such investments can enhance the flow of the multiple value streams that agroecological farming provides. Investing in smallholder agroecological farming will deliver further indirect benefits by supporting local economic growth, employment, social stability and equity.

Current agriculture and food supply systems are key contributors to negative externalities, including ecosystem and socio-economic limits. The pressures on resources are only set to increase, driven by demand growth, impacts of climate change and changing diets. In this context, a new approach to agriculture is desperately needed. This review of the scientific literature, including global and regional meta-reviews, and country and local level case studies, indicates that agroecological approaches are capable of regenerating degraded land, restoring flows of ecosystem services and providing food and livelihoods. Agroecological approaches share a number of common properties: they are multi-functional and aligned towards environmental integrity and social cohesion. These properties lead to a high efficiency of production and resilience towards economic and environmental variability. Consequently, agroecological methods have the capacity to contribute to a greener economy that is better equipped to navigate the inter-related global challenges that are facing humanity.

Annex

Performance of different agroecological management options

The systems described below include: conservation agriculture; integrated pest management; mixed rice-fish systems; mixed crop-livestock systems; organic agriculture; grasslands and forage crops; traditional polycultures; agroforestry systems; perennial grain polycultures; permaculture; and biodynamic agriculture. The analysis is followed by Table 1 that attempts to summarize their performance, in relation to their specific contribution to global food supply, livelihoods and the environment.

Conservation agriculture

Conservation agriculture (CA) is defined by the simultaneous application of three basic principles: minimum soil disturbance, permanent organic soil cover and a diversity of species grown. These three principles are complemented with other practices such as the use of improved seeds; integrated crop nutrition; integrated management of pests, diseases and weeds; and efficient water management (Kassam *et al.*, 2011). CA is indeed a structured integration of zero tillage with already existing practices from organic agriculture (mulching, rotations, legume cropping), biotechnology and breeding (improved seeds), integrated pest management and precision farming (for input application). No-tillage technology expanded from 45 million hectares in 1999 (Derpsch, 2001) to 117 million hectares in 2008/2009 (Derpsch and Friedrich, 2009b; Kassam *et al.*, 2011) and 125 million hectares in 2011 (FAO 2011).

- **Diversity.** No tillage safeguards soil biodiversity and the functioning of biological processes above and below the soil surface, and rotations and manuring benefits agro-ecosystem biodiversity. CA systems are particularly adapted for agroforestry since crops and trees can be grown easily in close vicinity without the disturbance of tree roots inherent in tillage-based agriculture (Sims *et al.*, 2009). However, many CA benefits, including those on biodiversity, depend on how weed control is managed, as weeds are the major challenge of no-till systems (Holland, 2004). Different results can be expected from IPM treatments, GMO and glyphosate combinations or manual weeding in low financial input systems with main products targeting non-cash crop, domestic markets.
- **Coherence**. CA's use of no-till, rotations and mulching benefits farm soil organic matter and nutrient cycles, increases soil biomass and positively impacts soil moisture

retention which, in turn, reduces irrigation requirements. Conservation agriculture, whether done by hand on small farms or mechanized on large farms, tends to reduce overall labour requirements and redistribute labour bottlenecks more evenly throughout the cropping cycle, particularly benefitting small-scale farmers with scarce labour availability.

- **Connectedness**. In general, no-till systems are associated with greatly reduced rates of soil erosion from wind and water (Schuller *et al.*, 2007), higher rates of water infiltration (Wuest *et al.*, 2006), groundwater recharge and enhanced conservation of soil organic matter (West and Post, 2002), with related benefits to watershed recharge and soil carbon sequestration, especially when implemented on large areas. In the USA, the adoption of no-till has increased soil organic carbon by about 450 kg C ha-1 yr-1, but the maximum rates of sequestration peak 5–10 years after adoption and slow markedly within two decades (West and Post, 2002). It is assumed that such a new equilibrium of soil organic matter with no further increase on cropland will be reached after 25–50 years (Reicosky and Saxton, 2007). In the tropics, soil carbon may increase at greater rates (Lovato *et al.*, 2004; Landers *et al.*, 2005).
- **Efficiency.** Crop yields and soil carbon per unit of inputs can be increased substantially with conservation agriculture. In general the system production efficiency in CA is significantly increased as compared to conventional HEI farming systems thanks to increasing yield levels (up to 10 percent per year) and reduced requirements for water (-30 percent), energy (-50 percent), labour (-50 percent), fertilizer (-30 to -50 percent) and pesticides (-20 percent) (FAO, 2008; Saturnino and Landers, 2002; Lindwall and Sonntag 2010; Baig and Gamache, 2009).
- **Resilience**. CA improves resilience against extended drought and reduced water availability, and extreme weather events such as torrential rainfall, strong winds and extreme temperatures (hot and cold). In addition, rotations in the production systems make farmers less vulnerable in case one crop fails. The use of genetically modified seeds in CA systems, which increase the dependence on external inputs from limited suppliers and related fluctuations in terms of availability and price increases, can also increase the vulnerability of these systems to macro-economic risks.

Capacity for a green economy. Crop yields increase in conservation agriculture in the long-term. However, significant yield increases can also be achieved in the short-term in low production systems on degraded soils. CA is an effective example of how increased productivity can be combined with decreased environmental impact, especially in areas endowed with large availability of natural (land and water) and economic (financial capital) resources, such as many areas in Latin America. However, it has to be recognized that much of the potential decrease of environmental impact is related to actual application of integrated weed control management (e.g., with low input of herbicides) and diversified rotations. In addition, permanent no-tillage may result in soil compaction, particularly with large-scale mechanized systems that will most likely have to revert to controlled traffic concepts (i.e. confining all agricultural machinery to the least possible area of permanent traffic lanes).

Integrated pest management

Integrated pest management (IPM) considers all available pest control techniques, and subsequently determines and integrates appropriate measures that discourage the development of pest populations, 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, 2009c).

IPM aims to prevent pest population build-up based on knowledge of local agro-ecosystems, controlling pests only when needed, choosing the most appropriate management strategy in the local context. Therefore IPM is not a farming system method *per se* because it does not encompass a comprehensive range of farming practices. However it is often used in combination with conservation agriculture and precision farming, but it is mainly widespread in low input agricultural systems. IPM approaches in agriculture may include genetic resistance, biological control and cultivation measures for the promotion of natural enemies and the control of plant diseases and weeds, trap crops, intercropping, the use of refugees for natural enemies, and ultimately, judicious use of pesticides (e.g. Lewis *et al.*, 1997). Contrasting interpretations of IPM have emerged, each with different emphases (McIntyre *et al.*, 2009).

- Pesticide-based IPM focuses primarily on the discriminate use of pesticides and improving the efficacy of pesticide applications (Ehler, 2006). The approach emphasizes pest monitoring, preventive measures and the use of less hazardous, lower dose and more selective pesticides, improved formulations, new application technologies, and resistance management strategies (CropLife, 2003; Syngenta, 2006).

- Biointensive IPM, also called preventative IPM or ecological pest management, emphasizes the ecological relationships among species in the agro-ecosystem (Shennan *et al.*, 2005) and the availability of options to redesign the landscape and ecosystem to support natural controls (Dufour, 2001). Biological and ecological pest management offer robust possibilities to reduce pesticide use significantly and sustainably without affecting production (van Lenteren, 1992; Badgley *et al.*, 2007; Scialabba, 2007).
- Indigenous pest management is based on detailed indigenous technical knowledge of pest ecology, local biodiversity and traditional management practices (ethnoscience). It focuses on achieving moderate-to-high productivity levels by using local resources and skills, while conserving the natural resource base (Altieri, 1993).

The sustainability impact of IPM interventions largely depends on the proportions of synthetic chemical pesticides and biological control measures.

- **Diversity**. When compared to unilateral use of pesticides, IPM provides a strategy for enhanced sustainability and improved environmental quality. This approach typically enhances the diversity and abundance of naturally-occurring pest enemies and reduces the risk of pest and disease organisms developing pesticide resistance, by lowering the single-dimension selection pressure associated with intensive pesticide use (McIntyre *et al.*, 2009).
- **Coherence**. When biological control is enforced, agro-ecosystems coherence increases. Ten percent of the world's cropped area involves classical biological control (McIntyre *et al.*, 2009), based on three major approaches: importation, augmentation and conservation of natural enemies (De Bach, 1964). In conservation biological control, the effectiveness of natural enemies is increased through cultural practices (DeBach and Rosen, 1991; Landis *et al.*, 2000) that enhance the efficiency of the exotic or indigenous natural enemies including predators, parasitoids and pathogens.
- **Connectedness**. IPM implementation has the potential to decrease the impact of pesticides on human health. For instance, Baker *et al.* (2002) found a 36 percent decrease in pesticide residues on IPM-grown samples of fruit and vegetable crops, as compared to non-certified foods (assumed to be conventionally grown).

- **Efficiency**. Overall, IPM shows the ability to maintain land productivity with lower pesticide input and, hence, can be considered a more efficient approach when compared with conventional techniques.
- **Resilience**. Pesticide-induced pest outbreaks could contribute to crop failures while a proper management of pesticides and pest control measures, including the elimination of unnecessary pesticide use could improve system stability and yields (Kenmore *et al.*, 1984).

Capacity for a green economy. IPM can be applied on practically all crops and cropping systems with different levels of “integration”, from slight pesticide substitution to zero pesticide use. Integrated production and pest management (IPPM) is a relatively recent development of IPM that focuses on realizing a balance between production and pesticide management through cultivation of a healthy soil and crops; conservation of natural enemies; observation of fields; and farmers becoming expert IPPM practitioners. By combining IPM with all other aspects of production management at farm level (e.g., management of weeds and soil fertility, certification for agri-environmental measures and marketing), IPM techniques evolve towards a comprehensive farming system. IPPM or integrated crop management (ICM) experiences developed in the private sector or the integrated and agriculture production and certification systems previously illustrated as an example of the possible evolution of HEI systems highly rely on the effective and safe use of pesticides, thus farmers need to be trained and provided with information on how to handle and use pesticides responsibly. Since the 1980s, a wealth of experience has been developed in the field of participatory education, and IPM has been implemented through farmer field schools (Röling and Wagemakers, 2000) across Asia, Latin America, Africa, and Central and Eastern Europe (UPWARD, 2002; Luther *et al.*, 2005; Braun *et al.*, 2006). The expansion of IPM as a green alternative will depend on i) the establishment of input standards and related certification systems from independent international bodies, with a view to monitor the various levels of environmental externalities to be expected from pesticide-based IPM, ecological pest management or indigenous pest management; and ii) on the actual capacity of lower impact systems (e.g., ecological and indigenous PM) to scale-up without unsustainable trade-offs in terms of decreased food productivity.

Mixed rice-fish systems

Fish culture in rice fields provides the means for the contemporaneous production of grain and animal protein on the same piece of land (Schuster, 1955) and is by far the most expanded mixed crop-fish farming system in the world. No other combination would seem to be so fundamental and nutritionally complete in the Asian and other context featured with water availability.

- **Diversity**. Nutritional benefits and lowered production risk may provide strong motivation for rice farmers to diversify, and rice-fish farming can be both socially and environmentally profitable (Halwart, 1999). Production diversification enhances biodiversity when agrochemical use is avoided.
- **Coherence**. Biodiversity is structured in a self-sustaining biocenosys, i.e. a self-sufficient community of naturally occurring organisms occupying and interacting within a specific biotope, which makes the rice field system more balanced and internally coherent. With fish removing weeds and reducing the insect pest population to tolerable levels, poisoning of the water and soil may be curtailed. Moreover, particularly in more remote areas, fish and other aquatic organisms from rice fields provide a very important component of the daily diet, hence the term "rice-fish societies" (Demaine and Halwart, 2001). Input analyses in Bangladesh, the Philippines and Vietnam consistently showed an increase from 10 to as high as 234 percent in the overall labour requirement when fish were raised in rice fields (Halwart and Gupta, 2004).
- **Connectedness**. The rice-fish culture required an estimated 26 percent more water than rice monoculture, which is a concern in water-scarce regions (Sevilleja *et al.*, 1992). Field surveys carried out in China and Indonesia found rice-fish systems able to make drastic reductions in the density of mosquitoes carrying malaria and dengue fever (Wang and Ni, 1995; Nalim, 1994). There are also examples of beneficial impacts of rice-fish systems on social connectedness through time-sharing of rice fields, where landless tenants and fish breeders are allowed to use the rice fields for fish culture during the fallow season (Koesoemadinata and Costa-Pierce 1992; Fagi *et al.*, 1992). The adoption of rice-fish systems can result in job creation and diversification, such as diking, making and renting nets and other accessories such as pumps and oxygen tanks, repairing pumps, and harvesting, packing and transporting of fingerlings (Halwart and Gupta, 2004).

- **Efficiency**. Studies of rice-fish systems in Bangladesh, China, Indonesia, the Philippines and Vietnam reported increases of net returns ranging from 27 to 270 percent above those from rice monoculture (Gupta *et al.*, 1998; Yan *et al.*, 1995a; Purba, 1998; Sevilleja, 1992; Mai *et al.*, 1992). In Thailand, profitability in the rice-fish fields was found to be only 80 percent of rice monoculture profitability (Thongpan *et al.*, 1992).
- **Resilience**. Diversification of products makes the fish-crop systems more resilient to price changes.

Capacity for a green economy. Over 90 percent of the world's rice, equivalent to approximately 134 million hectares, is grown under flooded conditions, providing not only home to a wide range of aquatic organisms, but also offering opportunities for their enhancement and culture (Halwart and Gupta, 2004). Although most countries do not have separate statistics on rice-fish farming areas or rice and fish yields in such areas, speculations indicate that the potential impact of conversion from rice monoculture to mixed systems is tremendous, also at the macro-economic level. For example, if 5 percent of the irrigated rice lands in the Philippines were stocked with fish, the production would increase by 29 000 tonnes and provide 5 900 tonnes of protein (Ahmed *et al.,* 1992). Cai *et al.* (1995a) estimated that if 10 percent of the rice fields south of the Huai He River, China, were used, the commercial fish yield would be 346 000 tonnes with a yield of 300 kg/ha, and five billion full-size fingerlings. In Asia, the main problem under 2050 scenarios will be land scarcity (particularly in South Asia) and the consequent need for high levels of intensification. Expansion of cropped land can only occur in some areas (at the expense of forests or pastures) but not in South Asia. Intensification would increase the risk of input price increase and water availability under extreme climate events and pollution. Therefore, it would be helpful to design new or encourage existing intensive farming systems to reduce the risk of input dependency and climate variability. The rice/fish system is an example of a natural resource management option with low external input that simultaneously meets the need of agricultural intensification and the need to decrease pollution. However, it requires a considerable amount of water and should be integrated at regional level with alternative water-saving options, such as sustainable rice intensification.

Mixed crop-livestock systems

Mixed crop-livestock systems are farming systems in which more than 10 percent of the dry matter fed to animals comes from crop by-products or stubble, or more than 10 percent of the total value of production comes from non-livestock farming activities (Steinfeld *et al.*, 1996). The integration of crops and animals on the same farm represents the backbone of small-scale agriculture throughout the developing world. Globally, mixed systems provide 50 percent of the world's meat and over 90 percent of its milk. With the demand for livestock products expected to surge in most low income countries, the potential for income generation exists. However, the expansion of large-scale, industrial production of crops and livestock has reduced resource availability at the expense of smaller mixed farming systems employed by the poor (McIntyre *et al.*, 2009).

- **Diversity**. Crop-livestock systems are usually horizontally and vertically diverse, providing small habitat patches for wild plants and animals (Altieri, 1999). In small-scale crop-livestock systems, fodder is often a limiting resource, which can be supplemented by tree/shrub fodder banks, with further increase of the agro-ecosystem's diversity, at least to the extent that the foraging ends up reducing readily available plants in nearby natural ecosystems.
- **Coherence**. Livestock have been part of global farming systems for millennia. Integrated systems provide synergy between crops and livestock, with animals producing manure that is used to amend soils or provide fuel, while crop by-products are a useful source of animal feed. The production of meat, milk and eggs within small-scale farms generates income and enriches the diet with consequent benefits for health.
- **Connectedness**. More efficient farm nutrient cycles decrease nutrient losses while improved soil structure avoids soil erosion phenomena. The organic matter content of the world's agricultural soils is typically 50–65 percent of pre-cultivation levels (Lal, 2004). Strategies to increase soil organic matter (and the carbon within it) include the integrating crop and livestock production in small-scale mixed systems (Tarawali *et al.*, 2001, 2004) and corralling, by rotating animals over patches of land.
- **Efficiency**. Output per farm of many small-scale enterprises may be small, but the aggregated effect can be large, such as small-scale dairy in India (Kurup, 2000), piggery in Vietnam (FAO, 2006) and backyard poultry in Africa (Guye, 2000).

- **Resilience**. Generally speaking, crop-livestock interactions increase productivity and the income of farmers, and improve system resilience and environmental sustainability (Devendra and Thomas, 2002; Parthasarathy Rao *et al.*, 2005). Livestock keeping can improve health and nutrition in small households and generate additional income and employment (ILRI, 2006), even when households have limited resources such as land, labour and capital (PPLPI, 2001).

Capacity for a green economy. Integrated crop and livestock systems offer a win-win strategy with greater productivity and increased mutuality that enhances soil fertility (McIntire *et al.*, 1992; Tarawali *et al.*, 2001). Without this linkage, soil fertility can fall in cereal-based systems and surplus livestock manure can create nutrient waste and pollution (Liang *et al.*, 2005). In dry areas, such as the Sahel and East Africa, intensification is not easy because low organic matter in soil leads to poor water conservation. Ecological intensification through mixed crop-livestock systems offers opportunities, especially in a context of higher demand for animal products, while recreating closed (or semi-closed) systems of nutrients and energy.

Organic agriculture

Organic agriculture (OA) is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity and biological cycles. It emphasizes the use of management practices in preference to the use of off-farm inputs. This is accomplished by using cultural, biological and mechanical methods, as opposed to using synthetic materials (FAO, 2009c). A specific feature of OA is that its production practices are defined by organic standards which ban the use of synthetic inputs and GMOs and, hence, has to maximize the use of ecosystem services in order to compensate for the input ban. OA is no longer a phenomenon in developed countries only, as it is commercially practiced in 160 countries, representing 37.2 million hectares and a market of USD 54.9 billion in 2009 (Willer and Kilcher, 2011).

- **Diversity**. As organic systems rely on ecosystem services to improve soil fertility, biological pest control and nutrient and energy balances in order to compensate for the prohibition on synthetic input use, they usually feature enhanced floral and faunal diversity as compared to conventional and integrated pest management systems (Maeder *et al.*, 2002; Pacini *et al.*, 2003).

- **Coherence**. The objective of organic management is to establish, to the extent possible, closed energy and nutrient cycles (e.g. biomass recycling). This coherence between natural and human processes is further extended in biodynamic agriculture, the earliest among the initiatives from which organic farming evolved since 1920s, currently covering more than 140 000 hectares in 47 countries (Demeter, 2011). A specific feature of biodynamic agriculture, inspired by Rudolf Steiner (1861-1925) is the regeneration of the forces that work through the soil to the plant by using compost and spray preparations from naturally fermented organic substances in minute doses to soils and crops. The use of biodynamic preparations has been shown to have substantial restoration power on exhausted soils and biodynamic animals seem to have better resistance to infection. By contrast, in some cases, such as horticulture in California, USA, enforcing of minimal compliance with organic standards has led to a process of intensification and specialization that disrupts the farm nutrient cycles when the cropping systems must heavily rely on imports of organic inputs (e.g. replacement of farm-produced animal and green manure with external organic fertilizer). For small-scale farmers in developing countries faced with lack of capital and low product prices, closing the nutrient cycle is a necessity rather than an optional commitment (Zundel and Kilcher, 2007). Within-farm, vertical integration gives rise to opportunities to keep the added value of high quality products in the farm budget that increase on-farm job opportunities and enhance farm socio-economic coherence.
- **Connectedness**. 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. Such habitat enhancement practices reduce landscape fragmentation and the absence of pesticides in the agro-ecosystem provides for biodiversity conservation, in addition to preserving human health (Scialabba and Williamson, 2004). In several settings, it has been noted that increased control over resources (labour power, production system) develops self-awareness and collective self-help, which lead to overcoming marginalization through participatory initiatives.

- **Efficiency**. With the current level of agroecological knowledge, average organic productivity (yield per hectare for ten plant and animal food categories recognised by FAO) ranges from -10 percent, as compared to high external inputs systems, to +80 percent in low external input conditions in developing countries (Badgely *et al.*, 2007). Increased biomass in organically managed soils decreases irrigation water needs, but more land is usually required due to lower productivity, as compared to high external input systems in developed countries. A 21 year study by the FiBL Institute in Switzerland (DOK trials) compared the performance of biodynamic, organic and two conventional systems and found that nutrient input in the biodynamic and organic systems was 34 to 51 percent lower than in the conventional systems, but crop yield was only 20 percent lower on average, indicating more efficient production. In regard to soil aggregate stability, soil pH, humus formation, soil calcium, microbial biomass, and faunal biomass, the biodynamic system was superior even to the organic system (Maeder *et al.*, 2002). Generally, less energy is needed due to foregoing synthetic inputs use – from 45 to 67 percent, as reported by Pimentel (2006) and Williams *et al.* (2006), respectively. However, this benefit is neutralized in industrial farms that substitute labour with mechanization. Overall, organic systems have demonstrated to compensate for GHG emissions through enhanced soil carbon sequestration and can often be carbon neutral (Scialabba and Müller-Lindenlauf, 2010). Labour costs in organic farms are usually 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, rendering organic farms economically more profitable than conventional, often even if extra prices for organic products are not obtained on food markets (Nemes, 2009).
- **Resilience**. By managing biodiversity in time (rotations) and space (mixed cropping and mixed crop-livestock systems), organic farmers also enhance diversity of cultivated and wild species, with positive effects in terms of resilience to climate variability and market price fluctuations of commodities and inputs.

Capacity for a green economy. The challenge of OA is to intensify production while maintaining ecosystem integrity. While in developing countries, organic management is an option for ecological intensification, in industrial contexts, it becomes an extensification strategy. The issue is whether enough surpluses could be produced on a global basis to meet population demands and at which price, given the fact that currently organic product prices are higher on average. The issue of land availability for extensification might be of concern in some areas, while in others, organic agriculture might relocalize food systems where food is most needed, such as market-marginalized areas where hunger prevails (e.g. areas of sub-Saharan Africa). Provided that organic farmers will be able to demonstrate and certify the environmental benefits they produce, in industrialized areas, there will be need to fund the transition phase and compensate for decreased yields until soil fertility is restored, while in developing countries, there will be need for promotion of agroecological knowledge generation and dissemination. Despite increasing trends of adoption, concerns are raised on the actual capacity of organic farming to meet food needs on global scale. The principal objections to the proposition that organic agriculture can contribute significantly to the global food supply are low yields and insufficient quantities of organically acceptable fertilizers. Badgely *et al.* (2007) modelled the global food supply that could be grown organically on the current agricultural land base, based on FAO data on ten plant and animal food categories. Model estimates indicate that 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. The authors also evaluated the amount of nitrogen potentially available from fixation by leguminous cover crops used as fertilizer in organic farming; data from temperate and tropical agro-ecosystems suggest that leguminous cover crops could fix enough nitrogen to replace the amount of synthetic fertilizer currently in use. It can be concluded that the OA potential for greening agriculture is considerable, especially under scenarios of ecological intensification in developing countries and in those areas faced with degraded soils or lack of capital and low product prices.

Grasslands and forage crops

Grasslands, including rangelands, shrub land, grazing land and cropland sown with forage crops, occupy almost 30 percent of the emerged ice-free land areas, represent 70 percent of the world's agriculture area, and provide approximately 23 percent of total meat and 27 percent of total milk production. Many different management practices have been developed to support animal production in a sustainable way to enhance production while maintaining a healthy growth of grasses. Among these practices are hay and silage production, cut and carry, and rotational grazing. Rotational grazing involves the frequent moving of livestock onto fresh grass – the system produces much of its own fertility and pest control, spreading and fertilizing seeds with manure, and enabling animals to use the diversity of grasses to medicate themselves, which in turn, builds new soil fertility and can sequester carbon from the atmosphere.

- **Diversity**. Livestock keepers and pastoralists have domesticated 40 livestock species on grassland-based systems and are protecting 7 616 breeds, while industrial production focuses on only five species (FAO, 2009b). Grasslands host more than 10 000 plant species, including ancestors of most important cereals (wheat, rice, sorghum) and important medicinal plants, and are vital to maintaining wild and cultivated genetic resources *in situ.* Well managed pastures can include up to 200 plant species (PAR, 2011) and nutritional diversity is also much higher due to the large quantities of omega-3 fatty acids, beta-carotene, vitamin E and folic acid present in green grass and to a high protein content present in legume species.
- **Coherence**. The organic matter on the rotational grazing farms can be much higher on average than agricultural lands, and the rotating mixture of animals on pastures can build up to 1 inch of soil annually (Leu, 2004). Well managed temperate grassland systems, including a good quantity of legume species, can fix 100–300 kg nitrogen per ha, leading to good levels of energy efficiency.
- **Connectedness**. Beyond their contributions to meat and milk production, grasslands and forage crops provide a number of environmental and social benefits. They are associated with protection of soil against erosion, reduced runoff (grasslands cover can capture 50–80 percent more water than bare ground), reducing risks of droughts and floods and nutrient leaching (Briemle and Elsasser, 1997) and the provision of habitat for wildlife including pollinators and migratory bird species. Production from grasslands and fodders is bulky and therefore, unlike cereals, is rarely traded, transported or stored. Its economic value is hidden and not captured in GNP or in most global and national statistics. However, they contribute to supporting the lives and livelihoods of over one billion women, men and youth, and are important elements of the cultural landscape, providing important heritage and aesthetic values for society.

- **Efficiency**. As grasslands and fodder production systems have a high degree of plasticity and can adapt to the productive potential of many ecosystems, their water, fertilizer and chemical inputs as well as their energy balance can be reduced by improving the management practices. Well managed grasslands based on perennial species outperform annual systems in production and environmental performance. According to Glover *et al.* (2010b), more nutrients can be produced in a hectare of well managed pasture than in a hectare of corn field. Grasslands and good grazing land management, including strategic animal rotations and harvesting methods, are considered to have the second most important technical mitigation potential among agricultural sectors (IPCC, 2007), with the potential to sequester 0.2–0.8 Gt CO_2 per year to 2030 depending on the practices imposed. When trees are added, their sequestration rates increase dramatically. It is important to recognize the unique contribution that grasslands systems can provide to climate change mitigation, adaptation, agriculture production, improvement of ecosystem health and resilience while serving as a basis for productivity, food security and economic growth. Increased understanding is needed of the energy efficiency of grasslands and fodder crops production, and animal production systems based on grasslands and fodder production especially need to be modified and adjusted to improve the energy flows in all components of the production cycle.
- **Resilience.** Grasslands support a wider range of ecosystem functions, higher levels of soil fertility, soil structure and more complex biological communities than annual crops (Culman *et al.*, 2010). A wise combination of grazing by different animal species, transhumance and strategic feeding of hay are among sustainable traditional pastoral practice used to maintain high diversity and buffer against climatic and economic adversities (FAO, 2009a).

Capacity for a green economy. Optimization of animal stock and timing of grazing can greatly increase yields, while improving the health of land, water and air related to the grassland systems. Therefore grasslands have a crucial role in climate change adaptation and mitigation. There is little information available on the energy efficiency of sustainable grasslands and fodder systems, it is therefore important to improve understanding and knowledge, in order to pursue a sustainable intensification of products and services from grasslands and fodder systems in different ecologies.

Traditional polycultures

Polyculture refers to the cultivation of two or more crop species in such a way that they interact biologically (Vandermeer, 1989). Traditional polyculture has been practised throughout almost all of farming history, providing food for humans, for a variety of animals, continuous ground cover and deep root systems to prevent erosion, legumes to provide natural fertilizers, and natural disease and pest control measures.

- **Diversity**. Polycultures can easily reach 30 and more species on a given plot of land. Perennial crops (usually trees) are often combined with annuals, and intraspecies diversity is generally high. Farmers often return to genetically heterogeneous local varieties to help recover from extreme weather events, and to cope with specific additional stresses (PAR, 2011), since the risk of crop failures is lower with landraces than with modern varieties.
- **Coherence**. Traditional polyculture systems, among the world's most ecologically complex farming systems, are characterized by a very strong coherence. This is due to their ecological features, such as spatial and temporal diversity and continuity; optimal use of space and resources through intercropping plants with different growth characteristics, canopies, and root structures to facilitate a more efficient use of water, solar radiation, and nutrients; relatively closed cycles of nutrients, energy, water, and waste; and cropping patterns adapted to the amount and distribution of rainfall (Altieri, 1995).
- **Connectedness**. Traditional polycultures are not dependent on external inputs, but rely on the diversity of locally available biological interactions. For instance, the maintenance of wild patches of vegetation in the farming landscape preserves useful wild species that can have a direct use in rural households and provide shelter and habitat for wild fauna that contribute to beneficial ecological processes, such as soil enrichment, pest control and pollination (Vandermeer *et al.*, 2002).
- **Efficiency**. Despite the resilient nature of farmers' traditional polyculture systems, they have often been considered low-yielding and environmentally unsustainable. Several studies have proven the opposite, due to the yield advantage of intercropping (Snaydon and Harris, 1981). The traditional corn/beans/squash polyculture of Mexico, for instance, produced overyields as high as 50 percent of corresponding

monocrops (Gliesmann, 1995). In India, the traditional cotton intercrops (chillies and onion or garlic), had income 210 percent higher than if cotton was planted as monocrop (Anon, 1989). Further, polycultures play a crucial role in conserving large carbon stocks. Many studies have shown that traditional polycultures are able to sequester about one-third of the amount of carbon that a mature forest is capable of capturing, because of its diversity and biomass (Perfecto *et al.*, 2007). A CIAT study (2011) concluded that polycultural coffee systems (traditional and commercial) in Mesoamerica conserve an average mean 81 tonnes CO_2 per ha, much higher than shaded or non-shaded coffee monocultures.

- **Resilience**. In general, traditional polycultures produce a whole range of products, making productivity in terms of resilience to climate change very favourable, while providing more income stability to farmers and protection from sudden market volatility in commodity prices.

Capacity for a green economy. The further management and up-scaling of traditional polycultures will promote dietary diversity, income generation, production and stability, risk minimization, reduced pest and disease incidence, efficient use of labour, intensification of production with limited resources and maximization of returns given low levels of technology (Francis *et al.*, 1976; Altieri, 1995). Therefore, they could have a crucial role in making agriculture more resilient, at least in those areas where agro-ecosystem degradation is at an advanced stage. Recently high performance commercial scale greenhouse polyculture systems have been developed by the private sector. Such systems are intended to have net zero impact, require smaller land areas and have yields of a diverse number of agricultural crops (Except, 2011). Such systems would therefore be ideal for urban areas with limited land availability, however, such systems are highly resource-intensive at the start, requiring high initial investment and expensive designs, thus their potential at the moment for scaling-up mostly lies in rich urban settings. In addition, more research is still needed to assess the viability and capability of such systems.

Agroforestry systems

Agroforestry is a collective name for land-use systems and technologies where woody perennials, such as trees, shrubs, palms and bamboos, are deliberately used in the same land management unit as agricultural crops and/or animals (FAO, 2009c). Agroforestry practices are numerous and diverse and used by 1.2 billion people (World Bank, 2004), with many of the benefits arising from local marketing (Shackleton *et al.*, 2007).

- **Diversity.** Agroforestry systems are well known as providers of enhanced biodiversity. Agroforestry types such as forest gardens have 100–200 species growing in them (Crawford 2010), and hold high potential for even increasing biodiversity. One of the most well-known forest gardens, the Schumacher Forest Garden in Totnes, Devon, England, grows some 500 species on 0.8 ha. Through the integration of trees in farming systems, agroforestry encourages the development of an agroecological succession (Leakey, 1996; Schroth *et al.*, 2004), which creates niches for colonization by a wide range of other above- and below-ground organisms in field systems (Ewel, 1999; Leakey, 1999b; Schroth *et al.*, 2004; Schroth and Harvey, 2007). Agroforestry systems provide a large range of diversified outputs including products (timber, fuelwood, food and medicines), inputs for crop and livestock production (fodder, soil nutrients and pollination) and services (watershed protection, climate regulation, carbon storage and biodiversity conservation).
- **Coherence**. Integrating trees encourages and enhances internal coherence of agro-ecosystems by promoting active life cycles, food chains, nutrient cycling and pollination at all trophic levels and helping to control pests, diseases and weeds (Collins and Qualset, 1999) in about two-thirds of the agroforests tested (Schroth *et al.*, 2000).
- **Connectedness.** Perennial trees, shrubs and vines reduce soil erosion by providing cover from heavy rain and reducing wind speed. Their integration into farming systems also creates a cool, shady microclimate, with increased humidity and lower soil temperatures (Ong and Huxley, 1996; Ong *et al.*, 1996; van Noordwijk *et al.*, 2004). The deep and widespread roots provide permanent physical support to the soil and aid in deep nutrient pumping, decreasing nutrient losses from leaching and erosion (Young, 1997; Huxley, 1999). Herbicide retention by buffers also can be substantial (Arora *et al.*, 2003). On a global scale, agroforestry systems could potentially store 12-228 (median 95) tonnes C per ha, under current climate and soil conditions (Dixon, 1995).

- **Efficiency.** Due to tree capacity to capture energy, nutrients and carbon, efficiency of agroforestry systems is higher than for most other farming systems. Furthermore, agroforestry can increase farmers' income. For example, project activities in the Nhambita community, Mozambique, yield carbon offsets equal to 24 117 tonnes CO_2 *per annum* over an area of about 20 000 ha. Farmers receive carbon payments at a rate of USD 4.5 per tonne of CO_2, or in the range of USD 433–808 per ha over 7 years. The project shows that carbon sequestration through land use, land use change and forestry (LULUCF) can promote sustainable rural livelihoods and also generate verifiable carbon emission reductions for the international community (World Agroforestry Centre, 2009a; 2009b).
- **Domesticating** wild fruit trees, such as African plums and the bush mango, has allowed smallholder farmers in Cameroon to increase their earnings fivefold, and indigenous, nitrogen-fixing trees planted with unfertilized maize have increased yields in numerous countries of Africa and are being grown on over 5 million hectares of cropland in Niger (Garrity and Stapleton, 2011).
- **Resilience**. Moving the "tree element" back into the farming landscape improves the resilience of the farming system as a whole by improving its diversity, both environmental and socio-economic. Many agroforestry tree crops are important as sources of feed for livestock (Bonkoungou *et al.*, 1998), and offer potential new markets such as vegetable oils (Kapseu *et al.*, 2002), pharmaceuticals or nutriceuticals (Mander *et al.*, 1996; Mander, 1998). They also help farmers meet specific income needs, e.g. school fees and uniforms (Schreckenberg *et al.*, 2002), and buffer the effects of price fluctuations in cocoa and other cash crops (Gockowski and Dury, 1999).

Capacity for a green economy. Agroforests have always made important contributions to the food security of a large part of the world's food insecure people and will likely have an even more crucial role in situations of increased food prices. They provide products (timber, fuelwood, food and medicines), inputs for crop and livestock production (fodder, soil nutrients and pollination) and services (watershed protection, climate regulation, carbon storage and biodiversity conservation). Scaling-up agroforestry practices will require knowledge sharing and management skills to ensure higher efficiency of the system. Carbon projects with agroforestry practices have proven that scaling-up is a viable possibility since farmers are rewarded for their extra efforts.

Perennial grain polycultures

Natural perennial polycultures can be found in all the world's grasslands and in other ecosystems as well. Glover *et al.* (2010a) refer to perennial grain polycultures as agricultural systems with the ecological stability of the prairie and a grain yield comparable with annual crops. Perennial grain polycultures are limited primarily to production of livestock fodder. There have been attempts to investigate perennial grains for humans' food production, starting with a large Russian perennial wheat breeding programme in the 1920s, and followed by programmes in Argentina, Australia, China, India, Sweden and the USA. These programmes all sought to identify and improve perennial grain species and hybrid plant populations derived from annual and perennial parents such as rice, wheat, maize, sorghum and pigeon peas, and from oilseed crops such as sunflower, flax and mustards (Glover *et al.*, 2010a).

- **Diversity**. Perennial grain polycultures dramatically increase biodiversity, much more than monoculture on the same plot of land. In a natural prairie, there can be more than 200 plant species in a given area and perhaps several times that number of microscopic soil animals (Dewar, 2011).
- **Coherence**. Perennial crops are hardier than annuals, more resistant to weeds once they are established and contain stronger resistance to disease and, perhaps most important, they regenerate the soil into a thriving ecosystem. Perennials need no ploughing or planting and can be harvested from early spring to late fall, allowing for a more flexible labour calendar. Furthermore, they reduce the amount of tilling, planting, weeding, fertilizing and pest killing required in agriculture, thereby reducing the work burden of women in subsistence agriculture situations.
- **Connectedness**. Perennial polycultures provide year-round ground cover, leading to a significant drop in soil erosion by both water and wind (Randall, 1997).
- **Efficiency**. Perennial grain polycultures has the potential to improve productivity and help reduce both hunger and poverty. With respect to food value, there is preliminary evidence that species being tested in perennial polycultures could compete with monoculture foods. A study of eastern gamagrass (Boehner, 1987) concluded that nutritional value of gamagrass grain as a food source is impressive. The protein content of the grain is 27 percent compared with wheat and corn which are 17 and 10 percent,

respectively. Gamagrass grain also has twice as much of the amino acid methionine as corn and is about 51 percent carbohydrate. Perennial polycultures also require fewer passes of farm equipment and less fertilizer and herbicide (Glover *et al.*, 2010b). With no fertilizer inputs and without the benefits of centuries of domestication, the perennial grass Miscanthus sp. plant canopy has 61 percent greater annual solar radiation interception efficiency and it can produce 59 percent more above-ground biomass than heavily fertilized, highly domesticated annual maize (Dohleman and Long, 2009). They also produce more plant material in the ground, thus sequester more carbon (Dewar, 2007), and require fewer inputs, allowing farmers to keep more of the profit.

- **Resilience**. Perennial grains can produce yields comparable to those of annual monocultures while actually adding nitrogen to the soil and stabilizing the soil year-round. Furthermore, Pimentel *et al.* (1997) found that cultivating perennial cereal grains in the USA that can be harvested continuously for 4–5 years without tilling and replanting could reduce erosion by 50 percent, saving USD 20 billion worth of soil and USD 9 billion in tractor fuel every year.

Capacity for a green economy. If natural perennial polycultures could be re-engineered to provide food on a large-scale, the potential benefits could have global impact. Advocates argue that it makes sense to replace annual monocultures with perennial polycultures, especially on marginal land and highly erodible soils. For example, perennial types of pigeon peas, important food crops and sources of biologically fixed nitrogen, are grown on steep slopes in regions of Malawi, China and India (Snapp *et al.*, 2003). In the USA alone, 350 million arable acres (87.5 percent of total) are mildly to highly erodible, and would be good candidates for perennial polycultures (Sanders, 1999). Plant breeding innovations can accelerate the development of perennial grains. However, this requires the initiation and acceleration of breeding programmes worldwide. It is not easy to predict how much time will be needed to produce edible material from sustainable production of improved varieties of perennial grain and to devise appropriate farming techniques (e.g. harvesting). However, interesting results probably could be reached in around 20 years (Glover *et al.*, 2010a).

Permaculture

Permaculture (permanent+agriculture) is the conscious design and maintenance of agriculturally productive ecosystems which have the diversity, stability and resilience of natural ecosystems. It is a land use and community building movement which strives for the harmonious integration of human dwellings, microclimate, annual and perennial plants, animals, soils and water into stable, productive communities (FAO, 2009c). It emerged as an environmental design concept during the 1970s and since has broadened to include not only food-sufficiency at the household level, but the whole human system with appropriate strategies for land access, business structures and regional self-financing (Holmgren, 2008).

- **Diversity**. In permaculture design, the number of elements is less important than the number of functional connections between elements. Polyculture and diversity of beneficial species (e.g. combination of perennials with annuals and animals, forest gardens, guilds) provide physical shelter and nutrients, and assist in pest control. Diversity in permaculture is also triggering higher productivity and more disperse yields over time.
- **Coherence**. Permaculture, together with forest gardens, which are an integral element of permaculture designs, may be considered the most coherent human-managed agriculture system that exists today. It is not energy- or capital-intensive but rather knowledge-intensive. Observation, discussion and thinking in terms of multiple disciplines are needed to design a system that saves energy and produces food.
- **Connectedness**. Permaculture principles also include creating edge and natural patterns, highly active zones where energy and materials are continuously in flux. Thus, increasing the amount of edges is an important tool for maximizing the productivity on-site. For example, ponds are designed with an irregular shape to maximize the water's edge, and wooded and grassland areas are intermingled, recognizing that natural patterns such as spirals, lobular patterns, ditch and bank systems (chinampas) and different types of edge cropping enhance productivity (Mollison, 1991).
- **Efficiency**. Permaculture emphasizes the use of biological resources over fossil fuel resources such as green manures and leguminous trees for fertilizer; weeder geese and short herbs rather than lawn-mowers and biological insect control rather than

insecticides. Energy recycling is done on-site, with kitchen waste going to compost, animal manures to biogas or to soil, greywater to gardens, green manures to earth, and tree leaves to mulch, so that incoming natural energies (sun, water, wind) combine with those generated on site to ensure a complete energy cycle and maximization of energy efficiency.

- **Resilience**. In permaculture, multi-functionality is a key principle and every element is placed so that it performs as many functions as possible. These can include offering shelter and protection from frost, wind or sun; hosting predators; preying on or deterring pests; providing nutrients and facilitating root penetration. Every important function is supported by many elements, further increasing resilience. In such a complex mix system, the sum of yields will be inherently larger than the yield of one species in an intensive monocropped system. The family can satisfy all its nutritional needs and improve its economic situation, as having more saleable products at different times of the year protects against market turndowns and severe losses of one crop. Resilience in a permaculture system is achieved mainly through proper design, timely and careful management and diversity.

Capacity for a green economy. Permaculture has been stress-tested in poor countries and in crisis situations. Due to an increasing lack of fossil fuel availability, permaculture's relevance due to its ability to mitigate energy resource scarcity in the agriculture sector will likely increase radically. Increasing community awareness of environmental issues, combined with increasing costs of energy, water and food are likely to lead to a considerable expansion of permaculture-inspired activity in cities, towns and rural landscapes (Holmgren, 2008). It is important that academics, planners and policy-makers understand permaculture as a factor in the social and physical fabric of societies and for a future of scarcer energy.

Table 1. **Summary of impacts of agroecological management options on ecosystem properties, and their current importance to global food supply, livelihoods and the environment.**
When not specified in notes, figures were retrieved from FAOSTAT, SOLAW's and other FAO's databases.

MANAGEMENT OPTION	POTENTIAL IMPACT ON AGRO-ECOSYSTEM PROPERTIES					CURRENT RELEVANCE			
	Diversity (++/--)	Coherence (++/--)	Connectedness (++/--)	Efficiency (++/--)	Resilience (++/--)	Area (Mha)	World Food supply	Labour[1]	ES[2]
Conservation agriculture	+	+/-	+/-	++	+	117[3]	n.a.	Less labour	P,R (soil)
Mixed rice-fish systems	+	+	+	+	++	~2	n.a.	10-234% more labour[4]	P,R
Mixed crop-livestock systems	++	+	++	+	++	2 600 (200 irrigated)[5]	70% ruminants; 90% milk; 1/3 pig & poultry[6]	More labour	P,R
Organic agriculture	++	++	++	+	++	37[7]	2% of global food retails[7]	~ 30% more labour	P,R,C
Grasslands and forage crops	++	++	++	+	++	3 930	23% meat; 27% milk	200 millions of workers	P,R,C
Traditional polycultures	++	++	++	+/-	++	80% land W Africa; unspecified amount LA and SE Asia[8]	20% (estimates to be investigated)[9]	More labour	P,R,C
Agroforestry systems	++	++	++	+/-	++	1 000[10]	Agroforestry systems are used by 1 200 millions[11]		P,R,C
Perennial grain polycultures	++	++	++	+/-	++	Negligible	Negligible	Less labour	P,R
Permaculture	++	++	++	+/-	++	Negligible	Negligible	More labour	P,R
Biodynamic agriculture	++	++	++	+/-	++	0.14[12]	Negligible	More labour	P,R,C

1 Including employment and family labour: less/more labour is considered as compared to standard conventional techniques.

2 ES, ecosystem services (according to Millennium Ecosystems Assessment):
P = provisioning services (i.e., food, fresh water, fuel wood, fiber, biochemicals, genetic resources);
R = regulating services (i.e., climate regulation, disease regulation, water regulation, water purification);
C = cultural services (i.e., spiritual and religious, recreation and ecotourism, aesthetic, inspirational, educational, sense of place, cultural heritage).

3 Derpsch and Friedrich, 2009b; Kassam *et al.*, 2011.

4 Halwart and Gupta, 2004.

5 This amount of land partly overlaps with grassland (~1200 M/ha) and partly with land of other food production systems (de Haan *et al.*, 1998; Steinfeld *et al.*, 2010).

6 Steinfeld *et al.*, 2010.

7 Willer and Kilcher, 2011.

8 West Africa, Latin America and South East Asia.

8,9 Altieri, 2009; 2011.

10 Land with tree cover of more than 10 percent (Zomer, *et al.*, 2009).

11 World Bank, 2004.

12 Demeter, 2011.

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