9 Managing Agroecosystem Services

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Abstract

Agriculture and ecosystem services are interrelated in various ways. Payments for ecological services (PES) and innovative methods of agricultural management, including ecological agriculture, conservation agriculture and the management of biological diversity are options for enhancing ecosystem services in agroecosystems while sustaining or increasing productivity. Successful actions will depend on strong supporting policies and legal frameworks, as well as on developing the knowledge and leadership capacity in farming communities to evaluate the potential benefits. The maintenance of ecosystem services and the long-term productivity and stability of agriculture ecosystems requires a paradigm shift in agriculture that moves away from single solutions to production problems towards a portfolio approach that supports multiple ways to better use soil, water and biotic resources to enhance ecosystem services.

Background

Agricultural production involves a wide range of ecosystem services and processes that use water, soil and biological components of the agricultural ecosystem, such as: nitrogen cycling, climate regulation, soil formation, pest and disease regulation and pollination, in addition to the obvious food production (Chapters 3 and 4). Some of these services are produced within the agricultural ecosystem itself while others rely on the supporting water, soil and biotic features of the environment that surround the agricultural production system. As weather patterns are becoming more unpredictable and extreme, with prolonged dry spells and very strong storm events (see Chapter 2), the concern over the long-term reduction in total water supply, and in the frequency and severity of pests and pathogens, calls for more attention to be given to the underlying ecosystem services that support these systems (Molden, 2007).

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In natural ecosystems, the relationship between diversity and ecosystem regulating and supporting services has been given economic value (Diaz and Cabido, 2001), but little attention has been focused on the ecological consequences of the loss of biotic diversity within agricultural ecosystems. This loss can affect the ecosystem regulating functions of agroecosystems, their capacity to support those ecosystem regulating services and the long-term stability of the ecosystem in the face of biotic and abiotic stresses (Hajjar *et al*., 2008). In any ecosystem, each time a species or variety goes locally extinct, energy and nutrient pathways are lost, with consequent alterations of ecosystem efficiency and the ability of communities to respond to environmental fluctuations (Diaz and Cabido, 2001). Reduction of crop diversity, and of the associated diversity in agricultural landscapes, together with the associated reduction in functional traits and facilitative interactions, has reduced the capacity of agricultural ecosystems to regulate pests, diseases and pollinators, to recycle nutrients and to retain soil water (Hajjar *et al*., 2008).

A fundamental research question emerges, therefore, on how to ensure that continued increases in agricultural intensification and productivity can be achieved in ways that use and enhance ecosystem services more effectively, as measured by increased stability and reduced variability in the agricultural production systems of small-scale farmers (Foley *et al*., 2005; Tilman *et al.,* 2011). This includes increasing the adaptability of agricultural ecosystems in such a way that communities and agroecosystems are able to respond to changing conditions without debilitating losses in livelihoods, productivity or ecosystem functions.

As discussed in Chapter 4, ecosystem services in agriculture – that is, those other than the production of food or other agricultural products – have been assigned relatively low economic values compared with those in other natural ecosystems, largely as a result of a lack of understanding and limited data availability. However, 5 billion ha of land is currently cultivated or used for pasture. This is an area equal to approximately one third of the earth's total land area (Foley *et al*., 2005), and it generates and interacts with an enormous range of agroecosystem services. There is a need to address this underestimation of ecosystem services in farmland, a need to develop concepts, policies and methods of evaluating them, and to find ways in which they can be maintained and enhanced in a way that is socially acceptable. Agroecosystems may very well offer the best chance of increasing global ecosystem services if land and water are managed in a way that enhances natural and social capital (Porter *et al*., 2009). Specifically, enhancing the supporting and regulatory services of ecosystems is vital to meeting the food demands of a population forecast to reach 9 billion by 2050 (UNFPA, 2009).

Managing Ecosystem Services in Agriculture

Swinton *et al*. (2006) suggest that incentivizing a systems approach to agricultural management (rather than a problem-response approach) could support sustainable production as well as ecosystem services such as climate regulation, wildlife conservation, and biological pest control and pollinator management. Bennett *et al*. (2005) note that the ways in which ecosystems produce services are insufficiently understood, and that this uncertainty needs to be accounted for in the decision-making process. They advise that future management questions will have to address the complexity of ecosystems in their social context in order that ecological services can be maintained, and also to assess the degree to which technology can substitute for ecological services.

The ecosystem services framework provides a useful umbrella for this endeavour as it can only be achieved by healthy agroecosystems. Sustainable management plans have been advocated for various agroecosystems, ranging from hyper-arid and dryland systems (Chapter 6), to wetland and aquatic ecosystems (Chapter 7). Furthermore, as stated in Chapter 4, managing agroecosystems for the delivery of multiple services considerably improves the value of the land.

For instance, the on-site costs of nutrient depletion (including soil loss through erosion) in the agricultural sector of sub-Saharan Africa vary between countries from less than 1% to more than 20% of the agricultural gross domestic product (GDP) (Drechsel *et al.*, 2004). The off-site costs, especially in controlling erosion, can be much larger, and affect a variety of non-agricultural ecosystems and their services (Enters, 1998). The protection of these services by reducing soil, water and land degradation appears to be a cost-effective investment. Payments for environmental services (see below) and other finance mechanisms could be good incentives to use for stopping these off-site costs, but they would be context specific.

Managing livestock

With their many environmental impacts on soil, water and the atmosphere (Chapter 4), there are many opportunities for ecosystem gains in livestock production systems. For instance, the high emission of greenhouse gases can be mitigated by practices such as carbon sequestration in rangelands or improved pastures, by reversing deforestation for the production of feedstuffs through increased agricultural productivity and by using other methods of intensification (Watson *et al.*, 2000; Schuman *et al.*, 2002; Woomer *et al.*, 2004). Much can also be done by keeping fewer, but more productive, animals by means of better nutrition, animal health, breeding and husbandry techniques (Tarawali *et al.*, 2011). Another innovative approach is the establishment of community-based breeding programmes for the purpose of genetic improvement (e.g. in Ethiopia, where breeding animals are being selected based on phenotypes recorded within the village population; Mirkena *et al.*, 2011). To mitigate greenhouse gas emissions from animal waste, options lie in increased feed digestibility, better storage and treatment of the waste and the appropriate application of waste (World Bank, 2009). There are many other suggestions on how livestock could make a positive contribution to ecosystem services; however, the implementation of some of the proposed alternatives, such as payments for carbon sequestration in rangelands, remains a challenge.

Similarly, health hazards and the pollution of land and water by livestock excreta could be turned around into enhanced nutrient cycling and increased soil water holding capacity by improved management practices. The most effective methods for addressing these problems in catchments are at the farm or production facility. Additional measures can control the effects of manure in watercourses, e.g. manure can be intercepted and stored in ponds, contaminated water can undergo on-farm treatment and constructed farm wetlands can be used to reduce the pathogen load (Dufour *et al.*, 2012). A potential method described by Masse *et al.* (2011) for developing more sustainable livestock operations utilizes anaerobic digestion biotechnologies to produce biogas, and by this means reduces the need for supplementary chemical nitrogen and phosphorus fertilizers.

The recovery of nutrients from manure, an important contribution to the supporting ecosystem service of nutrient cycling, is highly variable. Approximately 65% of manure nitrogen is recovered from (industrialized) intensive systems in Europe. Almost 30% of this is lost during storage and the maximum cycling efficiency as nitrogen available to crops is around 52%, with large differences between countries (Oenema *et al.*, 2007). In developing countries too, there is a large range of variation in nitrogen cycling efficiencies in manure management systems (Rufino *et al.*, 2006). Manure handling and storage, and synchronizing mineralization with crop uptake – and hence fine tuning nutrient cycling in the soil, are key ways in which nitrogen cycling efficiencies can be increased in mixed intensive systems, thus contributing to better regulation of water quality. Results from a recent study in England support earlier conclusions that additions of manure organic carbon produce measureable changes in a wide range of soil biophysical and physicochemical properties and processes that are central to the maintenance of soil fertility and functioning (Bhogal *et al.*, 2009, 2011). Smallholder farmers in Africa, who use little fertilizer, recognize the important role of manure in the efficient management and maintenance of soil fertility for crop production (Rufino *et al.*, 2007). Alternative management of livestock production systems shows that combinations of intensification, better integration of animal manure into crop production and matching the nitrogen and phosphorus supply to livestock requirements can effectively reduce nutrient flows (Bouwman *et al.*, 2011).

With respect to nutrient cycling, therefore, adjustments are needed both in nutrient-deficient systems, where soil fertility is being depleted, and in nutrient-loaded systems, where groundwater contamination, surface water eutrophication and soil pollution are major problems (World Bank, 2009). Technical solutions for reducing the quantity of animal waste and facilitating its proper management and application have to be supported by regulatory measures and financial instruments, such as subsidies and taxes. In nutrient-deficient systems, the proper integration of livestock and crop production components in mixed and agropastoral systems can alleviate nutrient export through the application of manure and urine to cultivated areas (Powell *et al.*, 2004).

Trees for agroecosystem services

A long tradition of separate science and practice in forestry and agriculture means that there are largely untapped opportunities for using trees constructively in agricultural landscapes to sustain food production, while improving a range of ecosystem services. Trees have great potential to play an important role in the sustainable management of agro-ecosystems. In addition to having impacts on the supporting, regulatory, and cultural services of ecosystems, trees in agroecological land-scapes may increase provisioning services by contributing fruit, fodder, fuelwood and timber.

The impact of changing tree cover on various ecosystem services depends on its amount, spatial configuration, species com-position and management. So there is a need to consider planned tree cover change at a landscape scale with the aim of meeting specific suites of objectives, including consideration of the trade-offs and synergies among the ecosystem services affected (Jackson *et al.*, 2013; see also Box 4.1, Chapter 4). The enhancement of tree cover on farmland has the potential to tighten nutrient, water and carbon cycles, and promote the abundance and activity of soil organisms (Barrios *et al.*, 2012), thereby increasing and sustaining soil and water productivity. Different tree species root to different depths, have leaves at different times throughout the year, and use more or less water through transpiration, attributes that are all affected by management practices such as pruning.

Land management

A variety of soil conservation techniques are available that can be integrated into agricultural and other land use practices to sustain and enhance agroecosystems and minimize their adverse impacts on their closer environment (Bindraban *et al.*, 2012). Integrated solutions for tackling land degradation can lead to improved water productivity and environmental health (Descheemaeker *et al.*, 2009), without reducing water availability for food and feed production. An example from Ethiopia describes how successful approaches integrate water and land management with improved agricultural practices (Box 9.1), but more examples exist of solutions developed for multifunctional agroecosystems (e.g. Matsuno *et al.*, 2002; Vereijken, 2003; Boody *et al.*, 2005; Boisvert and Chang, 2006; Nguyen-Khoa and Smith, 2008).

Payments for Ecosystem Services

Payments for ecosystem services (PES), also known as payments for environmental services (or benefits), is the practice of compensating individuals or communities for undertaking actions that increase the provision of ecosystem services such as water purification, flood mitigation and carbon sequestration (Kelsey Jack *et al.*, 2008). PES comes under the heading of economic or market-based incentives aimed at motivating the desired decision taking through charges, tradable permits, subsidies and market friction reductions. While the term 'PES' has been in

Box 9.1. Integrated watershed management for improved water productivity and ecosystem services in Ethiopia.

Crop–livestock farming is an important livelihood strategy for smallholder farmers in water-scarce areas of Ethiopia, which are characterized by land degradation, low agricultural productivity, food insecurity and increasing population pressure (Descheemaeker *et al.*, 2010b). Integrated watershed management has become a popular way to tackle the interrelated problems of land degradation, low productivity, institutional and organizational constraints and poverty (German *et al.*, 2007; Shiferaw *et al.*, 2009). Community-based integrated watershed management – through exclosures (areas closed for grazing and agriculture) and water-harvesting ponds – was implemented in the water-scarce Lenche Dima watershed in the northern highlands of Ethiopia (Liu *et al.*, 2008).

Exclosures were established on the degraded hill slopes in the watershed with the overall aim of rehabilitating the area (Descheemaeker *et al.*, 2010b). In these closed areas, contour trenches were established to improve water infiltration, and multipurpose trees were planted at the time of closing. These actions enhanced both regulatory (water regulation) and supporting (soil formation) ecosystem services. The community was responsible for the protection of the area and this was institutionalized through written by-laws. Provisioning services were also enhanced as the production of herbaceous and woody biomass in exclosures recovered dramatically (Fig. 9.1), and farmers harvested the grass for haymaking. The exclosures led to improvements in livestock water productivity as well (Descheemaeker *et al.*, 2009): by protecting about 40% of the rangelands in the watershed, the water productivity of the feed increased by 18–49%, depending on the amount of hay produced in the exclosures. As a result, the livestock production per unit of water depleted increased. Long-term environmental benefits (observed runoff reduction, groundwater recharge and the protection of downstream cropland from peak flows) and increased woody biomass production from the exclosures contributed to improved ecosystem services in the watershed (Descheemaeker *et al.*, 2010b).

Fig. 9.1. Degraded open access grazing land (left) and protected exclosures 3 years after closing (right) in Ethiopia (photos by Katrien Descheemaeker).

The second intervention was the construction of dome-shaped water harvesting structures in the farmers' homesteads (Descheemaeker *et al.*, 2010b). On average, farmers used 50% of the water to irrigate the fruit trees and vegetables planted in their homesteads. Domestic uses accounted for about 20% of the water use, and livestock drinking for the remaining 30%, mostly in the dry period. The effect of the water harvesting structures on livestock water productivity was brought about through the reduction of the energy spent by the animals in walking to the drinking points in the dry season (about 11% of their annual energy budget). This saved energy could, potentially, be used for productive purposes such as milk production (Descheemaeker *et al.*, 2010a). Other studies (Muli, 2000; Staal *et al.*, 2001; Puskur *et al.*, 2006) found that water harvesting structures enabled farmers to combine vegetable production with small-scale dairy farming, which significantly increased milk production and farmers' incomes. While animals were kept in the homestead for drinking, the pressure on the rangelands was reduced too, thus avoiding land degradation and the disruption of environmental flows (Descheemaeker *et al.*, 2010b).

common use since the 1990s, PES type schemes have been around since at least the 1930s when, in the wake of the American Dust Bowl, the federal government paid farmers to avoid farming on poor quality erodible land.

Various case studies are discussed in Dunn (2011); these look at the changing drivers for agriculture and at growing urbanization, which both threaten water quality, and at how organizations have set up PES schemes with local farmers. For example, companies pay farmers to adopt less intensive farming techniques, such as outdoor grazing, instead of fertilizer-intensive crop cultivation and feedlots, and the planting of trees to improve soil conditions and promote filtration services. Payments provide sufficient incentives to compensate the famers for these actions, and are developed in collaboration with famers and academics, and negotiated with each farmer. They are intended to reward services that go beyond what is legally required. Such schemes have documented successes in terms of their impacts on water quality, farmer profitability and biodiversity outcomes (see Dunn, 2011).

In several of the integrated watershed programmes that have been implemented in India, upstream farmers are compensated for changing their practices, but not necessarily always in cash (Box 9.2). Hence, demand for a wide range of ecosystem services from agriculture will increase owing to a greater awareness of both their value and the costs inherent in their depletion (FAO, 2007).

Today, there are literally hundreds of ongoing PES schemes of all shapes and sizes, all over the world. Some are directed towards achieving poverty reduction on a local level; others maximize the output of goods on an industrial scale. However, all of the schemes essentially involve three steps (WWF, 2010). First, an assessment of the range of ecosystem services that flow from a particular area, and who they benefit. Secondly, an estimate of the economic value of these benefits to the different groups of people. Finally, a policy, a subsidy or a market to capture this value and compensate individuals or communities for

Box 9.2. Payments for water services in Sukhomajri, India.

The small village of Sukhomajri in the foothills of the Shivaliks provides an early and complex example of watershed development that has helped to inspire modern watershed development programmes (FAO, 2007). In the 1970s, high rates of sedimentation in Lake Sukhna in the northern Indian state of Haryana created problems for the drinking water supply of the nearby town of Chandigarh (Kerr, 2002). The source of the problem was traced to a small upstream village named Sukhomajri, where villagers were cultivating steep lands, and allowing animals to graze freely throughout the watershed. Around 80–90% of the sedimentation in Lake Sukhna was found to originate from Sukhomajri (Sengupta *et al*., 2003). The agricultural practices of the Sukhomajri farmers were not only felt downstream, but also in the village itself, where runoff water on one side of the watershed flooded and destroyed agricultural lands.

A central government agency, the Central Soil and Water Conservation Research and Training Institute (CSWCRTI) revegetated the watersheds and installed conservation structures such as check dams and gully plugs to stop the flow of silt. Villagers were asked to refrain from allowing grazing animals on to the watersheds. Benefits to the villagers were twofold: damage to agricultural lands was reduced, and there was access to irrigation water stored by the check dams. Although no direct payments were involved, the villagers were thus indirectly compensated for providing the environmental service. At the time of the implementation of the project, the notion of markets for environmental services was little known but, in effect, the project functioned as an environmental services payment scheme.

A drawback was that only a minority of landowners in the village benefited from the scheme; other villagers, particularly the landless, stood to lose from reduced access to grazing lands. The problem was solved by distributing rights to the water to all villagers and allowing them to trade among themselves – a system that was later abandoned in favour of user fees for water. The project resulted in a 95% decrease in siltation into Lake Sukhna, and saved the town of Chandigarh about US$200,000 annually (Kerr, 2002).

their action. In China's renowned 'Grain for Green' programme, the government thus compensates farmers with grain and cash for planting trees on their sloping farmlands (Box 9.3).

Developing mechanisms to implement PES is challenging, not least because although the concept is simple, the reality of making such schemes operational can be very complex, and budgetary resources are often a constraint – especially in poorer countries. Nevertheless, PES can trigger creativity in finding innovative solutions. When effectively designed, PES schemes can give both providers and users of ecosystem services more accurate indications of the consequences of their actions, so that the mix of services provided matches more closely the true preferences of the society concerned (FAO, 2007). This is the case in Brazil, where water users pay for measures that prevent pollution and erosion (Box 9.4). Water users themselves rarely take the initiative but, in Nepal, a fishing community has developed its own, demand-led, mechanism to ensure good water quality (Box 9.5).

A related and comparable concept is that of green water credits, where incentives are given for sound water management or sediment control by appropriate tillage methods or other eco-efficient farming techniques (Dent and Kauffman, 2007; Jansen *et al*., 2007). The idea is to create investment funds so that farmers can take intervention measures for better management of soil and water upstream, which will then be paid for by downstream users that receive more and better quality water.

Box 9.3. China's Grain for Green programme.

Pushed into action by a series of devastating floods in 1998, the Chinese government launched the Grain for Green programme in 1999 (FAO, 2007). This is one of the largest conservation set-aside programmes in the world, and its main objective is to increase forest cover on sloped cropland in the upper reaches of the Yangtze and Yellow River basins to prevent soil erosion. When possible in their community, households set aside all or parts of certain types of land and plant seedlings to grow trees. In return, the government compensates the participants with grain, cash payments and free seedlings. By the end of 2002, officials had expanded the programme to some 15 million farmers in more than 2000 counties in 25 provinces and municipalities (Xu *et al*., 2004). A recent impact analysis of 11 river basins covered by the Grain for Green programme suggests that both runoff and soil erosion have been reduced (Deng *et al*., 2012).

Box 9.4. Brazil's Water Producer Programme (TNC, 2008)

The Paraná River is the second longest river in South America, running through Brazil, Paraguay and Argentina over a course of 2570 km. The river provides multiple ecosystem services to the populations living within its watershed, including water for irrigation and the provision of drinking water to South America's largest city, São Paulo. However, the water quality of the Paraná River has declined over time as a result of the intensive deforestation of the Atlantic Forest at its headwaters. Without forest cover around the river's edge (the riparian zone), rainwater washes away soil, leading to a build-up of sediment that alters the water quality and may invade irrigation systems.

In an effort to improve the water quality of the Paraná River while at the same time protecting the biodiversity of the Atlantic Forest, The Nature Conservancy (an international organization) developed the Water Producer Programme, and it is implemented by Brazil's National Water Agency (ANA), the Agriculture and Environment Secretaries of São Paulo, the Piracicaba–Capivari–Jundiai (PCJ) watershed committee and the municipal government of Extrema in the state of Minas Gerais. The programme proposes using a portion of the water fees collected from major water users, such as water supply companies, and major industries to plant trees along riparian zones in the river's headwaters. These activities are executed by farmers and ranchers who receive a payment to reforest and maintain key sections of their land that are critical to the health of the Paraná River, thus contributing to the regulatory services of the river. Landowners also receive technical assistance on reforestation, soil conservation and erosion prevention from the programme's partners.

Box 9.5. The Rupa Lake Cooperative, Nepal (Pradham *et al.*, 2010).

Rupa Lake is the third largest lake (area 1.35 km^2) in Nepal. It is located in the mid-western part of the country at an altitude of about 600 m asl. The area was once rich in biodiversity, but the ecosystem had deteriorated over the last few decades because of human encroachment of the land around the lake. Its conversion to agriculture had resulted in an increase in heavy landslides, pollution by chemical waste and the silting of downstream areas, all of which threatened the livelihoods of the fishing households earning their living from the lake.

The Rupa Lake Restoration and Fishery Cooperative, founded in 2001 by a downstream community for which fishery is an important part of their livelihood strategy, established a benefit-sharing mechanism to provide incentives to communities and various upstream user groups to conserve the catchment. The process was developed through local, traditional mechanisms, in the absence of official markets for the environmental services. The Rupa Cooperative decided to pay 10% of its income from fishery management to the upstream communities with the aim of ensuring good upstream crop management practices to reduce siltation and promote water quality. The payment mechanism is voluntary, and there is no contract or agreement made between the buyers (the Cooperative) and the sellers (the upstream users). Direct payments are made by the Cooperative on an annual basis to different user groups, such as Community Forest User Groups, schools and communities who request funding for specific watershed management activities. Rewards or indirect payments are also made by the Cooperative in kind through the provision of seedlings and gabion boxes.

Ecological Agriculture

Another way of targeting more ecosystem services in agriculture is through alternative approaches to agriculture that are more sustainable and safeguard ecosystem services, in particular from the point of view of water management. Several tools and approaches have been used to implement the concept of sustainable agriculture, such as sustainable land management, ecoagriculture, conservation agriculture, conservation farming, organic agriculture, increased genetic diversity in the production system and others (Francis and Porter, 2011; Gomiero *et al.*, 2011; Mulumba *et al.*, 2012). There are also successful local experiences that have made a paradigm shift away from single solutions to using a portfolio of methods to promote sustainable agriculture; this process should meet the following criteria (FAO, 1995):

- Ensure that the basic nutritional requirements of present and future generations are met both qualitatively and quantitatively, while providing a number of other agricultural products and ecosystem services.
- Provide durable employment, sufficient income, and decent living and working conditions for all those engaged in agricultural production.
- Maintain and, where possible, enhance the productive capacity of the natural resource base as a whole, and the regenerative capacity of renewable resources, without disrupting the functioning of basic ecological cycles and natural balances, or destroying the sociocultural attributes of rural communities, or causing contamination of the environment.
- Reduce the vulnerability of the agricultural sector to adverse natural and socio-economic factors and other risks, and strengthen self-reliance.

Examples of such successful local experiences include two from Kenya: the programme to regain the eroded uplands of Machakos by the Akamba people (summarized in UNDP *et al.*, 2000); and projects carried out by SACDEP-Kenya (Sustainable Agriculture Community Development Programmes in Kenya) (outlined in Box 9.6).

Conservation agriculture also tries to increase ecosystem services in agriculture, mainly through reducing tillage and restoring land cover, as shown by an example from Zambia (Box 9.7). Its primary purpose is to bring water back into the soil and keep it there,

Box 9.6. Small-scale sustainable agriculture in Kenya.

Since 1993, SACDEP-Kenya (Sustainable Agriculture Community Development Programmes in Kenya; see http://sacdepkenya.org/) trained over 40,000 farmers in 14 districts in Kenya. During those years, the strategies of sustainable agriculture have been refined. While conventional agriculture is mainly about increased production and incomes, SACDEP uses four principles to guide sustainable agriculture: that it be economically feasible, environmentally friendly, socially just and culturally acceptable. In order to make these principles practically operational, the necessary pillars of sustainable agriculture were defined. These pillars are based on farmer working groups, low-cost external inputs, organic agriculture, the ability of communities to mobilize finances, renewable energy, farmers' participation in conservation, and processing and value addition; they also include marketing decisions (including pricing) and the formulation of policies for agricultural and rural development. SACDEP has had successful projects in Kenya on organic products, draft animal power, low cost livestock (such as dairy goats), wind energy, Direct Organic Markets and high value alternative and emerging crops. It would be interesting to measure the impact of the combined interventions on ecosystem services, particularly on regulatory and supporting services, such as ecosystem resilience.

Box 9.7. Conservation farming in Zambia.

As an example of local initiatives in Africa, the PELUM Association (www.pelumrd.org) is a network of 207 civil society organizations in eastern, central and southern Africa that is working towards poverty eradication and food security through sustainable agriculture. It aims to build the capacity of farming and rural community groups to accumulate skills, to stimulate farmer learning and to inspire experimentation and innovation in the quest to achieve food security. In doing this, it builds on the potential of indigenous knowledge and indigenous farming and cropping patterns.

A study by PELUM on 15 small farms and two commercial farms in Zambia before and after conversion towards conservation farming showed that it can be an important first step to enabling smallholder farmers to get out of poverty and towards sustainable farming:

- Conventional small-scale farming in Zambia had nationwide average yields of 1.1 t/ha, and mostly economic deficits, because of the high costs related to inputs such as tillage and fertilizer.
- Almost a third of all fields were abandoned at the time of harvest every year, because inputs (labour, ploughs, fertilizers) were not available at the right time.
- In the 'worst' sub-village, a pilot project with technical support from PELUM achieved a 70% increase of yield and profit after 6 days of training and individual coaching.
- A comparison between various ploughing techniques and implements showed that:
  - Ploughing led to the lowest yields (average 2.4 t/ha)
  - Ripping was better (yields about 4 t/ha)
  - Hand hoeing gave the best results (yields 5–8 t/ha)
  - The highest yields of 8 t/ha were only reached by farmers who used manure (chemical fertilizers showed lower yields).

The sustainability of farms was measured before and after the conversion to conservation farming. Profit was the indicator for economic sustainability, while for ecological sustainability carbon dioxide (CO_2) equivalents were used. In Zambia, conservation farming proved to be significantly more profitable (70% more profit 1–2 years after conversion) than conventional farming. This applied to small and large farms applying zero tillage and direct drilling into the stubble. Although ecosystem services were not explicitly measured by PELUM, it appears, in any case, that the supporting service of soil formation was enhanced.

but it can have much larger benefits, such as shown by the example of Itaipu, in Brazil (Box 9.8). The Itaipu case demonstrates that, by considering and managing ecosystem functions and services, win–win solutions for both agriculture and other needs can be achieved. The interventions made have increased agricultural productivity and sustainability, in addition to delivering benefits to other ecosystems, such as reduced erosion. The

Box 9.8. Conservation agriculture in the Itaipu watershed, Brazil.

Farming activities in the Itaipu watershed, in the Paraná Basin in Brazil, were a significant threat to the Itaipu dam, a major facility generating hydroelectric power for Brazil, Argentina and Paraguay. The promotion of conservation agriculture in this watershed has enabled farmers to deliver improved ecosystem services, in particular through the reduction of soil erosion and the delivery of clean water to the reservoir (Mello and van Raij, 2006; ITAIPU, 2011). Not only did this approach improve farmer livelihoods, it also extended the life expectancy of the dam fivefold. This translated into a considerable benefit, considering the original investment costs of the dam and its regional economic importance. Furthermore, as in many cases, irrespective of increased farm profitability, the on-farm value of agricultural produce (direct farm profits) was eclipsed by the value of the improved catchment services provided through more sustainable farming.

move from conventional agricultural and environmental management practices to non-conventional practices such as conservation agriculture represents a great challenge in terms of changing habits and minds (Table 9.1).

Ecoagriculture is another of the many approaches towards sustainable farming, and is highlighted in this book because of its landscape scale and its compatibility with modern high input agriculture (see also Chapter 11). It is 'the design, adaptation and management of agricultural landscapes to produce ecosystem services (e.g. watershed services, wild biodiversity) and generate positive co-benefits for production, biodiversity, and local people, while addressing climate change challenges' (Scherr and McNeely, 2008; Ecoagriculture Partners, 2012). Such integrated agricultural landscapes provide critical watershed functions through careful rain and soil water management. This integrated management encompasses the choice of water-conserving crop mixtures, soil and water management (including irrigation), the maintenance of soils to facilitate rainfall infiltration, vegetation barriers to slow the movement of water down slopes, year-round soil cover, and maintenance of natural vegetation in riparian sites, wetlands and other strategic areas of the watershed.

Parallel to the demand for more sustainable agriculture, the health sector has developed interdisciplinary approaches such as 'One

Table 9.1. Comparison of conventional farming with conservation agriculture (from Thiombiano and Meshack, 2009).

Farming practice	Conventional farming	Conservation agriculture	Rationale
Tillage	Farmers plough and hoe to improve the soil structure and control weeds	Direct planting without prior inversion of the soil Planting on the rip line or making holes for planting with a hoe	In the long term, ploughing destroys the soil structure and contributes to declining fertility and levels of organic matter
Crop residues	Farmers remove or burn residues or mix them into the soil with plough or hoe	Crop residue left on the field Planting of cover crops	Crop residues improve soil structure Cover crops protect soil from erosion and limit weed growth
Mix and rotate crops	Monocultures or crop rotations in a tillage framework where the soil is inverted with a mouldboard plough or similar implement	Crop rotation or intercropping is a permanent feature of the cropping system	Helps to maintain soil fertility Breaks disease cycles

Health', striving to attain optimal health for people, animals and our environment, and 'Ecohealth', a participatory methodology for understanding and promoting health and well-being in the context of social and ecological interactions. Both of these methods fit well within an ecological approach to agriculture as the two integrated health approaches emphasize a multidisciplinary process and the importance of agriculture and ecosystem-based interventions (Waltner-Toews, 2009). This makes them highly suitable for addressing water-related diseases, in a manner that is complementary to that of sustainable agriculture (see Chapter 5). Agricultural practices that create health risks, such as those related to water management, obviously require farm-level interventions, and food-borne diseases require management along the 'field-to-fork', or 'boat-to-throat' risk pathway. This includes management of water used at different stages, be it as a production input, in processing, or in meal preparation. Most zoonoses need veterinary and agroecological interventions in addition to medical interventions, as they cannot be controlled as long as diseases remain in the animal reservoir. For zoonoses transmitted through water (e.g. leptospirosis) or via aquatic hosts (e.g. schistosomiasis) interventions may also need to be directed at the aquatic ecosystems.

Managing Biological Diversity Within Agroecosystems

Recently, more attention has been given to the role of the biological diversity of cultivated ecosystems in providing ecosystem regulating and supporting services (FAO and PAR, 2011). There is a growing body of literature that functional diversity – the value and range of species traits rather than just species numbers – is important to short-term ecosystem resource dynamics and long-term ecosystem stability, as it increases positive interactions or complementary functions (Diaz and Cabido, 2001; Wilby and Thomas, 2007). First, crop genetic diversity has been shown to have a direct effect on the maintenance of ecosystem services by providing both: (i) increased numbers of functional traits; and (ii) facilitative interactions that maintain above- and below-ground associated biodiversity. This has been shown to be useful in pest and disease management, and has the potential to enhance pollination services and soil processes (nutrient cycling, decomposition and erosion control) in specific situations (Hajjar *et al.*, 2008). Secondly, by increasing long-term stability of the ecosystem in the face of biotic and abiotic stresses and socio-economic variability, crop genetic diversity promotes the continuous maintenance of biomass and the ecosystem services that it provides.

Maintaining or increasing the genetic diversity within the farmer's production system through the use or development of varietal mixtures, or of sets of varieties with non-uniform resistance, has been an alternative agricultural management practice for regulating pests and diseases in many parts of the world (Finckh *et al.*, 2000; Finckh and Wolfe, 2006). The main purpose of genetic mixtures (crop variety mixtures) for pest and disease management is to slow down the spread of pests and pathogens (Wolfe, 1985). Recent studies have shown that a diverse genetic basis of resistance is beneficial for the farmer because it allows a more stable management of pest and disease pressure than does a monoculture (Trutmann *et al.*, 1993; Thurston *et al.*, 1999; Thinlay *et al.*, 2000; Finckh, 2003; Di Falco and Chavas, 2007; Jarvis *et al.*, 2007). The high levels of diversity of traditional rice varieties in Bhutan have been shown to have high functional diversity against rice blast (Thinlay *et al.*, 2000; Finckh, 2003). Increased levels of common bean and banana diversity in Uganda when disease levels were high showed a significant reduction in pest and disease damage in farmers' fields (Mulumba *et al.*, 2012; Box 9.9).

There is growing evidence of the potential of crop genetic diversity to enhance an agroecosystem's capacity to sustain biomass levels through improving the resilience and resistance to environmental variability of that system (Sadiki, 2006; Sawadogo *et al.*, 2006; Weltzien *et al.*, 2006). High levels of crop genetic diversity occur most commonly in areas where the production environment itself is extremely variable. Here, crop genetic diversity, through its increased portfolio of

Box 9.9. Crop varietal diversity to regulate pests and diseases in Uganda (Mulumba *et al*., 2012).

Bananas and plantains (*Musa* spp.) and common beans (*Phaseolus vulgaris*) are important carbohydrate sources for local people in Uganda. Both crops are maintained as a mixture of different genotypes in farmers' fields. The varietal diversity of the local crops was measured at both community and household levels within 60 farmers' fields in each of four agroecological areas of Uganda. Participatory diagnostics of farmers' knowledge linked to cross-site, on-farm and on-station trials was then used to assess the resistance of traditional and modern varieties of *P. vulgaris* to anthracnose, angular leaf spot and bean fly, and of traditional and modern varieties of *Musa* spp. to black sigatoka, banana weevils and nematodes; the assessments of resistance were then compared with the intraspecific diversity of these two crops in the farmers' fields.

A general trend for both crops was that with increased diversity of crop varieties, as measured by the number of varieties (varietal richness) and their evenness of distribution, there was a decrease in the average damage levels across sites. Moreover, this increased diversity was related to a reduction in the variance of disease damage. That there was a reduction in the variance of disease damage as the diversity increased is an indication that some of the uniform farms (i.e. those growing a particular variety) will be fine, but only in the case that they happen to be growing a winning variety for that year; otherwise, these farms will be hit far worse in terms of crop damage when there is a change in pathogen or pest biotype.

The results support what might be expected in a risk-minimizing argument for using diversity to reduce pest and disease damage: diversity may both reduce current crop damage and have the potential to reduce future vulnerability to pest and disease infestations. The relationship of increased diversity to decreased damage was particularly evident when the damage of the disease was higher i.e. in sites with higher disease incidence, households with higher levels of diversity in their production systems had less damage to their standing crop in the field.

types, provides the capacity to cope with multiple stresses and changing conditions, thereby ensuring a more stable vegetation cover under a less predictable environment (Brush 1991; Aguirre *et al*., 2000; Hajjar *et al*. 2008).

The provision of ecosystem services that support soil, water and nutrient availability (Chapter 3), and consequently biomass yield, is a management issue that also has the potential to be addressed through crop genetic diversity. In Nepal, farmers typically plant several varieties of rice to match the soil, moisture and other micro-ecological conditions in upland, lowland and swamp environments, which are often all found on the same farm. More than twice the number of rice varieties are found in the hills (which are generally more prone to erosion) as in the lowlands; moreover, farming on slopes tends to be associated with greater diversity in both crops and varieties (Gauchan and Smale, 2007). In these cases, tolerant varieties are planted where there would otherwise be no vegetative cover, and multiple varieties are planted to best match soil type. This provides for a more continuous planted biomass, and so avoids or decreases soil erosion (and at the same time enhances the soil's ability to sequester carbon).

There are well-documented cases where the low fruit set of crops – and the resulting reduction in yield – has been clearly attributed to pollinator impoverishment. As most temperate and tropical fruit trees are obligatory outcrossers, and rely on insects or small animals for pollination, there is great potential for enhancing the role of the varietal diversity of the fruit trees themselves in promoting cross-hybridization and better fruit production. Studies have shown that strategic plantings, alternating different varieties in a chequerboard pattern for example, can optimize effective pollination visits to two varieties of different attractiveness and, at the same time, promote cross-hybridization and better fruit production (Kubišová and Háslbachová, 1991). In a similar approach, pollinator-attracting genotypes of certain crops have been explored as a management strategy for enhancing pollination services (Suso *et al*., 2008), as genetic polymorphism in the reproductive characters of flowering plants can influence pollinator foraging (Cane and Schiffhauer, 2001). Diversity that promotes staggered flowering times among crop varieties has the potential to prolong season-long visitation by bees throughout the protracted flowering season (thus increasing the chances of pollinator population survival to the next growing season), as well as to increase the types of bees visiting at different times during the season, because several bee species are sensitive to climatic variation (Willmer *et al.*, 1994; Kremen *et al.*, 2002). In the Yucatan, Mexico, this management strategy is used with maize varieties; short-cycle maize and the more popular long-cycle maize are planted together in order to supply bees with pollen during the wet season and sustain the bee population until the next floral season (Tuxill, 2005).

Constraints and Policy Options

Though many of the management practices discussed here are both more environmentally sustainable and could result in beneficial economic returns, adoption is not guaranteed (see also Chapter 8). This can be due to limited access to information, to appropriate technologies or to finance (FAO, 2007). In addition, subsidies for agricultural production can lead to practices that degrade ecosystems. Other reasons for the non-adoption of sustainable technologies include inclusion in or exclusion from social networks (Warriner and Moul, 1992), land tenure (Tenge *et al.*, 2004) and sociocultural determinants.

Policy makers have an important role to play in safeguarding ecosystem services. Accounting for the benefits and costs of the full range of ecosystem services in policy making, and greater emphasis on natural resources and water use efficiency in food production, will promote better decision making that will lead towards more sustainable farming. Subsequently, coherence in cross-sector policies is fundamental to supporting collaboration among various stakeholders. Inter-sectoral collaboration at the ministerial level is essential for ensuring good ecosystem care, while providing the necessary food and services to communities. The need for coherence applies at the national level, between ministries of agriculture, the environment, water and natural resources; likewise, it applies in donor policy and, not least, between national governments and international institutions (Fresco, 2005).

Conclusions

To harness the full value of the ecosystem services that can be derived from sustainable water management practices linked to sustainable soil and biological diversity within agricultural ecosystems and their surrounding areas, a paradigm shift is needed in the way agriculture is carried out. This shift will require a move away from single solutions to production problems, towards risk reduction by creating insurance through a multitude of ways to better use soil, water and biotic resources that enhance ecosystem services. It will support the need for the enhanced capacity of natural resource managers to recognize, assist and create partnerships with small-scale farmers that adopt water, soil and biotic management methods – methods that will both reduce vulnerability in the production system and, at the same time, maintain productivity. The change will also require efforts to promote different norms among the consumers and retailers that support agricultural production systems, so that the vulnerability of these systems is reduced, together with continued productivity through enhanced ecosystem services. A change such as this will need to be supported by policies, legal measures and incentives that support production systems with less dependence on external inputs, and/or wiser management of these resources.

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