Smallholders, food security, and the environment

IFAD
Enabling poor rural people
to overcome poverty

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Acronyms and abbreviations

ASTI	Agricultural Science and Technology Indicators Program (IFPRI)
CA	conservation agriculture
CGIAR	Consultative Group on International Agricultural Research
DAC	Development Assistance Committee (OECD)
EPAT	Environmental and Natural Resources Policy and Training Project (USAID)
FAO	Food and Agriculture Organization of the United Nations
FTS	fertilizer tree system
GEF	Global Environment Facility
GHG	greenhouse gas
IFPRI	International Food Policy Research Institute
IIED	International Institute for Environment and Development
IPM	integrated pest management
ODA	official development assistance
OECD	Organisation for Economic Co-operation and Development
PES	payment for ecosystem (or environmental) services
R&D	research and development
TEEB	The Economics for Ecosystems and Biodiversity (for Agriculture)
UNEP	United Nations Environment Programme
WCMC	World Conservation Monitoring Centre (UNEP)

Executive summary

There are 1.4 billion poor people living on less than US$1.25 a day. One billion of them live in rural areas where agriculture is their main source of livelihood. The 'green revolution' in agriculture that swept large parts of the developing world during the 1960s and 1970s dramatically increased agricultural productivity and reduced poverty. Many of the productivity gains accrued to smallholder farmers, supported through research and extension services. However, those achievements came with environmental externalities, leaving soils degraded and groundwater depleted, undermining the very resource base that made the revolution possible. Moreover, two decades of underinvestment in agriculture, coupled with growing competition for land and water, rising input prices and climate change, have left smallholders more vulnerable and less able to escape poverty.

Yet poverty and environmental degradation need not be an inevitable outcome of modern development. At a time when there is renewed focus on agriculture in the context of sustainable development, there is a need and an opportunity to enhance the role that smallholders play in food production and natural resource stewardship.

This report, commissioned by IFAD and the United Nations Environment Programme, aims to improve understanding among policymakers and practitioners – together with those influencing and making decisions in relevant business sectors – of the relationships between smallholders, food security and the environment. It leads to the conclusion that, with targeted support, smallholder farmers can transform the rural landscape and unleash a new and sustainable agricultural revolution.

KEY MESSAGE 1

Smallholders form a vital part of the global agricultural community, yet they are often neglected

Smallholders manage over 80 per cent of the world's estimated 500 million small farms and provide over 80 per cent of the food consumed in a large part of the developing world, contributing significantly to poverty reduction and food security. Increasing fragmentation of landholdings, coupled with reduced investment support and marginalization of small farms in economic and development policy, threaten this contribution, leaving many smallholders vulnerable.

KEY MESSAGE 2

Smallholder productivity in particular depends on well-functioning ecosystems

The productivity of smallholder agriculture and its contribution to the economy, food security and poverty reduction depend on the services provided by well-functioning ecosystems, including soil fertility, freshwater delivery, pollination and pest control. Smallholder farming practices, in turn, affect the condition of ecosystems. These impacts are not always negative, but poverty and immediate needs can drive smallholders to put pressure on ecosystems, for example through habitat modification, overextraction of water and nutrients, and use of pesticides.

KEY MESSAGE 3

Growth in agricultural production to meet rising global needs using prevailing farming practices is unsustainable – a transformation is needed

The demand on agriculture to feed a larger and more urbanized population through global markets over the next 40 years will continue to grow, placing additional pressure on available land and other natural resources. Current practices are undermining the ecological foundation of the global food system through overuse and the effects of agricultural pollution, thereby enhancing degradation, reducing ecosystem capacity to generate sustainable yields and threatening to negatively impact food security and poverty reduction. Sustainable agricultural intensification can be the answer to enhanced food security, environmental protection and poverty reduction.

CONCLUSION

With the right conditions, smallholders can be at the forefront of a transformation in world agriculture

With their immense collective experience and intimate knowledge of local conditions, smallholders hold many of the practical solutions that can help place agriculture on a more sustainable and equitable footing. To do this, they need help to overcome market failures and other disincentives for sustainable land use, including insecure land tenure, high transaction costs and weak institutional support. A major challenge will be to address the discrepancies of scale between decisions made at the farm level and impacts at larger ecosystem scales.

Finally, further research is needed in the following areas:

- **Biodiversity/ecosystem services.** More needs to be known about the relationship and dynamics between biological communities and the services they provide, including how these relationships change over time and how this affects the stability and resilience of the services and crop productivity.
- **Synergistic effects of below- and above-ground services.** It is not known whether suites of below- and above-ground services contribute synergistically, or trade off in their contribution to crop yield and quality.
- **Effect of land use on biological communities.** For successful management of multiple services, more information is needed on how land use and other environmental factors affect the distribution, abundance and community composition of organisms that contribute to crop production.
- **Climate change and agricultural productivity.** Understanding must be deepened of the impacts of climate change on agricultural yields, cropping practices, crop disease spread, disease resistance and irrigation development.
- **Economics of sustainable intensification.** For ecosystem services to become an integral part of farming, further insights are needed into the economic benefits and costs associated with ecological intensification.
- **Economics of ‘multifunctional agriculture’.** Agricultural landscapes deliver other services than crop production, such as climate and water regulation and biodiversity conservation, many of which provide benefits on regional or global scales. ‘Multifunctional agriculture’ is emerging as an important research topic to quantify these benefits and propose strategies to encourage farmers and land managers to support them.
- **Costs of the transformation.** The cost of the failures identified in this report, the investments needed to achieve the proposed transformation to a global, greener economy centred on smallholders, and the resultant benefits should be quantified. The Economics for Ecosystems and Biodiversity (TEEB) for Agriculture initiative provides the scope for this kind of assessment.

Agriculture and smallholder farmers at a crossroads

Global agricultural production has kept pace with population growth over the past 50 years, mainly due to intensification associated with the 'green revolution' (Royal Society 2009) and expansion into previously uncultivated areas (Green et al. 2005; Ramankutty et al. 2008). But despite global gains in production, access to food remains unevenly distributed. As a result, 870 million people remain food insecure, with many more suffering from 'hidden hunger' caused by micronutrient or protein deficiencies (Graham et al. 2007; Keatinge et al. 2011; FAO 2011a; Khush et al. 2012).

Agriculture serves as a valuable source of income, contributing to poverty reduction. While progress has also been made on the poverty front, 1.4 billion people still live in extreme poverty. Seventy-five per cent live in rural areas of developing countries, especially sub-Saharan Africa and southern Asia (UN 2011; IFAD 2011a). Globally, there are approximately 2.5 billion people involved in full- or part-time smallholder agriculture, managing an estimated 500 million small farms.

The green revolution in agriculture swept through large parts of the developing world during the 1960s and 1970s. Through advances such as high-yielding crop varieties, irrigation, agrochemicals and improved management techniques, farmers' grain production increased from 800 million to more than 2.2 billion tons from 1961 to 2000 (World Bank 2007; FAO 2011a). Smallholder farmers achieved many of those developments, supported through government and/or donor-funded extension services. Intensive crop production helped boost agricultural output, reduce the number of undernourished people and drive poverty reduction through thriving rural economies (Hazell 2003; Cervantes-Godoy and Dewbre 2010a). The green revolution, particularly in Asia, showed that the potential of smallholder farming could be harnessed and realized.

But those achievements came at a cost. In some countries, certain practices introduced through the green revolution led to land degradation, groundwater depletion, pollution of soil and water, pest upsurges and loss of biodiversity (Hazell 2003). Moreover, not all regions in the world or all farmers have benefited equally from the advances brought by the green revolution (Hazell and Ramasamy 1991; Hazell 2003). Significant gains in production were achieved in Asia and Latin America, but impacts in sub-Saharan Africa were much smaller (Ellis 2005).

The conditions that smallholders face have changed. Farmers face a series of unprecedented, intersecting challenges, often originating at global levels: increasing competition for land and water, increased influence of and changing markets, rising fuel and fertilizer prices, and climate change. This changing context poses difficult challenges for smallholders, who are more directly dependent on ecosystem services and have less capacity to adapt to changing contexts, compared with larger, more resource-endowed farmers. Until recently, international investments in agricultural development and policy had been lagging behind other sectors (Bioversity et al. 2012). Smallholders have often been neglected in debates on the future of agriculture, and left out of policymaking at numerous levels (Wiggins 2011; Vorley, Cotula and Chan 2012).

Where can we go from here? As the economic sector that covers the largest surface area in the world, agriculture must take its place at the heart of economic growth, poverty reduction and environmental protection. For agriculture to realize this potential, it will have to change dramatically, and smallholder farmers need to be critical agents in this transformation. Renewed focus on the development support and investment needs of smallholder farmers is critical.

Sustainable agricultural intensification involves scaling up farming practices that maintain the resource base on which smallholders depend, so that it continues to support food security and rural development into the future. A greener agricultural system should be based on and bring about competitive economic returns, the supply of essential and life-supporting ecosystem services, decent jobs and livelihoods, a smaller ecological footprint, increased resilience to climate change, and enhanced food security.

This report proposes sustainable agricultural intensification to achieve multiple environmental, agricultural, social and economic benefits among smallholders and towards sustainable rural development.

Various approaches have been and are being investigated to make smallholder agriculture more productive and sustainable (ecologically, economically and socially). **Many of these methods are proven on a limited scale, and we argue that by scaling them up, smallholders can be at the forefront of a sustainable revolution in agriculture.**

KEY MESSAGE 1

Smallholders form a vital part of the global agricultural community, yet they are often neglected.

Smallholders manage over 80 per cent of the world's estimated 500 million small farms and provide over 80 per cent of the food consumed in a large part of the developing world, contributing significantly to poverty reduction and food security. Yet small-scale farmers often live in remote and environmentally fragile locations and are generally part of marginalized and disenfranchised populations.

Who are the world's smallholders?

Approximately 2.5 billion people live directly from agricultural production systems, either as full- or part-time farmers, or as members of farming households that support farming activities (FAO 2008a). Smallholders produce food and non-food products on a small scale with limited external inputs, cultivating field and tree crops as well as livestock, fish and other aquatic organisms.[1] But they are not always full-time smallholders. Many, in fact most, poor families earn their incomes in multiple ways, and productivity on farms should be viewed in the overall context of total family income (Reardon et al. 1998).

There is no universally accepted definition of a small farm. 'Small' may refer to the number of workers, capital invested, or amount of land worked. Land size is the criterion most commonly employed, but given the differing potential of land in soil quality and rainfall, a single measurement hardly captures the sense of limited resources or relative powerlessness characteristic of smallholders.

Overall, smallholder farmers are characterized by marginalization, in terms of accessibility, resources, information, technology, capital and assets, but there is great variation in the degree to which each of these applies (Murphy 2010). With these qualifications, the Food and Agriculture Organization of the United Nations (FAO) adopted a 2-hectare (ha) threshold as a broad measure of a small farm (which is not inclusive of fishers and other small-scale food producers).

The vast majority of smallholders live in rural areas, although urban and peri-urban smallholdings are an increasingly important source of supply for developing urban areas (IFAD 2011a). Women play a crucial role within the smallholder system and are commonly responsible for the production of food crops, especially where the farming system includes both food and cash crops (see World Bank, FAO and IFAD 2009 for an overview of gender in agricultural systems). Smallholders include some 350 million indigenous peoples, who conserve many different crop varieties and livestock breeds. Their agricultural practices and techniques offer an important source of knowledge for the transition to sustainable agricultural intensification.

Role of smallholders in global food production

The regional maps in figure 2 show diverse agricultural systems across an enormous geographical reach. Smallholder farming systems are very diverse, and contribute considerably to global agricultural output of a variety of crops. Smallholders produce the bulk of food in developing countries, and in

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1/ 'Smallholder' can also refer to artisanal fishers, gardeners, hunters and gatherers, etc.

many instances their contribution is growing (Koohafkan 2011). They produce 70 per cent of Africa's food supply (IAASTD 2009a) and an estimated 80 per cent of the food consumed in Asia and sub-Saharan Africa together (IFAD 2011b). In Latin America, smallholder farmers occupy almost 35 per cent of total cultivated land (Altieri and Koohafkan 2008). There is substantial variation among smallholders according to livelihood assets and strategies, e.g. the share of crops produced for subsistence and for local and export markets (Nagayets 2005; Murphy 2010).

Role of smallholder farming in economic development and poverty reduction

Historically, most advanced economies received their initial boost from considerable growth in the agriculture sector. Smallholder development can create strong links to the rest of the rural sector, both through hiring of extra local labour at peak farming times and through more-favourable expenditure patterns for promoting growth of the local non-farm economy, including rural towns. Small farmers tend to spend extra income locally, on construction materials, locally made furniture, entertainment, etc., thereby stimulating local (small-scale) business and job creation (Diao et al. 2007; Wiggins 2011).

Numerous studies find a positive relationship between growth in agriculture and poverty reduction. In a cross-country study on the links between agricultural yields and poverty, Irz et al. (2001) found strong evidence that increases in crop yields led to a decrease in the number of poor by about 0.7 per cent (at the US$1/day limit). They also estimated that for every 10 per cent increase in farm yields, there was a 7 per cent reduction in poverty in Africa and more than a 5 per cent reduction in Asia. Growth in manufacturing and services did not show a comparable impact on poverty reduction.

In another cross-country study, Christiaensen, Demery and Kuhl (2011) found that a 1 per cent increase in agricultural per capita GDP reduced the poverty gap five times more than a 1 per cent increase in GDP per capita in other sectors, especially among the poorest people. Finally, agriculture's potential to reduce poverty exceeds that of non-agricultural activities (Lipton 2005), whether the comparison is within or between countries: more than half the reduction in poverty achieved in 25 countries – studied in detail by Cervantes-Godoy and Dewbre (2010a) for the Organisation for Economic Co-operation and Development (OECD) – could be attributed to growth in agricultural incomes.

Smallholdings can address one specific aspect of well-being very effectively: nutrition (Wenhold et al. 2007). Smallholder farming can potentially impact human nutrition by providing a variety of foods in sufficient quantities to enable all household members to eat a nutritionally adequate diet. Greater and more-sustained yields may increase access of households to a larger food supply. The availability of a greater variety of nutritious foods at community and household levels can be increased through the introduction of new crops, the promotion of underexploited traditional food crops, and home gardens (FAO 1997; Faber and Wenhold 2007).

Despite their importance in global and regional food production, smallholder farmers comprise the majority of the world's undernourished population and most of those living in absolute poverty (UN Millennium Project 2005a; IFAD 2011a). Not all studies linking agricultural development and poverty address the role of smallholder farmers specifically, but their importance as food producers and the fact that they comprise such a large proportion of the world's poor indicate that their development significantly helps reduce poverty and hunger. These effects may be stronger in sub-Saharan Africa and South Asia, as greater poverty-reducing effects of growth originate from non-agricultural sectors in East Asia and Latin America (Hasan and Quibria 2004), although there is also considerable heterogeneity within regions (de Janvry and Sadoulet 2010).

Smallholder farmers are often relegated to infertile soils and to decreasing plot sizes (De Schutter 2011; UN Millennium Project 2005b). Many of these smallholder farmers migrate to cities because their farms become non-viable or because they are expelled from their land (De Schutter 2011), seriously threatening food self-sufficiency and food sovereignty. Labour created on large farms rarely compensates for the livelihoods lost by former smallholders (Wiggins 2011). In other areas, the decline of land per capita may lead to fragmentation at first, particularly in densely populated areas, threatening the ability of the remaining land to provide adequate livelihoods (Jayne and Muyanga 2012). Yet, combined with the income opportunities offered by urban centres, this may lead to some abandonment of land and to subsequent consolidation by more successful farmers, but this is likely to be a more gradual process than that caused by large-scale land grabbing (Lipton 2005). Even if smallholders fulfil a transitional role from a more agrarian to a more industrialized and urban economy, this process will take decades. But until such alternative livelihoods emerge in urban or in rural non-farm sectors, smallholders now generate incomes and offer the basis for significant improvement in living standards for many poor people. Moreover, multiple studies have found that smallholdings are relatively more productive per hectare than large-scale plantations (Feder 1985; Barrett 1993; Banerjee, Gertler and Ghatak 1998; Rosset 1999; Borras, Kay and Akram-Lodhi 2007) and are also more resource-efficient (Altieri and Koohafkan 2008).

The globalization of food systems exposes smallholders to unpredictable price fluctuations. The local impacts of such shocks vary depending on the crops grown, level of specialization, patterns of household food consumption, existence of functioning safety nets, and national trade policies (Fleming, Abler and Goetz 2010; Godfray et al. 2010; Swinnen 2010). Smallholders often cannot afford to wait for the best price or look for more profitable markets for their produce. The need for immediate cash (e.g. for school fees) may lead people to sell produce (and even productive assets) at low prices, thereby pushing them into poverty or preventing them from escaping poverty or poverty traps (Deaton 1991). At the same time, producers with the least resources (land, household labour, etc.) face challenges in investing in productivity-enhancing measures to take advantage of higher prices (FAO 2011b) and can't afford expensive, imported foods when harvests fail due to drought, pests and the like.

Post-harvest losses reduce income, but also affect reserves and thus food security, resilience and the ability to take advantage of better prices for products. Storage, transport and transformation systems must be improved. Rural infrastructure also plays a crucial role in ensuring access to markets and in controlling prices. There is no point in increasing productivity for the market without the means to bring the products to that market.

Smallholder farming in policy, research and development funding

Notwithstanding the advantages of investing in small farms and smallholder capacity in developing countries, agricultural policy often favours larger-scale investments through measures such as preferential access to land, subsidized credit, tax exemptions, market protection against cheap, subsidized imports and infrastructure provision (Vorley, del Pozo-Vergnes and Barnett 2012). Large farms are often seen as modern, technically advanced and efficient, a view reinforced by large-scale farmers themselves, who are often better organized to lobby for public support. In some cases, large farms are state enterprises or owned by national elites, and have often benefited disproportionately from subsidies and other state-provided services (Wiggins 2011).

On the other hand, smallholders often have limited control over land and natural resources. Many live on land over which they have customary rights that do not always adequately protect them from land and resource dispossession by more powerful stakeholders such as the government (Vorley, Cotula and Chan 2012). Weak tenure rights can limit smallholders' access to credit and their ability to invest in longer-term, sustainable practices. Small farmers are seen as inadequate in the face of globalization, because they lack economies of scale, capacity to invest and technical know-how, and will likely decline in number over time (Collier 2008).

Market protection by industrialized trading partners has improved since the 1980s (Cervantes-Godoy and Dewbre 2010a), but smallholders in developing countries are still disadvantaged by international trade barriers and agricultural subsidies, which make it difficult for them to compete in the global market. Finally, when their crops fail, they must purchase food for their own consumption from global markets, often at too-high international prices.

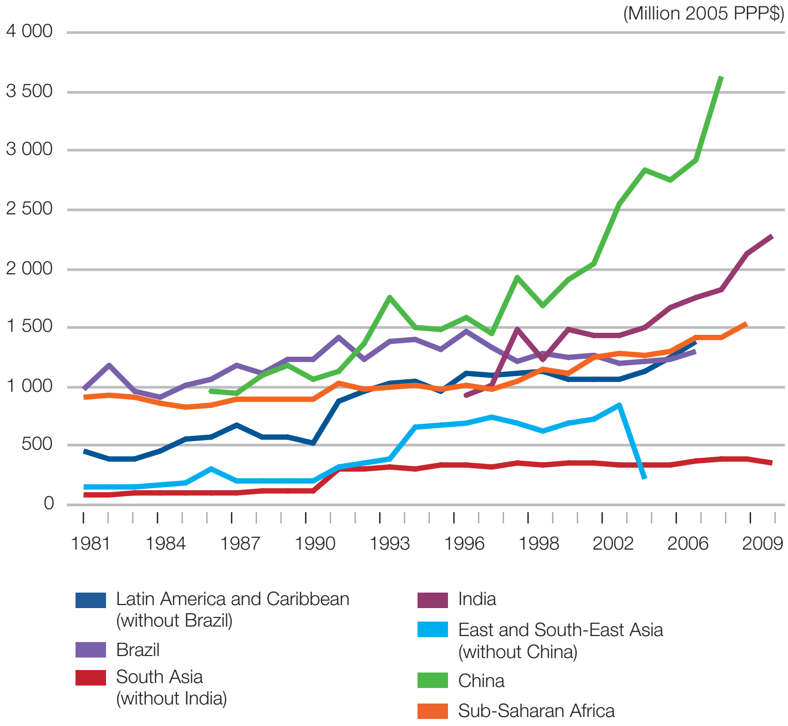
The disappointing rate at which agriculture has helped smallholders fight their way out of poverty has also been attributed to an unbalanced development agenda. Development policy has historically been biased against agriculture in favour of other sectors (Bioversity et al. 2012), and within the agriculture sector, it has focused on large-scale farming businesses, mimicking the investment strategies of developed countries and not taking into account the different realities and investment needs of smallholders (Wiggins 2011; Vorley, del Pozo-Vergnes and Barnett 2012). Structural adjustment programmes in the 1980s led many countries to reduce their support to agriculture and, since then, they have only been increasing slowly (figure 1).

The development of smallholder farming requires innovation to improve the efficiency of input use (often limited), for example to develop drought- or disease-resistant species and to conserve the natural resources on which such production systems depend. Actual expenditures have been rising in some countries since about 2000 (figure 1), but the share of agriculture in total research and development (R&D) expenditures is generally still low (Cervantes-Godoy and Dewbre 2010a; Lowder and Carisma 2011; Bioversity et al. 2012). There are variations between and within regions, and the poorest countries lag behind (Bioversity et al. 2012; figure 1). Private-sector investments in agriculture have increased, but they are generally focused on market-oriented, high-value production systems and are generally lower in developing countries (7 per cent).

Improved technologies addressing smallholders' needs in different regions have been developed through international agricultural research, e.g. by the centres of the Consultative Group on International Agricultural Research (CGIAR) (Bioversity et al. 2012). Official development assistance

FIGURE 1

Public expenditure on agricultural R&D by region

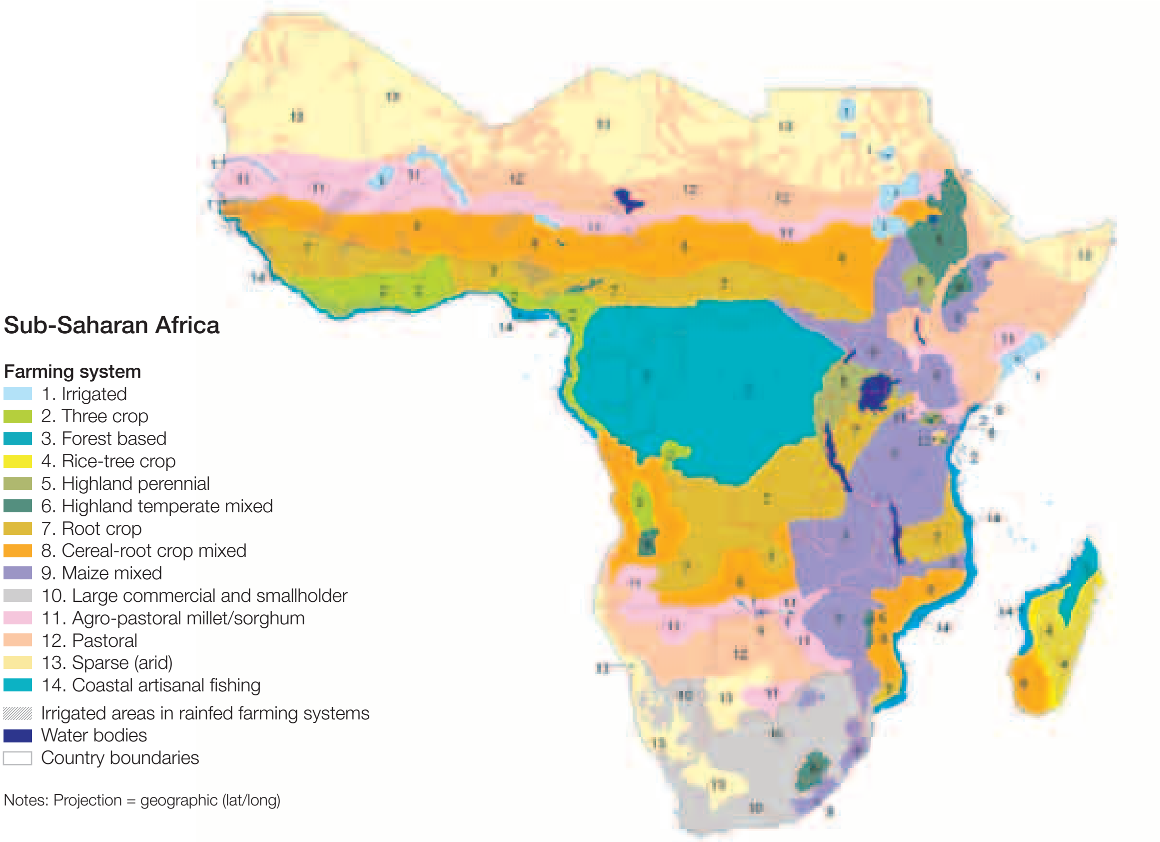


Source: ASTI (2012).

Note: The drop in expenditures for East and South-East Asia is largely due to a gap in the data for certain countries.

FIGURE 2

Major farming systems in Sub-Saharan Africa, South Asia, East Asia and the Pacific, and Latin America and the Caribbean



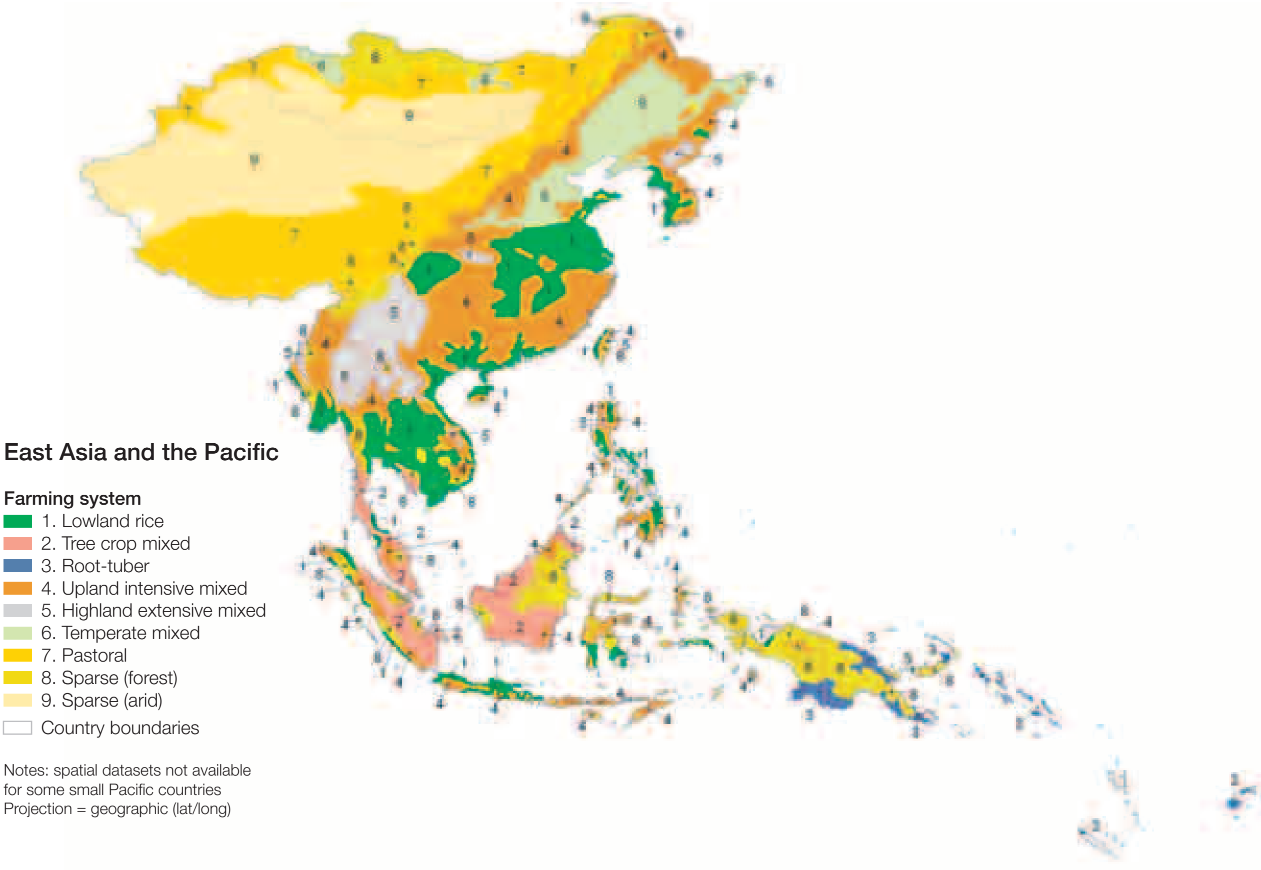
Sub-Saharan Africa

Farming system

- 🟦 1. Irrigated
- 🟩 2. Three crop
- 🟦 3. Forest based
- 🟨 4. Rice-tree crop
- 🟩 5. Highland perennial
- 🟩 6. Highland temperate mixed
- 🟨 7. Root crop
- 🟧 8. Cereal-root crop mixed
- 🟪 9. Maize mixed
- ⬜ 10. Large commercial and smallholder
- 🟪 11. Agro-pastoral millet/sorghum
- 🟧 12. Pastoral
- 🟨 13. Sparse (arid)
- 🟦 14. Coastal artisanal fishing

- ▨ Irrigated areas in rainfed farming systems
- 🟦 Water bodies
- ☐ Country boundaries

Notes: Projection = geographic (lat/long)



East Asia and the Pacific

Farming system

- 🟩 1. Lowland rice
- 🟥 2. Tree crop mixed
- 🟦 3. Root-tuber
- 🟧 4. Upland intensive mixed
- ⬜ 5. Highland extensive mixed
- 🟩 6. Temperate mixed
- 🟨 7. Pastoral
- 🟨 8. Sparse (forest)
- 🟨 9. Sparse (arid)
- ☐ Country boundaries

Notes: spatial datasets not available for some small Pacific countries
Projection = geographic (lat/long)

Latin America and the Caribbean

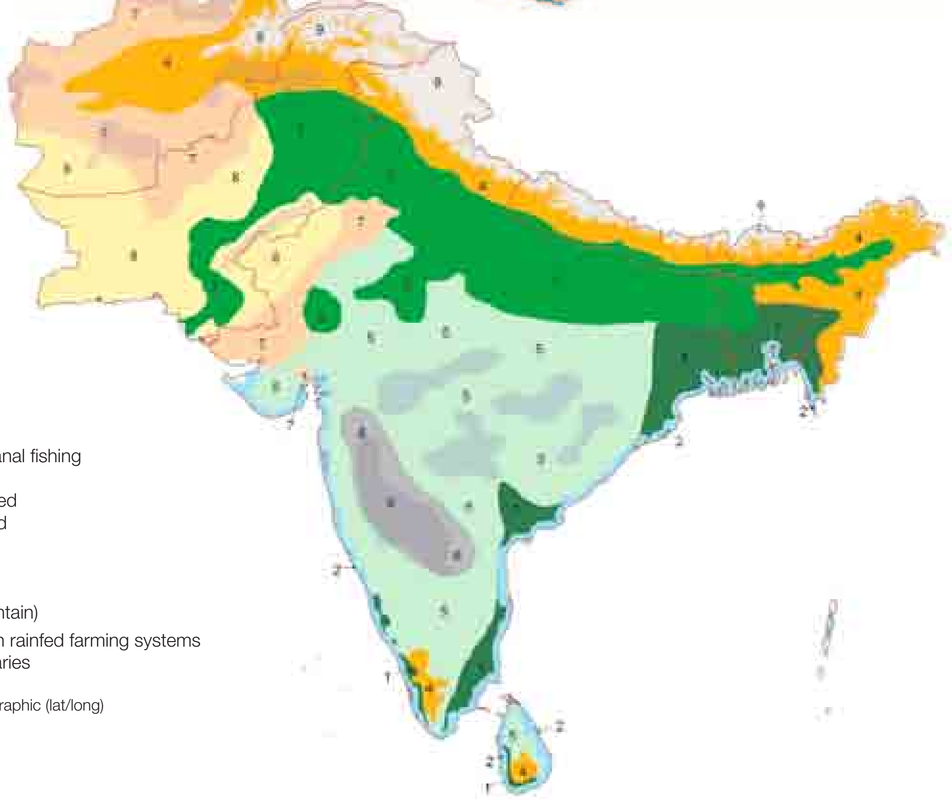
Farming system

- 1. Irrigated
- 2. Forest based
- 3. Coastal plantation and mixed
- 4. Intensive mixed
- 5. Cereal-livestock (campos)
- 6. Mize-beans (Mesoamerica)
- 7. Extensive mixed (cerrados and llanos)
- 8. Intensive highland mixed (North Andes)
- 9. High altitude mixed (Central Andes)
- 10. Mediterranean mixed
- 11. Temperate mixed (pampas)
- 12. Extensive dryland mixed
- 13. Pastoral
- 14. Sparse (forest)

☐ Country boundaries

Notes: Projection = geographic (lat/long)

South Asia



Farming system

- 1. Rice
- 2. Coastal artisanal fishing
- 3. Rice-wheat
- 4. Highland mixed
- 5. Rainfed mixed
- 6. Dry rainfed
- 7. Pastoral
- 8. Sparse (arid)
- 9. Sparse (mountain)

▨ Irrigated areas in rainfed farming systems

☐ Country boundaries

Note: Projection = geographic (lat/long)

The designations employed and the presentation of the material in the maps do not imply the expression of any opinion whatsoever on the part of IFAD concerning the delimitation of the frontiers or boundaries, or the authorities thereof.

Source: Dixon et al. (2001).

FIGURE 3

Percentage of ODA commitment to agriculture of total commitment (three-year moving average)

Source: OECD/DAC (2010).

(ODA) aid to agriculture increased during the 1970s, with a strong peak in the 1980s, but in the early 1990s it declined again to levels similar to those of 1975 (figure 3), reducing funds available for R&D investments and extension services available to smallholder agriculture. In fact, total ODA has increased since the 1980s, but the percentage going to agriculture has not followed proportionally. There has been a slight increase again in recent years (Lowder and Carisma 2011).

Government agencies in developing countries often lack the capacity to make the corporate sector responsible for economic development and for preventing harm to the environment. For example, pesticides illegal in Europe are commonly applied throughout sub-Saharan Africa, owing to the industry's 'open-door pesticide policy' (EPAT 1994). Concern about global climate change, pressures on agriculture to feed a growing population, and their implications for world food security (Key message 2) have led to increased attention to sustainable agricultural intensification (Key message 3).

KEY MESSAGE 2

Smallholder productivity in particular depends on well-functioning ecosystems

The productivity of smallholder agriculture and its contribution to food security and poverty reduction depend on the services provided by well-functioning ecosystems, including soil fertility, freshwater delivery, pollination and pest control. Farming, in turn, including by smallholders, affects the condition of ecosystems. These impacts are not always negative, but poverty and the need to satisfy immediate needs can drive smallholders to adopt environmentally damaging agricultural practices, resulting in soil erosion, nutrient depletion, salinization, water scarcity and pollution.

The importance of ecosystem services

The natural processes that underpin agricultural production and rural livelihoods have historically been understood within a framework of traditional knowledge, encompassing an intuitive understanding and respect for nature acquired over thousands of years of direct human contact with the environment (Inglis 1993). While these natural processes have supported smallholders – being provided by nature at no explicit cost – agronomists and the farming community have rarely addressed them. In the past 50 years, however, new practices have developed that may increase agricultural production in the short term, but can have unforeseen costs in the long term. Land degradation has an impact on the natural regenerative capacity of the land and the ability of natural processes to sustain production in the future, which is a cause for concern. The ability of agricultural ecosystems to provide valuable goods and services to people indefinitely has been taken for granted for too long.

All agriculture is ultimately dependent on functioning ecosystems. Three closely interrelated concepts have been identified: ecosystem services; the underlying ecosystem processes underpinning the generation and regulation of these services; and the goods provided by these services. The distinction between services and goods is crucial, because humans directly use and value ‘goods’, such as food, and it is the production of these goods by smallholders that contributes to their global importance, bringing them to the fore of international development priorities. Nevertheless, the underlying processes and services leading to the production of goods are vital.

Our collective understanding of the ‘ecological foundations’ of food security is improving. The variety and variability of animals, plants and microorganisms – at genetic, species and ecosystem levels – are necessary to sustain key functions of the ecosystem. Biodiversity needs to be carefully managed in smallholder cultivation practices. In general, the more diversified the agricultural land use, the more resilient the land is to climate change and other disturbances, and the more it can produce relative to energy, water and other costs.

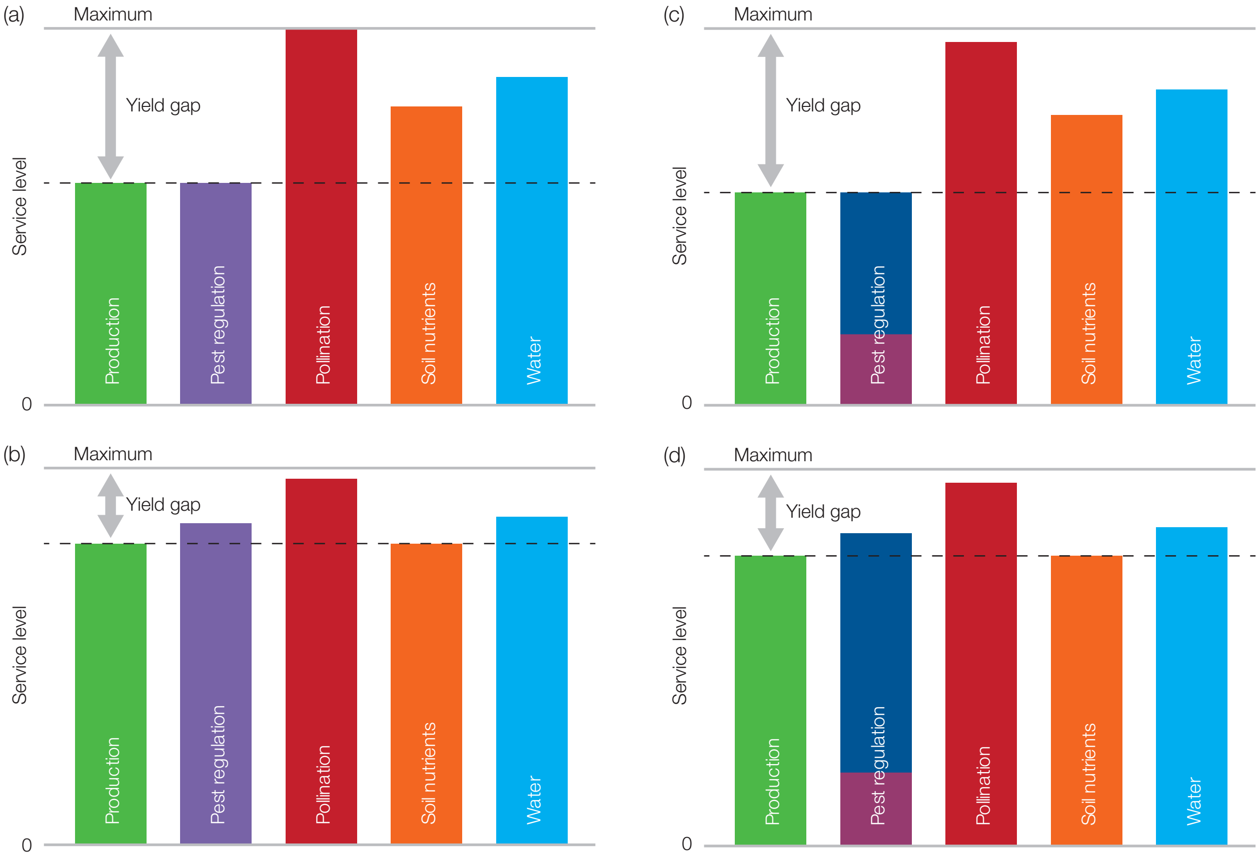
Diversity on the farm also helps maintain the genetic pools of plants and animals (UNEP 2012). Smallholders and indigenous peoples play a critical role in in situ conservation of crop genetic diversity, since local varieties are often more resilient than modern varieties. For example, during the spring drought in south-west China in 2010, most of the modern varieties were lost, while most of the landraces survived (Swiderska et al. 2011).

Crop varieties, themselves, form a crucial component of biodiversity, and improved germplasm could make a big difference to smallholder production systems. Seed is currently developed mainly to meet the requirements of larger farmers, and smallholders are neglected – availability of improved seed in Africa is particularly poor. The high-yielding varieties of the first green revolution often only produce such yields under high-input conditions. There is a major opportunity to improve smallholder agriculture by developing and distributing seeds of more-resilient crops that will thrive under smallholder cultivation conditions (FAO 2010; Miller et al. 2010).

The 'yield gap' – the difference between potential and actual yield – widens as the provisioning of ecosystem services diminishes, e.g. lack of water, lack or imbalance of nutrients, pest damage, weed competition and lack of pollination (figure 4). The necessary investment to close this yield gap through inputs, such as (artificial) fertilizers and pesticides, increases as ecosystem services decline. This has been found to occur when landscape structures become simplified (see, for example, Meehan et al. 2011). Applying or increasing the levels of artificial inputs applied is generally non-economic for resource-constrained smallholder households (Heisey and Mwangi 1996; Odhiambo and Magandini 2008). Thus their ability to close the yield gap depends more on improving the integrity and extent of natural supporting and regulating services, such as pest control, water retention and nutrient cycling.

FIGURE 4

Contribution of regulating and supporting services to provisioning services (crop production)



(a) **Production** can only attain a level set by the lowest underpinning regulating or supporting service, in this case pest regulation, despite other services being superoptimal. (b) **Pest regulation** is enhanced and so production increases and the yield gap is reduced to the level set by the next limiting service, in this case soil nutrients. (c) **Ecological replacement**, where a proportion of one of more underpinning services (e.g. pest regulation) is supplied by biodiversity-derived services (e.g. natural enemies, green bar) rather than anthropogenic-derived services (e.g. insecticides, red bar); production remains the same overall, but more of the regulating and/or supporting service(s) are provided by biodiversity. (d) **Ecological enhancement**, where the level of one of more underpinning services (e.g. pest regulation) is boosted by biodiversity-derived services (green bar) rather than anthropogenic-derived services (red bar), with the result that production increases overall.

Source: Bommarco, Kleijn and Potts (2013, 232).

BOX 1

Save and grow

FAO's *Save and grow* is a policymaker's guide to the sustainable intensification of smallholder crop production (see also Pretty 2008; Foresight 2011). It provides concrete examples of efforts required to enable smallholders to increase sustainable crop production:

1. Farming systems. The ecosystem approach to farming regenerates and sustains the health of farmland. Farming systems for sustainable crop production intensification will be based on conservation agriculture practices, the use of good seed of high-yielding adapted varieties, integrated pest management, plant nutrition based on healthy soils, efficient water management, and the integration of crops, pasture, trees and livestock. The very nature of sustainable production systems is dynamic: they should offer farmers many possible combinations of practices to choose from and adapt, according to their local production conditions and constraints. Such systems are knowledge-intensive. Policies for sustainable crop production intensification should build capacity through extension approaches such as farmer field schools, and facilitate local production of specialized farm tools.

2. Soil health. Soils rich in biota and organic matter are the foundation of increased crop productivity. The best yields are achieved when nutrients come from a mix of mineral fertilizers and natural sources, such as manure and nitrogen-fixing crops and trees. Judicious use of mineral fertilizers saves money and ensures that nutrients reach the plant and do not pollute air, soil and waterways. Policies to promote soil health should encourage conservation agriculture and mixed crop, livestock and agroforestry systems that enhance soil fertility. They should remove incentives that encourage mechanical tillage and the wasteful use of fertilizers, and transfer knowledge to farmers of precision approaches such as urea deep placement and site-specific nutrient management.

3. Crops and varieties. Genetically improved cereal varieties have accounted for some 50 per cent of the increase in global crop yields over the past few decades. Plant breeders need to achieve similar results in the future. However, timely delivery to farmers of high-yielding varieties requires significant improvements in the system that connects plant germplasm collections, plant breeding and seed delivery. Over the past century, about 75 per cent of plant genetic resources have been lost and a third of today's diversity could disappear by 2050. Increased support for collection, conservation and use of these resources is crucial. Funding is also needed to revitalize public plant-breeding programmes. Policies should help link formal and farmer-saved seed systems, and foster the emergence of local seed enterprises.

4. Water management. Cities and industries are competing intensively with agriculture for the use of water. Despite its high productivity, irrigation is under growing pressure to reduce its environmental impact, including soil salinization and nitrate contamination of aquifers. Knowledge-based, precision irrigation that provides reliable and flexible water application, along with deficit irrigation and wastewater reuse, will be a major platform for sustainable intensification. Policies will need to eliminate perverse subsidies that encourage farmers to waste water. In rainfed areas, climate change threatens millions of small farms. Increased rainfed productivity will depend on the use of improved, drought-tolerant varieties and management practices that save water.

5. Plant protection. In well-managed farming systems, crop losses to insects can often be kept to an acceptable minimum by deploying resistant varieties, conserving predators and managing crop nutrient levels to reduce insect reproduction. Recommended measures against diseases include the use of clean planting material, crop rotations to suppress pathogens, and eliminating infected host plants. Effective weed management entails timely manual weeding, minimized tillage and the use of surface residues. When necessary, lower-risk synthetic pesticides should be used for targeted control, in the right quantity and at the right time. Integrated pest management can be promoted through farmer field schools, local production of biocontrol agents, strict pesticide regulations and removal of pesticide subsidies.

6. Policies and institutions. First, farming needs to be profitable: smallholders must be able to afford inputs and be sure of earning a reasonable price for their crops. Some countries protect income by fixing minimum prices for commodities; others are exploring 'smart subsidies' on inputs, targeted to low-income producers. Policymakers also need to devise incentives to small-scale farmers for using natural resources wisely – for example, through payments for environmental services and land tenure that entitles farmers to benefit from increases in the value of natural capital – and reduce the transaction costs of access to credit, which is urgently needed for investment. In many countries, regulations are needed to protect farmers from unscrupulous dealers selling fake seed and other inputs. Major investment will be needed to rebuild research and technology transfer capacity in developing countries in order to provide farmers with appropriate technologies and to enhance their skills through farmer field schools.

Source: Adapted from FAO (2011b).

Issues of scale: from the farm to the wider ecosystem

While the delivery of ecosystem services is highly dependent on the structure of the agroecosystem itself, many services originate in the wider landscape in which this system or the individual farm are embedded. This means that the scale of farm management and the scale at which ecological processes operate are often different.

Water delivery to agroecosystems is influenced by a variety of larger-scale biophysical factors across the landscape. Forest fragments, for example, have been shown to influence local weather (Garcia-Carreras, Parker and Marsham 2010).

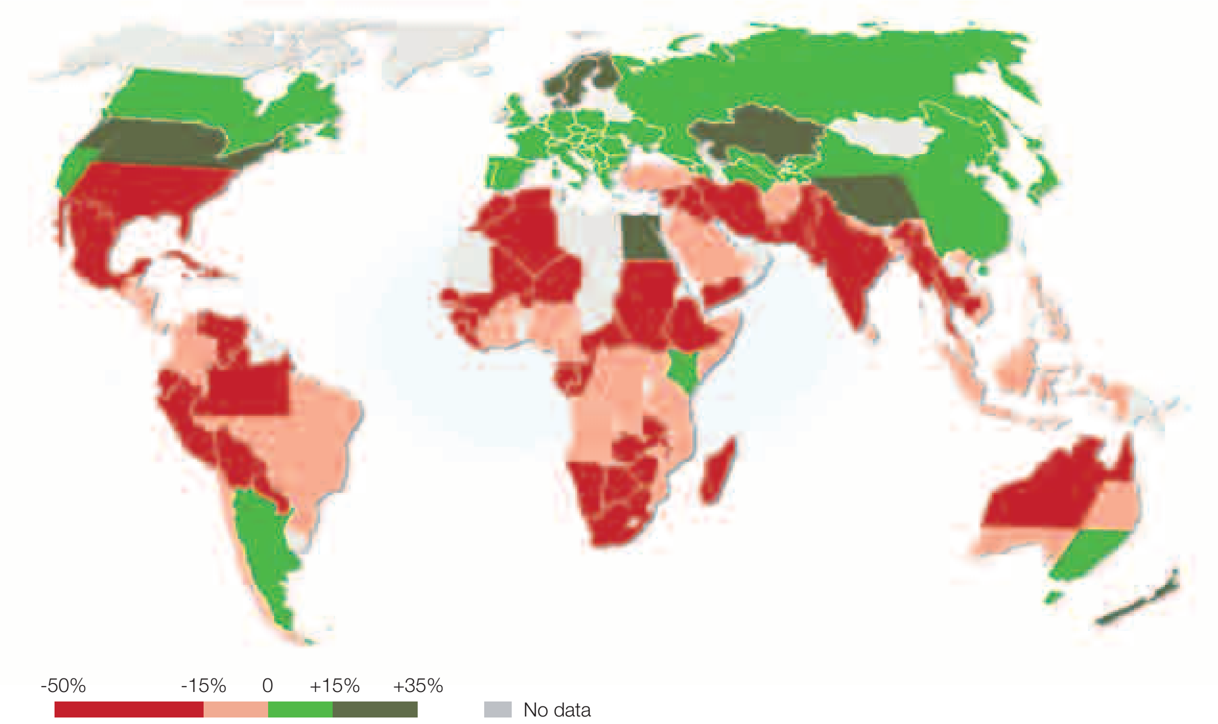
Both natural biological control services and pollination services depend on the movement of organisms across the agricultural and natural habitats that provide them with refuge, food resources and nesting material (Coll 2009). Pollinators and natural predators are affected by changes in the abundance, diversity, distribution and temporal availability of food plants and the availability of nesting sites and materials (Greenleaf and Kremen 2006; Potts et al. 2006; Holzschuh et al. 2007; Williams and Kremen 2007). Coffee farmers in Indonesia depend on pollinators from adjacent forests, and pollinator visitation rates decline as forest quality deteriorates (Kremen et al. 2004; Olschewski et al. 2007).

For this reason, land-use practices and their impacts need to be considered at multiple scales, from a local 'farmscape' to the wider landscape. Unsustainable practices at the landscape level, which may occur independently of smallholder agriculture, can still have an impact on the ecosystem services available at the farm level. Equally, activities at the farm level can influence the ecosystem services available in the wider landscape, and in other spatially distinct agroecosystems.

Decisions by individuals affecting diverse landscape elements, such as forest fragments and water courses, will have consequences for other farmers in the wider landscape (Benton 2012). Focusing too narrowly on the farm

FIGURE 5

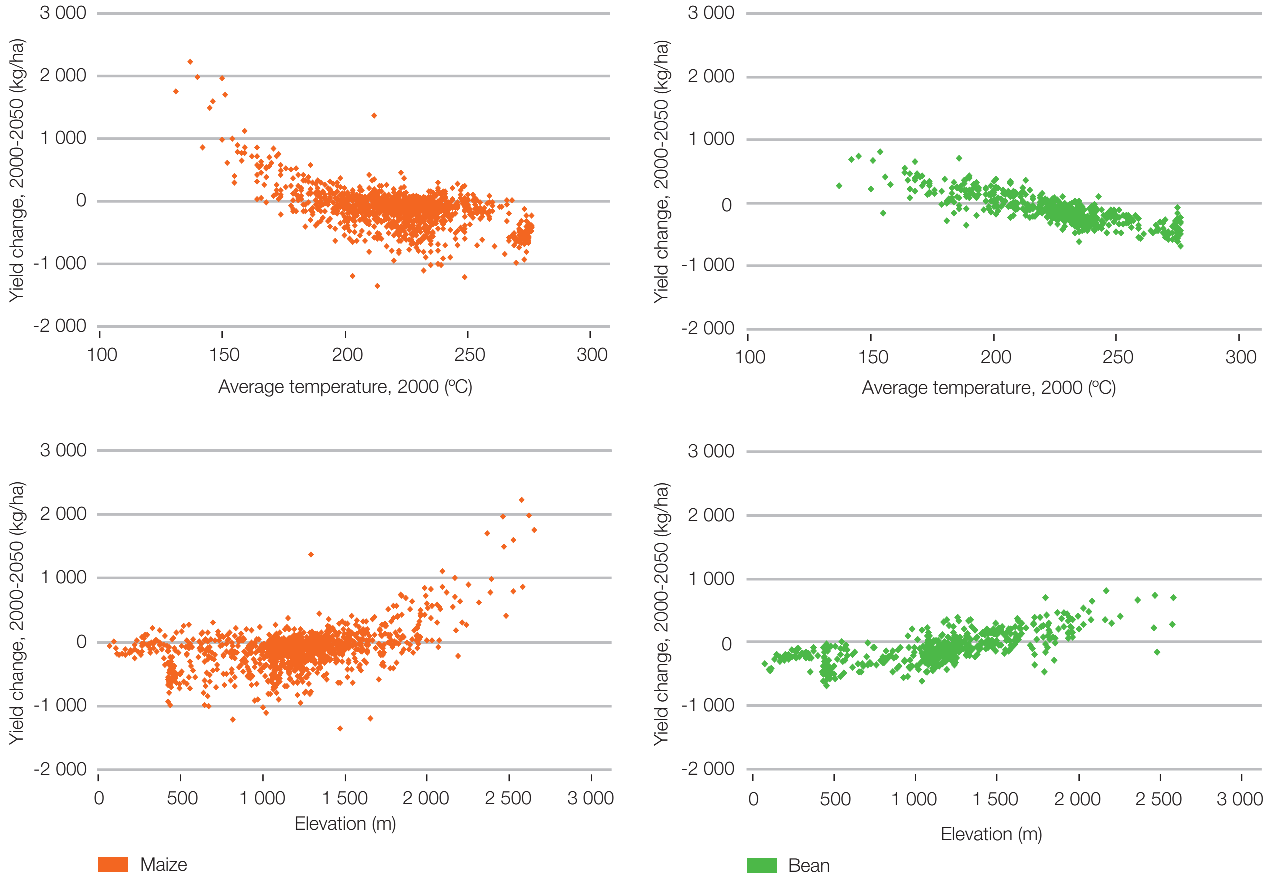
Projected changes in agricultural production in 2080 due to climate change, incorporating the effects of carbon fertilization



Cartography: Hugo Ahlenius (UNEP/GRID-Arendal).
www.grida.no/graphicslib/detail/projected-agriculture-in-2080-due-to-climate-change_141b.

FIGURE 6

Determinants of smallholder maize and bean production responses to climate change in East Africa



Source: Thornton et al. (2009).

will not necessarily secure the delivery of the ecosystem services on which smallholders themselves depend. Landscape-level interventions or management are needed, e.g. suitable habitat for beneficial organisms may arise from an aggregation of smaller farms.

Climate change impacts on ecosystem services and smallholder farming

Farmers are vulnerable to environmental change, including climate-induced change. Climate change and the associated rise in global average temperatures, as well as increased unpredictability of rainfall, will have profound impacts on agriculture in the twenty-first century. Thus they will inevitably affect smallholder production systems. Climate change is linked to extreme anomalies in weather events (Hansen, Sato and Ruedy 2012) and increased variability and unpredictability in rainfall, which may have more serious consequences than climate change per se. Extreme weather events include spells of very high temperature, torrential rains and droughts. Overall, agricultural production is predicted to decrease throughout much of the developing world (Cline 2007; Gornall et al. 2010; figure 5), with projections for East Africa suggesting that changes are not necessarily uniform among and within countries (Thornton et al. 2009; figures 5 and 6). Simulations show that maize yields in northern Uganda, southern Sudan and semi-arid areas of Kenya and the United Republic of Tanzania may decline by 20 per cent (range 200-700 kg/ha). In contrast, yields for the same crop are projected to increase in some of the highland areas of the region: in the southern Ethiopian highlands, the central and western highlands of Kenya and the Great Lakes Region, mostly by 200-700 kg/ha (figure 6).

Differences in crop production responses to climate change are explained by topographical and biophysical characteristics of the farming sites, with those at higher elevations with lower average temperatures experiencing increased production, while those at lower elevations with higher average temperatures (20° C and above) show declining yields.

Climate change, more broadly, could alter the geographical distribution of pests and pathogens, while the magnitude of the carbon-dioxide fertilization effect varies with different crop (and weed) types and the supply of water and nutrients (Black, Kniveton and Schmidt-Verkerk 2011). Thus smallholder crop production may be influenced indirectly by climate change through resulting changes in the number, distribution patterns and virulence of pests and diseases.

While these interactions are complex and the full implications in terms of crop yield are still uncertain, indications suggest that pests, such as aphids (Newman 2004) and weevil larvae (Staley and Johnson 2008), respond positively to elevated levels of carbon dioxide (CO_2). Increased temperature also reduces the overwintering mortality of aphids, enabling earlier and potentially more widespread dispersion (Zhou et al. 1995). Climate change impacts such as elevated temperatures or recurring droughts can also affect the resistance of crops to diseases (Gregory et al. 2009).

The effects of climate-induced environmental changes on smallholder crop production are compounded by local land and wider ecosystem degradation. However, smallholder agriculture, given the application of appropriate farming practices and an enabling governance and infrastructure environment, can be sustainable and contribute to both mitigation and adaptation of climate change and land degradation trends. Nevertheless, in the preceding decades, unsustainable destructive agricultural practices have in many places led to increased agricultural production in the short term, but with negative impacts on the natural regenerative capacity of the land and the ability of natural processes to sustain production in the long term (UNEP 2012).

Impacts of (smallholder) farming on ecosystem services

Impacts of smallholder farming on ecosystem services are highly context dependent. In some places, long-term practices may be sustainable, while in others, poverty and the need to satisfy immediate needs, as well as unsupportive policies (Key message 1), may lead to unsustainable practices. Such practices can then undermine the very ecosystem services on which smallholders depend. A growing human population, especially in rural areas, reduces land holdings per household and increases pressure on the land. Together with fluctuations in global crop prices and climate shocks that erode resilience, this may drive smallholders to overuse natural resources or to expand agricultural land by removing margin vegetation and modifying natural habitat (Robinson and Sutherland 2002). For instance, converting forest to agricultural land often results in a loss of topsoil and negatively impacts soil productivity, especially in the humid tropics with high levels of rainfall, and when combined with steep slopes (Matson et al. 1997).

It is especially important for smallholder agriculture to stay within ecological thresholds and contribute to maintaining ecosystem services at both the farm and wider landscape levels. Once ecological thresholds are crossed, such as through overgrazing, inadequate fallow periods or cultivating on steep slopes, these systems become unsustainable, eventually leading to land degradation and/or suboptimal yields. Paradoxically, these suboptimal yields push producers further towards unsustainable practices in order to maintain livelihoods.

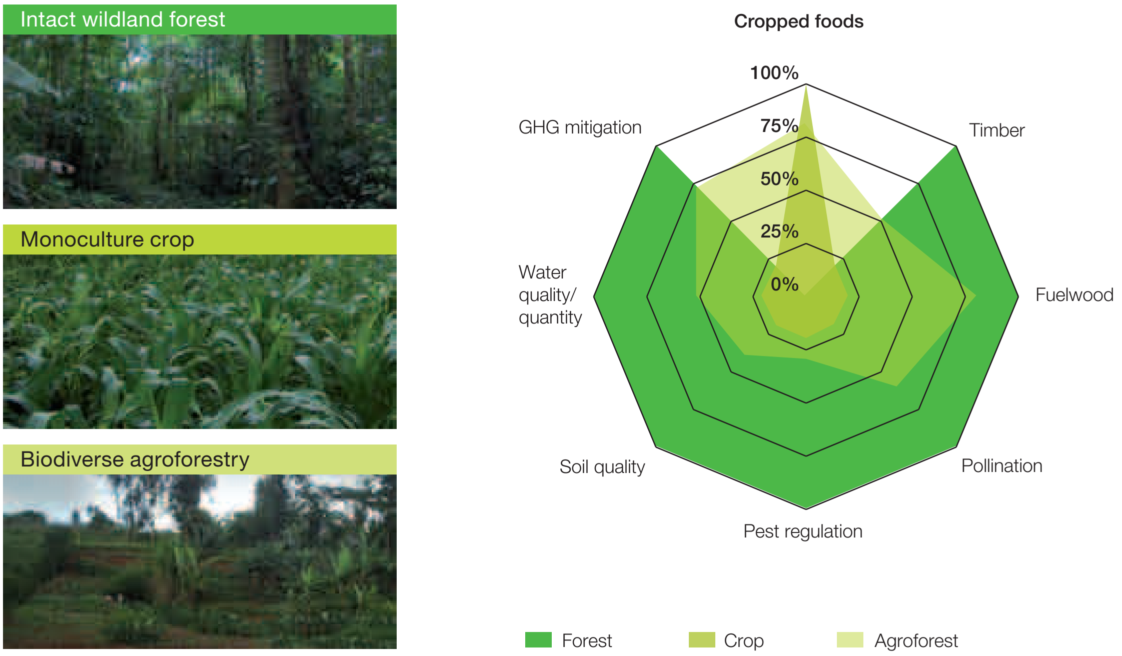
Figure 7 shows a hypothesized relationship between ecosystem benefits and different levels of habitat modification. It highlights the potential reduction of benefits under an intensive monoculture farming scenario and the potential of substantially higher benefits under a more sustainable agroforestry scenario.

Soil and land degradation

Soil degradation was estimated to have reduced global agricultural productivity by 13 per cent since the mid-1990s (Wood, Sebastian and Scherr 2000). Degradation possibly affected from 1 to 8 per cent of the land globally (Nellemann et al. 2009), and Africa was possibly the most affected continent. In their review, Nellemann et al. (2009, p. 40) reported that "Satellite measurements show that between 1981 and 2003, there was an absolute decline in the productive land area (as Net Primary Productivity) across 12 per cent of the global land area. The areas affected are home to about 1-1.5 billion people, some 15-20 per cent of the global population…." In some sub-Saharan African countries, productivity declined in over 40 per cent of the cropland area in two decades, while population doubled. Yield reduction in Africa due to past soil erosion may range from 2 to 40 per cent, with a mean loss of 8.2 per cent for the continent (Nellemann et al. 2009). Degradation can be seen as being related to farming intensity or the fraction of the land used for agriculture. Smallholders in the Ethiopian highlands benefit from good soils and relatively abundant rainfall. However, increasing intensification and continuous cultivation on sloping lands, without supplementary use of soil amendments and conservation practices, resulted in nutrient depletion and soil erosion averaging 42 tons/ha/year, which could increase to 300 tons/ha/year in individual fields.

FIGURE 7

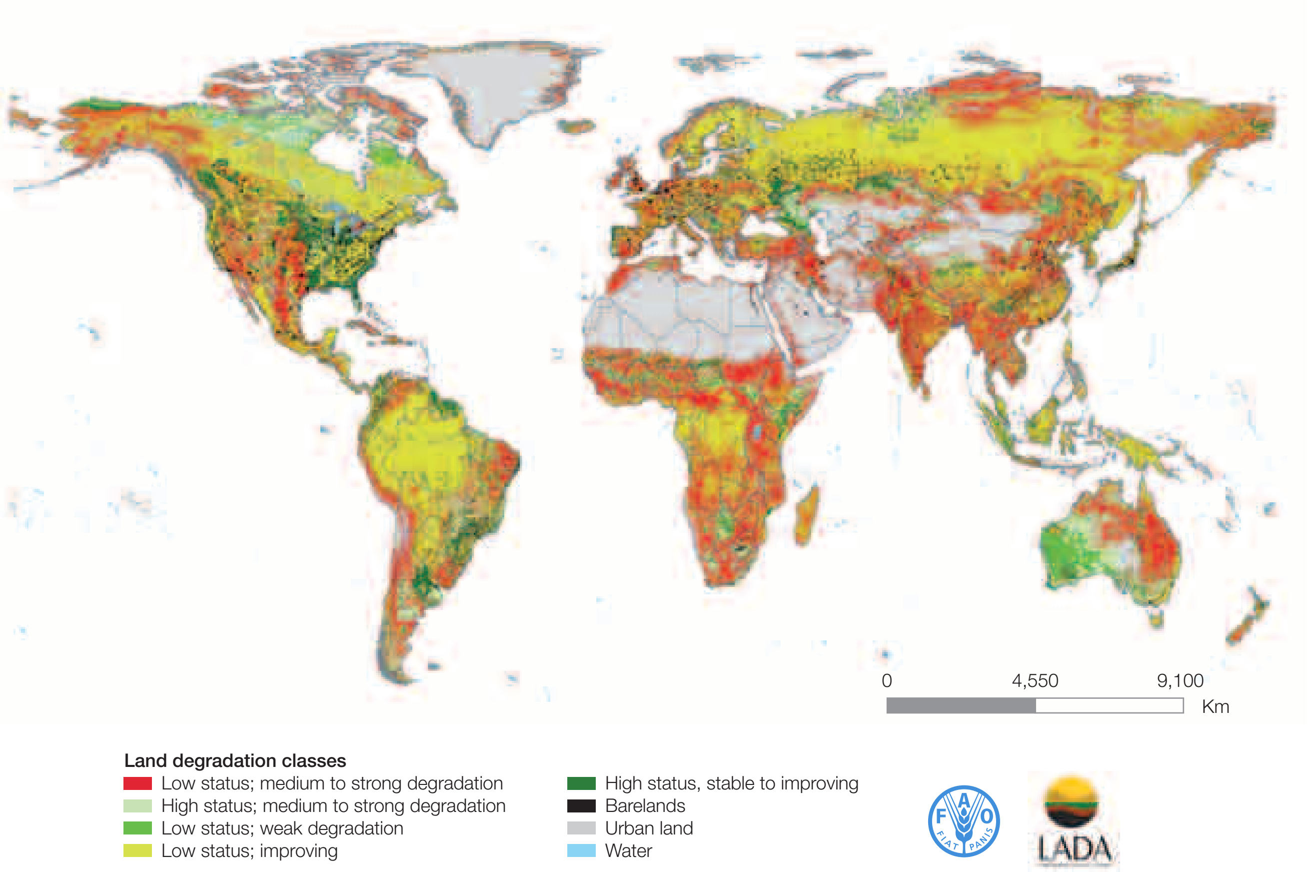
Hypothesis of relationship between ecosystem benefits and different levels of habitat modification



Source: Smukler et al. (2012).

FIGURE 8

Status of global land degradation



Source: Nachtergaele et al. (2011).

This led to declining per capita food production and increased food insecurity (Shiferaw and Holden 1999). A worldwide map of land degradation is provided in figure 8.

Overall, this evidence suggests that land degradation – through erosion, biological soil degradation, physical degradation, chemical degradation (acidification, toxicity) and salinization – probably affects smallholder activity and reduces benefits derived from ecosystem services, limiting their agricultural production (IAASTD 2009b; Neely and Fynn 2011).

Agricultural management practices that degrade soil structure and soil biotic communities include tilling, irrigation, burning, harvesting, pesticide use, etc. (Giller et al. 1997). In parts of the humid tropics, establishment of agricultural areas on previously forested land can have direct effects on soil productivity through loss of topsoil. The conversion of tropical forests to agriculture can result in substantial losses of soil organic carbon by as much as 50 per cent within five years (Matson et al. 1997). Moreover, soil communities from agricultural systems can be substantially poorer in abundance and diversity than the soil communities of the natural systems from which they are derived (Lavelle 1996; Matson et al. 1997).

Impacts on water

Agriculture is the main global consumer of water resources and, particularly in irrigated areas, affects both the quality and quantity of water and causes soil salinization and waterlogging. Large parts of the developing world already experience high levels of agricultural water stress (figure 9), where water supplies are often scarce but agricultural demands high, and where shortages of sufficient amounts of clean water limit agricultural productivity (Cassman et al. 2005). For example, water shortages and pollution have had significant impacts on food production in the Indian Punjab, which is considered one of the world's 'breadbaskets' (de Janvry 2010), and the impact of water shortages in sub-Saharan Africa is predicted to become particularly severe (Power 2010). Water delivery to agroecosystems depends on flow patterns across the landscape and can be influenced by a variety of biophysical factors. Stream flow is influenced by withdrawals for irrigation, as well as by landscape simplification.

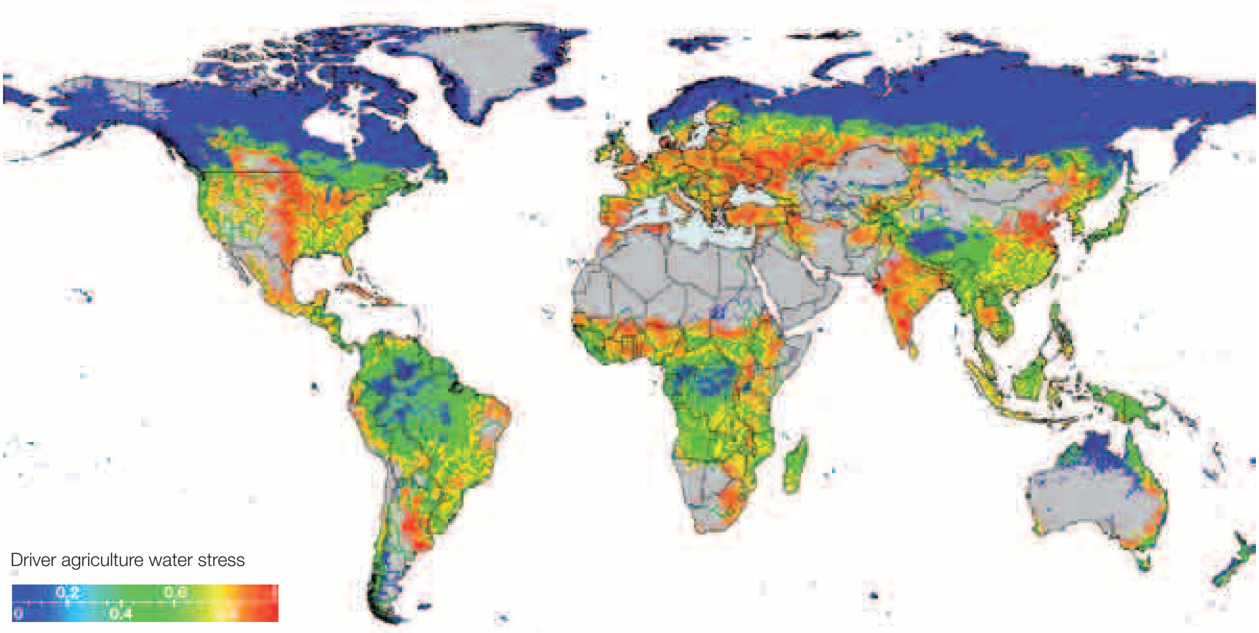
Figure 9 shows the estimated burden that crop production places on renewable water supplies, thus reflecting co-option by humans of a portion of the water cycle, both explicitly through irrigation and implicitly through precipitation and soil water availability. The less water available per area of cropland, the greater the potential competition for water use between agriculture and other sectors (Vörösmarty et al. 2010).

Farming accounts for about 70 per cent of global water use. In South Asia, the share of agriculture in total water withdrawal is more than 90 per cent; in Africa, it is more than 80 per cent (Molden 2007). Industrial agriculture tends to place high demands on water resources, while smallholder agriculture is largely rainfed. With increasing demand for agricultural produce and reduced and more unpredictable supplies of water associated with climate change and the depletion of aquifers, it is important to consider how the efficiency of water use in agricultural systems could be improved (Molden 2007; Davies et al. 2011). Development of more drought-tolerant crop cultivars could make a big difference. Also, smallholders are less likely to have control over impacts on water provision and quality in the broader landscape or watershed than are larger-scale or more powerful actors. Sustainable landscape design needs to take such issues and challenges into account.

Achieving sustainable agricultural production may require more integrated action at wider landscape scales. The importance of smallholder farmers to global food production and poverty reduction (Key message 1) and their dependence on the services provided by well-functioning ecosystems (Key message 2) require development of and support to more integrated and sustainable approaches to smallholder farming, which are discussed in the following section.

FIGURE 9

Agricultural water stress: estimation of the burden placed by crop production on renewable water supplies



Source: Vörösmarty et al. (2010).

KEY MESSAGE 3

Growth in agricultural production to meet rising global needs using prevailing farming practices is unsustainable – a transformation is needed

The demand on agriculture to feed a larger and more-urbanized population through global markets over the next 40 years will continue to grow, placing additional pressure on available land. Current practices are undermining the ecological foundation of the global food system through overuse and the effects of agricultural pollution, thereby enhancing degradation, reducing ecosystem capacity to generate sustainable yields and threatening food security. There is an urgent need to scale up sustainable agricultural intensification (Royal Society 2009).

Pressures on agriculture

Population growth and higher per capita consumption will have major implications for food demand in the next 40 years (figure 10). Global population is projected to surpass 9 billion by 2050, with most of the extra 2 billion people living in developing countries. At the same time, 70 per cent of the world's population is projected to be in urban areas (87 per cent in Latin America, 64 per cent in Asia and 58 per cent in Africa) and to depend on rural farmers to provide sufficient food (UN 2012). Food consumption patterns are changing as a result of economic growth, urbanization and shifts from local markets to a globalized trade in agricultural products (Caballero and Popkin 2002; Gerbens-Leenes, Nonhebel and Krol 2010). Consumption per capita is increasing (Kearney 2010) and diets contain more animal protein as people become more affluent (Gerbens-Leenes, Nonhebel and Krol 2010). A meat-based diet requires three times as many grain-equivalent inputs to produce the same energy as a vegetarian diet (Koning et al. 2008; Nellemann et al. 2009). Overall, this change in diet may double the demand for calories and protein by 2050 (Tilman et al. 2001).

Cropland expanded by 50 per cent during the twentieth century, with the highest expansion occurring in the former Soviet Union, South America, and South and South-East Asia (Ramankutty, Foley and Olejniczak 2002), notably due to cattle ranching, soybeans, palm oil and sugarcane (Barona et al. 2010; Gibbs et al. 2010). To satisfy projected future food demand, it is estimated that cropland will have to increase by 2.7 million hectares per year (Lambin and Meyfroidt 2011). At the same time, increasing demand for sources of energy, including biofuels, requires an additional 1.5 million hectares per year (FAO 2008a; IAASTD 2009b; Cireria and Masset 2010; Kearney 2010; Lambin and Meyfroidt 2011; Pelletier and Tidemers 2011), while farmers compete with urban dwellers for prime land with good access to markets (Zhong et al. 2011).

Recent estimates of agricultural land lost to urbanization range from 5 to 12 million hectares (additionally, about the same area of productive land is lost to land degradation) (Döos 1994; Young 1999). Uncultivated and unreserved land suitable for agriculture is still available, mainly in dry areas of Africa and Latin America, but most is easily degradable and under forest cover (Fischer et al. 2001; Koning et al. 2008).

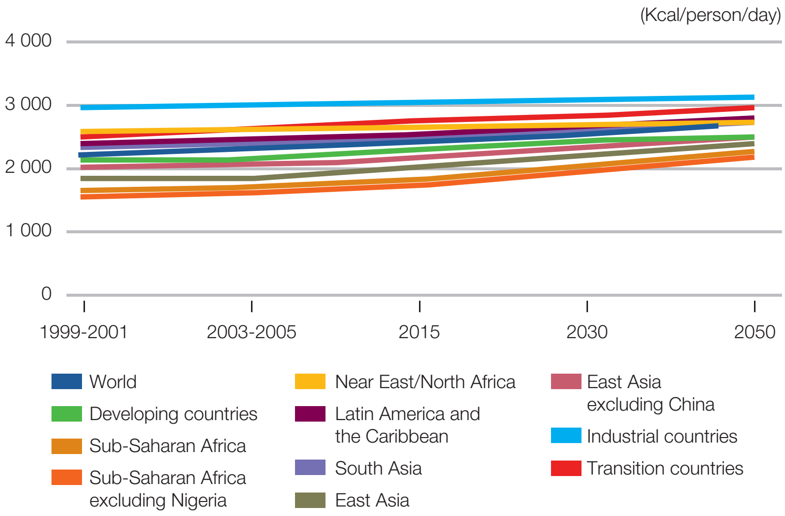
All land-use change projections assume increases in crop yields and livestock efficiency. There is great potential for gains in productivity from intensifying agricultural production and closing yield gaps (the difference between the potential yield in an area and the actual yield obtained) because of relatively more limited access in developing countries to factors of production such as inputs and infrastructure (Duvick and Cassman 1999; Tilman et al. 2002; Peng and Khush 2003; Godfray et al. 2010; Foley et al. 2011; Tilman et al. 2011). This is also where most gains in terms of contribution to food availability and poverty reduction can be made (Key message 1). Ensuring that this intensification is sustainable and equitable is a major challenge for the coming decades (von Braun and Brown 2003; Spiertz 2010).

Getting more (and more nutritious) food to the hungry has more to do with governance, distribution, food prices and protecting local food production than it does with raising global levels of farming output (FAO 2009; Swinnen and Squicciarini 2012). Limiting overconsumption and reducing post-harvest waste (30-40 per cent of production) can contribute to meeting food security objectives (Parfitt, Barthel and Macnaughton 2010; Clay 2011), and so an answer to hunger need not necessarily come only from an increase in cropland and crop production (with resulting potential environmental impacts).

FIGURE 10

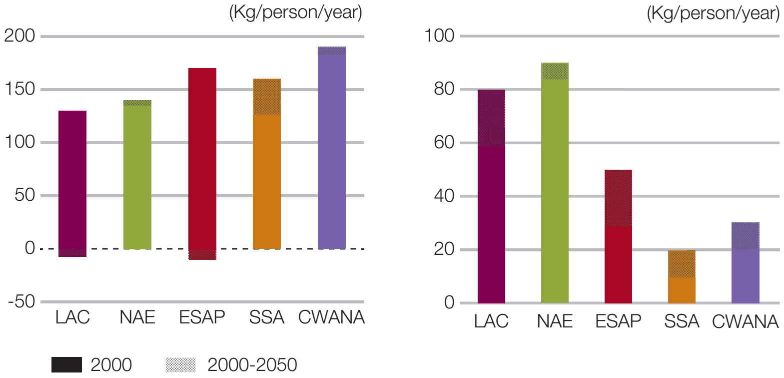
Projected change in demand for food and other agricultural products over the period 2000-2050

Per capita food consumption

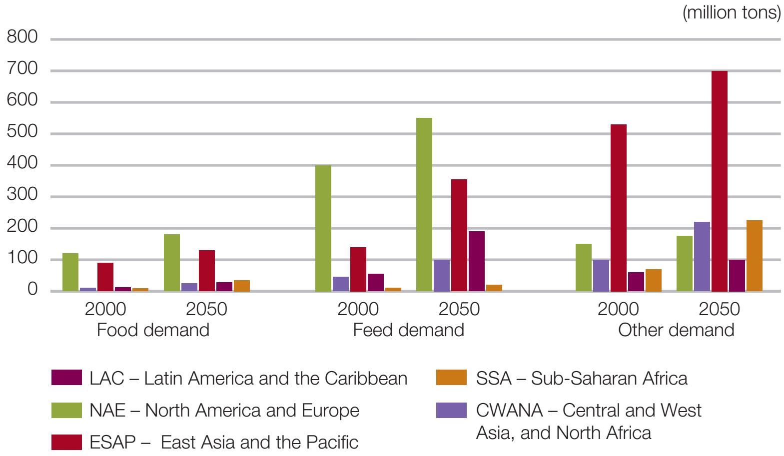


Per capita availability of cereal as food

Per capita meat consumption



Cereal demand as feed, food and other uses



Source: Adapted from Alexandratos (2009) and the IMPACT Model simulations of the International Food Policy Research Institute (IFPRI) (Rosegrant et al. 2008).

It is estimated that over a third of current food production (1.3 billion tons per year) is lost between farms and consumers (Godfray 2011; Gustavsson et al. 2011). The reasons for losses differ between developed (waste in the retail, food service and home stages) and developing countries (lack of food chain infrastructure, storage, processing and transport facilities) and so will require different actions according to the context (World Bank 2011; Godfray 2011).

Increased agricultural production will need to come primarily from improved productivity on existing agricultural land, but needs to be combined with more equitable distribution of food, protection of productive assets for the food insecure, and a reduction of losses and waste of agricultural products in the field, the value chain and in consumers' homes.

Impacts of prevailing (global) agricultural trajectories on the environment

There is abundant evidence that we are undermining the ecological foundations of the world food system. The inappropriate use of land to provide food, feed, fibre and fuel can contribute to soil degradation or loss, and water and atmospheric pollution, with consequent negative impacts on agricultural production and human health (Neely and Fynn 2011).

A recent report by the United Nations Environment Programme (UNEP 2012) highlights two ways in which humans undermine the ecological foundation of the food system and thereby put pressure on food security. First, we undercut the basic natural conditions needed to produce food (e.g. water, soil formation, biodiversity) through excessive use, inappropriate management and overextraction. Second, we produce side effects (groundwater contamination, pollution of surface water and greenhouse gas [GHG] emissions) that undermine the ecosystem's capacity to generate yields sustainably and to recuperate from pressures and shocks (Neely and Fynn 2011; UNEP 2012).

Many agricultural practices impact negatively on biodiversity, as seen in the observed loss of native biodiversity. The loss of agrobiodiversity in the past 50 years has been significantly influenced by the spread of monocultures of a small number of crop types. Global food systems are responsible for 19-29 per cent of all anthropogenic GHG emissions (Vermeulen, Campbell and Ingram 2012). Agricultural expansion through habitat conversion is responsible for some 50 per cent of the GHGs emitted by agriculture (figure 11), the loss of significant biodiversity and other impacts on ecosystem services (Vitousek et al. 1997; Foley et al. 2005; Green et al. 2005; Smith et al. 2007; Butchart et al. 2010).

In many farming systems, especially in marginal environments, the unconstrained use of irrigation, pesticides and fertilizers is a major cause of soil acidification and salinization, eutrophication and contamination (Tilman et al. 2002; Cassman et al. 2003; Foley et al. 2005; Shively and Birur 2009; Miao, Stewart and Zhang 2011; Guo et al. 2010; MacDonald et al. 2011; Hochman et al. 2013). Land degradation may in turn lead to land abandonment and the conversion of natural or semi-natural habitats into new farmlands by displaced farmers (Pimentel 2000).

Approaches to managing and improving soil fertility and other ecosystem services

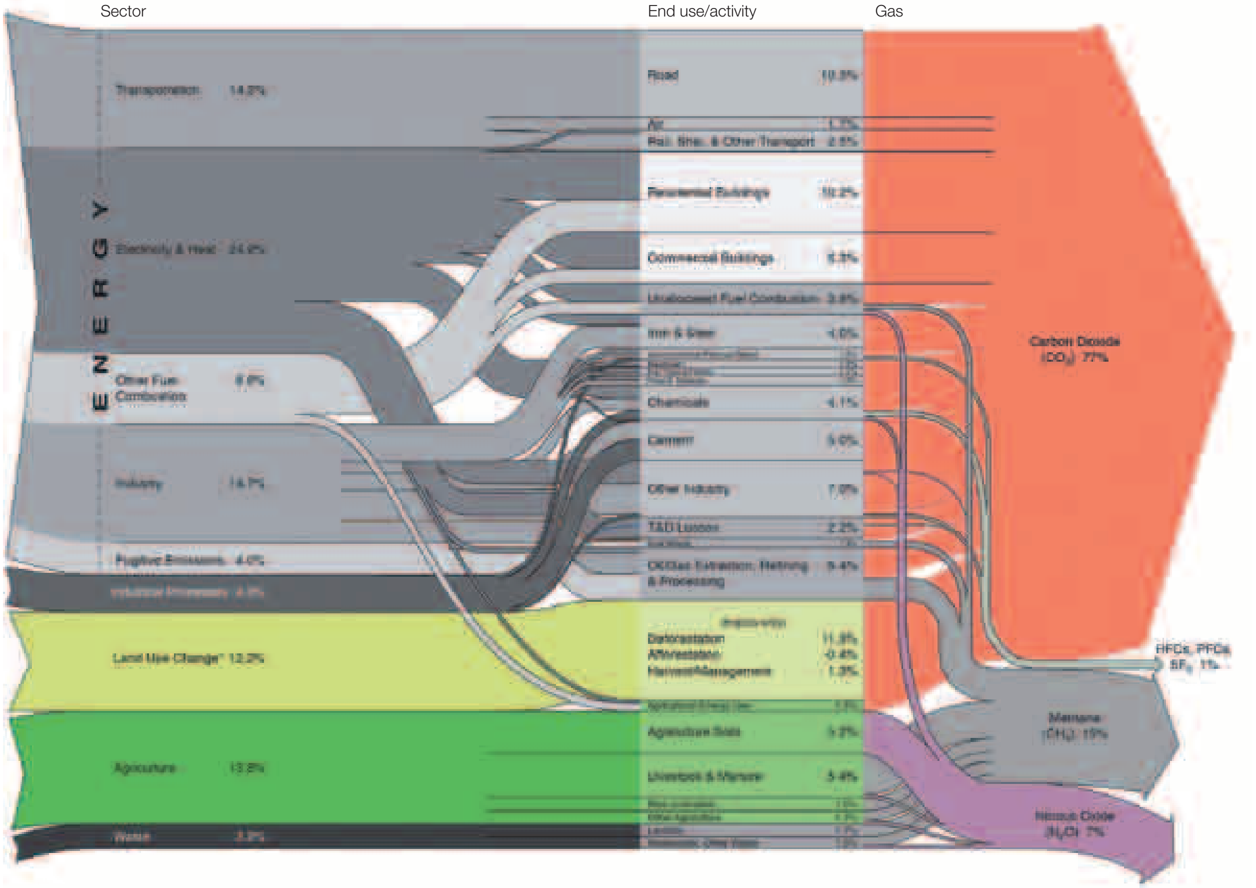
The relationship between agriculture and the environment needs to be redefined. Ecosystem-based land-use planning should be recognized as a tool for improving land management. Moreover, smallholders should be included as important custodians of natural resources and as entrepreneurs with the capacity to invest in natural assets and contribute to national and global production systems. Fortunately, an array of sustainable agricultural intensification approaches exist, ready for scaling up, that increase yields and food security, increase resilience to climate and other risks and shocks, reduce GHG emissions and do not degrade the environment.

In many areas fallows are no longer an option because all land is in use. In increasingly depleted soils, the major challenge is to increase organic matter content, which also impacts

FIGURE 11

Agriculture’s contribution to greenhouse gas emissions in 2005

World greenhouse gas emissions in 2005, total: 44,153 $MtCO_2$ eq.



Sources and notes: all data are for 2005. All calculations are based on CO2 equivalents, using 100-year global warming potentials from the IPCCC (1996), based on a total global estimate of 44,153 MtCO2 equivalent. See appendix 2 of *Navigating the numbers: Greenhouse Gas Data and International Climate Policy* (WRI, 2005) for a detailed description of sector and end-use activity definitions, as well as data sources. Dotted lines represent flows of less than 0.1 per cent of total GHG emissions.
*Land Use Change includes both emissions and absorptions, and is based on analysis that uses revised methodologies compared to previous versions of this chart. These data are subject to significant uncertainties.

Source: WRI (2009).

on the effectiveness of the use of inorganic fertilizer. A number of approaches exist.[2]

One such approach is conservation agriculture (CA). Farmers have employed CA practices, based on no tillage and retention of soil cover through cover crops and/or mulch (FAO 2001), for a long time. In sub-Saharan Africa and Latin America, in particular, such practices show positive outcomes for both farmers and the environment (Knowler and Bradshaw 2007; annex, table A1).

Agroforestry systems such as the fertilizer tree system (FTS) are designed to improve soil nutrient balances. FTS involves the planting or regeneration of fast-growing nitrogen-fixing trees or woody shrubs (e.g. *Gliricidia* or *Sesbania* spp.) that produce high-quality leaf biomass and are adapted to local climatic and soil conditions. The integration of trees into the farming system also commonly reduces erosion and enhances soil fertility, water quality, biodiversity and carbon sequestration (annex, table A1) (see, for example, Schroth and Harvey 2007), although benefits depend on regional factors such as climate and soil (Rao, Nair and Ong 1997). FTS is used by 100,000 smallholders in southern and eastern Africa.

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[2] / Further details on the following approaches are listed in annex I.

Where FTS is adopted, yields in staple crops such as maize increase and improvements in household food security have been recorded (Ajayi et al. 2011). FTS has also had a positive impact on biodiversity, through enhancing the ecosystem services rendered by soil invertebrates (Sileshi and Mafongoya 2006), suppressing weeds (Sileshi, Kuntashula and Mafongoya 2006) and sequestering carbon (Makumba et al. 2007). The returns on investment are also very high (Franzel, Phiri and Kwesiga 2002; Franzel 2004; Ajayi et al. 2007; Ajayi et al. 2009).

One other area of development is that of integrated pest management (IPM) (annex, table A1) and the use of companion crops. For example, 'push-pull' cropping systems use companion plants growing among and around the main crop plants to repel pests and attract beneficial organisms. Companion plants attracting parasitoids that control the African witchweed, or *Striga*, have led to an increase in cereal yields (maize, sorghum, millet) from about 1 ton/ha to 3.5 tons/ha in places where the system is used. These plants can provide multiple additional benefits such as nitrogen fixation (in the case of legumes such as beans) and high-value animal fodder that helps increase milk production. 'Push-pull' systems are based on locally available crops, have low external input levels and fit within traditional, mixed cropping systems. Thus they are appropriate for resource-poor smallholders (Khan et al. 2010).

Organic agriculture for smallholders leads to increased food production and increased benefits for the ecosystem services that support agricultural production: improved organic matter, reduced soil erosion and increased biodiversity. Producing organically also enables farmers to earn premium prices and tap into niche export markets. Certified organic farms constitute 23 per cent of the world's organic land in Latin America, 7 per cent in Asia and 3 per cent in Africa (FiBL and IFOAM 2012). However, 20-24 per cent of the world's certified organic farms are in Africa and exports are increasing (UNEP and UNCTAD 2008).

The outcomes of interventions in farming systems are context-dependent. For example, synthetic fertilizers may be beneficial in areas where the supply of organic manure is insufficient, whereas manure can have negative consequences for water quality in other areas (Tim Benton, pers. comm.). As discussed in Key message 2, the ecosystem processes on which smallholder production depend and that they impact on often originate at larger scales than that of the farm. The annex provides examples of approaches that lead to positive effects on ecosystems through smallholder farm management systems.

Different approaches are being investigated that would enable more sustainable management of (farm) land at the landscape scale**. Approaches such as sustainable land management (SLM) (Liniger et al. 2011) or the new paradigm of 'ecoagriculture' (Scherr and McNeely 2008) include many of the practices described above.** They are based on increased water-use efficiency and productivity, improving the balance between nutrient removal and input, managing on-farm vegetation, and generally generating positive benefits for production, biodiversity and people at the larger landscape scale.

For example, 'farmscapes' or 'agricultural mosaics/landscapes' that include both farm agrodiversity and semi-natural ecosystems of woodland would support sustainable food production, grazing and wood products, as well as maintain ecosystem services. Others argue that food production and nature are better off separated with distinct areas of more intensive agriculture and untouched nature (Green et al. 2005). Issues of scale of food production and demand, and the potential of low- or high-yield farming in terms of environmental sustainability are the subject of research and debate broadly referred to as 'land-sharing versus land-sparing' (Phalan et al. 2011; Balmford, Green and Phalan 2012).

In many cases smallholders simply lack the incentives to sustainably manage ecosystems. Poor farmers, concerned about their short-term survival, tend to have high discount rates for future benefits, so they seek to maximize food production today rather than contribute to other services with some benefits in the long term (Chavas 2004; Boerner, Eisenbeiss and

BOX 2

Benefits from investments in greening agriculture

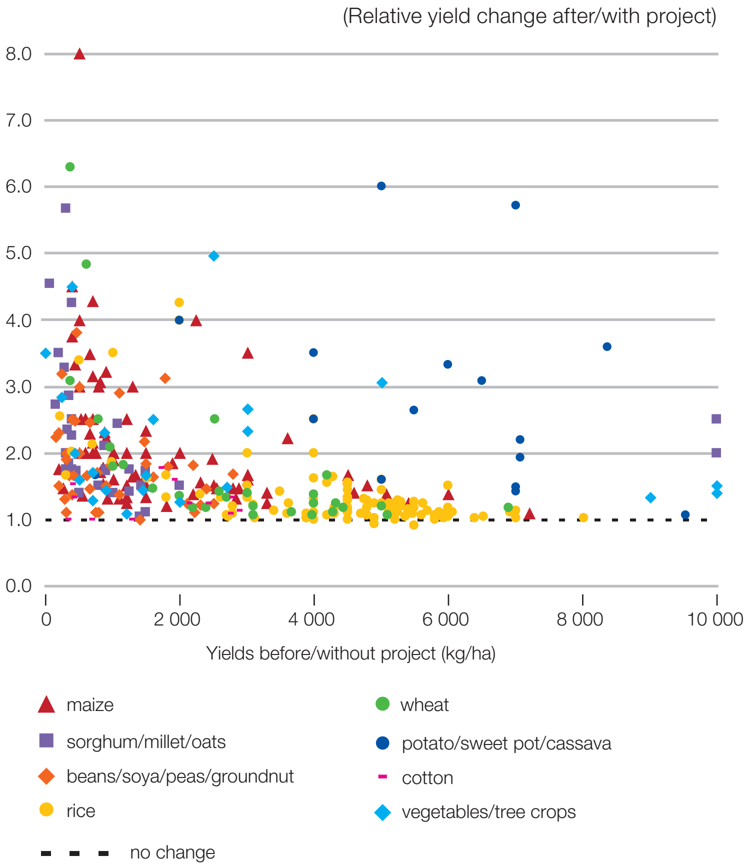
1. Work by Pretty et al. (2006) clearly demonstrates that investments in sustainable agriculture can lead to substantial increases in per-hectare food production. Their analysis of 198 projects showed benefits realized from one or more of the following mechanisms:

(i) Intensification;
(ii) Addition of new productive elements to a farm system, such as fish or shrimp in paddy rice or agroforestry, which provide a boost to total farm food production and/or income, but do not necessarily affect cereal productivity;
(iii) Better use of natural capital to increase total farm production, especially water;
(iv) Introduction of new regenerative elements into farm systems (e.g. legumes, IPM);
(v) Introduction of new, locally appropriate crop varieties and animal breeds.

These included interventions related to: IPM, integrated nutrient management, conservation tillage, agroforestry, aquaculture, water harvesting in dryland areas, and livestock integration into farming systems, including zero grazing.

2. On an aggregate scale, UNEP (2011) assessed a scenario in which an additional 0.16 per cent of global GDP is invested in green agriculture per year (equalling US$198 billion) from 2011 to 2050. The green scenario was compared with the same amount of additional investment made in conventional and traditional agriculture over the 40-year period ('BAU2' in the table). Overall, the green investments led to improved soil quality, increased agricultural yield and reduced land and water requirements. They also increased GDP growth and employment, improved nutrition, and reduced energy consumption and CO$_2$ emissions:

Changes in crop yelds with sustainable intensification



Source: Reprinted with permission from Pretty et al. (2006). Copyright 2006 American Chemical Society.

Outcomes of green and conventional scenario investments

	Year	2011	2030		2050	
	Scenario	Baseline	Green	BAU2	Green	BAU2
Agriculture-sector variables	Unit					
Agricultural production	Bn US$/yr	1 921	2 421	2 268	2 852	2 559
Crop	Bn US$/yr	629	836	795	996	913
Livestock	Bn US$/yr	439	590	588	726	715
Fishery	Bn US$/yr	106	76	83	91	61
Employment	Mn people	1 075	1 393	1 371	1 703	1 656
Soil quality	Dimensionless	0.92	0.97	0.80	1.03	0.73
Agricultural water use	Km^3/yr	3 389	3 526	4 276	3 207	4 878
Harvested land	Bn ha	1.20	1.25	1.27	1.26	1.31
Deforestation	Mn ha/yr	16	7	15	7	15
Calories per capita per day (available for supply)	Kcal/p/d	2 787	3 093	3 050	3 382	3 273
Calories per capita per day (available for household consumption)	Kcal/p/d	2 081	2 305	2 315	2 524	2 476

Source: UNEP (2011).

Griesser 2007). Where significant intrinsic values are not attached to wider ecosystem services, farmers have little incentive to support services that do not provide direct benefits (Swift, Izac and van Noordwijk 2004; Pascual and Perrings 2007). In some places, however, cultural and spiritual values attached to landscapes can help sustain wider ecosystem services, for example Potato Park in the Peruvian Andes (Argumedo 2008). Box 1 (page 19) provides an overview of means to improve smallholder agricultural production through sustainable intensification, recommended by FAO's *Save and grow* (FAO 2011b).

The way forward: transforming smallholder farming

Promoting the intensification of sustainable agricultural management practices requires the design of farm- and community-level mechanisms through which smallholders can address the trade-offs between individual productivity and increased collective sustainability. In the past, the promotion of sustainable agriculture has focused on minimizing the impacts of agriculture on the environment, and many smallholders have felt, and continue to feel, that this robs them of already limited opportunities for growth. The challenge will be to develop and scale up a sustainability landscape approach that takes these concerns into account.

Removing policy barriers to sustainable agricultural growth requires the design of market-based mechanisms that provide smallholders with proper incentives to invest in sustainability. Removing subsidies on unsustainable fertilizers and subsidizing practices that encourage soil and water conservation can help small producers green their own supply chains (agricultural inputs, feed and drip irrigation). Similarly, expanding fair or green certification schemes would allow products originating from smallholders to compete in new niche markets locally and internationally. Much can be done at multiple levels to assist developing country governments in setting up policies and markets conducive to smallholders' sustainable growth.

Smallholders need information. Investing in the modernization of extension services is essential, including approaches such as farmer field schools (FAO 2008b), the use of rural radios and other mobile telecommunication methods (Munyua 2000; Bhavnani et al. 2008). An efficient extension system can reach smallholders with targeted, adapted advice that takes into account local environmental conditions, production practices and market access to help in decision-making and risk reduction. Extension service systems need to be adapted to local needs and build on farmer knowledge and exchange. At the country level, stronger in-country research/extension linkages need to be built, and the use of modern technology needs to be further developed. This will increase the efficiency and effectiveness of both public and private extension services. Agricultural extension officers must also take on more responsibility for environmental considerations. Agricultural training facilities and colleges could better integrate sustainable approaches into their curricula to support the training of environmentally aware extension officers at all levels.

Finally, additional research is also needed on the drivers of change that influence smallholder practices – both negative (e.g. agriculture policies and subsidies) and positive drivers/incentives (e.g. secure land rights, collective institutions and cultural values). A key question is how to achieve coordinated landscape management by smallholders. This is essential to support the implementation of environmental conservation strategies without compromising food production or livelihoods. In addition, there is a need to facilitate sustainable, autonomous, smallholder livelihoods adapted to local conditions and to enable smallholders to develop their own futures. This is a question that ecologists, agronomists and social scientists will need to work together to address.

Specifically, the following research gaps were identified:

Biodiversity/ecosystem services. More needs to be known about the relationship and dynamics between biological communities and the services they provide, including how these relationships change over time and how this affects the stability and resilience of the services and crop productivity. In particular, there is a lack of knowledge about biological communities and how they function within several ecosystem services simultaneously, and how these interactions vary across farming systems and as a function of the spatial scale at which land is devoted mostly to food production.

Synergistic effects of below- and above-ground services. It is not known whether suites of below- and above-ground services contribute synergistically, or trade off in their contribution to crop yield and quality. This has important implications for decision-making and for developing management interventions that can boost the limiting service(s) without negatively affecting others.

Effect of land use on biological communities. For successful management of multiple services, more information is needed on how land use and other environmental factors affect the distribution, abundance and community composition of organisms that contribute to crop production. Intermediate services are being produced by a wide range of contrasting organism groups and are generated at varying spatial and temporal scales. To be able to promote synergies and avoid trade-offs, one needs to know which service-providing communities should be managed at what spatial scale and by what form of management, and how interventions aimed at enhancing one target service affect the stock and flow of the others.

Climate change and agricultural productivity. Understanding must be deepened of the impacts of climate change on agricultural yields, cropping practices, crop disease spread, disease resistance and irrigation development.

Economics of sustainable intensification. For ecosystem services to become an integral part of farming, further insights are needed into the economic benefits and costs associated with ecological intensification.

Economics of 'multifunctional agriculture'. Agricultural landscapes deliver services other than crop production, such as climate and water regulation and biodiversity conservation, many of which provide benefits on regional or global scales. 'Multifunctional agriculture' is emerging as an important research topic in order to quantify these benefits and propose strategies to encourage farmers and land managers to support them.

Costs of the transformation. The cost of the failures identified in this report, the investments needed to achieve the proposed transformation to a global, greener economy centred on smallholders, and the resultant benefits should be quantified. The Economics for Ecosystems and Biodiversity (TEEB) for Agriculture initiative provides the scope for this kind of assessment.[3]

3/ The TEEB study was launched by Germany and the European Commission in response to a proposal by the G8+5 Environment Ministers in 2007 to develop a global study on the economics of biodiversity loss. The second phase of the study is hosted by UNEP with support from a number of organizations, including: the European Commission; the German Federal Ministry of Environment, Nature Conservation and Nuclear Safety; and the Department for Environment, Food and Rural Affairs (United Kingdom).

With the right conditions, smallholders can be at the forefront of a transformation in world agriculture

With their immense collective experience and intimate knowledge of local conditions, smallholders hold many of the practical solutions that can help place agriculture on a more sustainable and equitable footing. Markets currently do not capture this potential, and smallholders need tailored mechanisms to overcome market failures and disincentives for sustainable land use. A major challenge will be to address the discrepancies of scale between decisions made at the farm level and impacts at larger ecosystem scales.

The case for supporting small farms is compelling. There is widespread awareness of the policy and market failures that keep small farms from delivering on their promises (Dorward et al. 2004; Hazell et al. 2010). Islands of success provide lessons and lend support for investment in the smallholder sector (Juma 2011). Successes often have one of two factors in common:

- Either they have received considerable and consistent government support packaged with a strong political will;
- Or they have reduced the relative costs faced by smallholders, for example through coordination of producer groups to effectively leverage the economies of scale that otherwise place smallholders at a disadvantage in the market.

These successes and the factors behind them offer insights into the key policy levers that, strategically engaged, can help unleash the productivity promise of small farms. Underlying this is a growing recognition that the regulations and institutions that govern dynamics within agricultural markets and generate incentives (or disincentives) to production are central to levelling the playing field between smaller and larger farms (Kirsten et al. 2009).

Whereas ecosystem management decisions are taken at the farm level, with conservation costs met by each individual farmer, many of the benefits accrue to a wider group of society at a landscape or global level. Markets currently do not capture the full economic values of ecosystem service provision, which leads to decisions biased in favour of provisioning services that can be exchanged at markets (Pascual and Perrings 2007). It is important to align short-term private incentives with the long-term public interest with a view to better ecosystem management – addressing the spatial mismatch between costs and benefits of non-provisioning ecosystem services.

Mechanisms are needed to help capture the benefits provided by ecosystem services and to compensate smallholders for costs incurred in order to strengthen sustainable practices. Such mechanisms would increase smallholders' incentives to work towards managing their ecosystems more sustainably while generating benefits for the wider society. As Jack, Kousky and Sims (2008) note, "… incentive-based policies address externalities by altering the economic incentives private actors face, while allowing those actors to decide whether and how much to change their behavior." Finally, more research is needed on the relationship between farm size and environment, since farm dimension is usually not included as a factor in comprehensive statistical data.

Annex

TABLE A1

Examples of smallholder management systems with positive effects on ecosystems

Sustainable agriculture practices	Positive effects	Geographical scope	Case study
Conservation agriculture Maintains a permanent or semi-permanent organic soil cover. This can be a growing crop or dead mulch. Its function is to physically protect the soil from sun, rain and wind and to feed soil biota. The soil microorganisms and soil fauna take over the tillage function and soil nutrient balancing. Mechanical tillage disturbs this process. Therefore, zero or minimum tillage and direct seeding are important elements of CA. A varied crop rotation is also important to avoid disease and pest problems.	Reduced soil erosion; maintaining soil fertility; improved soil moisture retention; reduced pollution due to reduced pesticide use.	Worldwide (100 million ha; about 8 per cent of total arable land).	In Lempira, Honduras, farmers moved from a traditional slash-and-burn system to the Quesungual system. This CA system uses trees and mulch. An economic analysis of this transition showed that during the first two years, maize and sorghum yields were about equal to those obtained with the traditional slash-and-burn system. From the third year, however, yields increased. In addition, the system provided the farmer with firewood and posts, which gave an extra value to the production. Because of the increased production of maize, the quantity of stover, which could be sold as livestock fodder, increased as well. Additionally, from the first year onward, the farmer could rent out the land for livestock grazing because of increased biomass production. Usually this was done for two months. The application of the Quesungual system not only met the household subsistence needs for fruit, timber, firewood and grains, but also generated a surplus that could be sold, providing an additional source of income (Welches and Cherett 2002).
Agroforestry The use of trees and shrubs in agricultural crop and/or animal production and land management systems.	Improved soil fertility and soil moisture through increasing soil organic matter. Nitrogen-fixing leguminous trees and shrubs can be especially important to soil fertility where there is limited access to mineral fertilizers. Production of fodder and non-timber forest products (NTFPs). Carbon sequestration. Contributes to climate adaptation and mitigation.	Cropping systems worldwide (12.5-25 per cent of total agricultural land), e.g. coffee production in Central America, cocoa production in Brazil.	*Faidherbia albida* is a tree commonly found in agroforestry systems in sub-Saharan Africa. This tree, which is widespread throughout the continent, thrives on a range of soils and occurs in ecosystems from deserts to wet tropical climates. It fixes nitrogen and has the special feature of 'reversed leaf phenology' (i.e. it is dormant and sheds its leaves during the early rainy season and leafs out when the dry season begins). This feature makes it compatible with food crop production, because it does not compete for light, nutrients or water. Farmers have frequently reported significant crop yield increases for maize, sorghum, millet, cotton and groundnut when grown in proximity to *Faidherbia*. From 6 per cent to more than 100 per cent yield increases have been reported in the literature (e.g. Kho et al. 2001 for millet in Niger).

Sustainable agriculture practices	Positive effects	Geographical scope	Case study
Sustainable rangeland management	Reduced soil erosion; increased soil fertility; increased provisioning services.	Arid lands worldwide.	The Kazakhstani model of sustainable rangeland management, representing the alliance of traditional approaches and innovative technologies, involves the following: seasonal rotation is being revived, strategically important wells are being repaired, and anti-erosion pasture rotation is being organized around these wells. In order to create livestock forage, fallow lands are being transformed into highly productive grasslands (UNDP 2011).
Integrated pest management IPM is an ecosystem approach to crop production and protection that combines different management strategies and practices to grow healthy crops and minimize the use of pesticides. IPM-based projects have seen reductions in synthetic pesticide use (e.g. in cotton and vegetable cultivation in Mali). In some cases, biological control agents have been introduced where pesticides were not being used at all.	Regulation, e.g. disease and pest control services. Reduced run-off and soil erosion, and thus increased groundwater reserves, provide a measurable effect on pesticide residues in surface water. Biodiversity: A spin-off benefit is greater diversity of trees, crops (e.g. beans, fodder shrubs, grasses) and non-cropped habitats (Foresight 2011). Provisioning, e.g. food and grain, fodder.	Worldwide	In Burkina Faso, Mali and Niger, the introduction of the parasitic wasp [*Habrobracon hebetor*] helps control the millet head miner (Payne et al. 2011).
Aquasilviculture Integration of aquaculture and mangrove forestry, mainly through integration of mangrove ponds and pens for fish and crab production.	Sequestering of carbon, but also greater resilience to shocks and extreme events, which leads to increased production because of improved ecosystem services.	Commonly used in Indonesia and Viet Nam and in the early stages of development in other locations such as Hong Kong, the Philippines and Malaysia.	A good example of the benefits of aquasilviculture can be seen in the introduction of the system in the Tambak Region of Java, an area of over 300,000 ha of extensive ponds that lacked mangroves. The introduction of mangroves led to an increase in production of food supplies and contributed significantly to the socio-economic well-being of the rural coastal population. The system was thus more profitable than simply direct planting of mangrove trees, and the net financial benefits to the reforestation programme of the State Forestry Corporation were considerable (Sukardjo 1989).

Sustainable agriculture practices	Positive effects	Geographical scope	Case study
Precision agriculture – drip irrigation Involves dripping water onto the soil at very low rates (2-20 litres/hour) from a system of small-diameter plastic pipes fitted with outlets called emitters or drippers. Water is applied close to plants so that only the part of the soil in which the roots grow is wet.	Reduced water use for irrigation; maintains soil nutrients; improves soil retention.	Worldwide, however most suitable for row crops (vegetables, soft fruit) and tree and vine crops, where one or more emitters can be provided for each plant. Generally only high-value crops are considered because of the high capital costs of installing a drip system.	In northern Benin, solar-powered drip irrigation as a strategy for enhancing food security was tested in different villages. The study found that it significantly increased household income and nutritional intake and was cost-effective compared with other technologies (Burney et al. 2010). In on-station trials in Niger, experiments comparing drip irrigation and irrigation with watering cans showed that drip irrigation helped achieve higher yields, higher returns to water and higher returns to labour (Woltering et al. 2011).
Collective crop rotation systems Community members decide collectively which plots within a given area to use for which crops and which to reserve as fallow. It is a self-regulating mechanism in which individual interests (e.g. maximizing cultivation of the most profitable crop) are balanced against the collective interest of rotating crops and leaving land fallow in order to maintain soil fertility, regulate crop pests and diseases, and provide land for livestock grazing and for the collection of wild plants.	Improved soil fertility; reduced soil erosion; improved pest regulation; grazing and fodder provisioning.	High Andes – crop and livestock systems.	In the Northern Altiplano (Lake Titicaca), farmers rotate plots between quinoa, potatoes, other cereals, beans and fallow periods of 1-2 years. In the Southern Altiplano (Salar de Uyuni), they grow quinoa for one season and then leave the plot as fallow land for 3-6 years. These differences are due to agroecological conditions.
Co-culture systems Pond-based, co-culture systems involving plant and animal crops (fish, shrimp, etc.).	Reduced pesticide and fertilizer use.	China	A 1,200-year-old south Chinese rice and fish co-culture method in which carp eat insect pests and then defecate in the paddy, decreasing the need for pesticides and fertilizers, while maintaining rice yields and providing a protein harvest.

TABLE A2

Means to provide market-based incentives for smallholders

Mechanism for incentives	Case examples
Property rights over land and the natural resources managed on these lands If there is a trade-off between reaping immediate benefits or securing a continuous flow of benefits in the future, farmers will only opt for the latter if they have established long-term rights (even customary) to access and manage these resources, withdraw benefits from them and exclude others from doing so. If future paybacks are not secured, there is little incentive to refrain from making the most use of the resource in the short run, thereby often depleting or degrading it and compromising activities that would improve or sustain the flow of benefits in the long run (Schlager and Ostrom 1992).	Evidence from Ethiopia, where smallholders often lack secure tenure, shows that they do not invest in land measures, such as terracing, that would increase future productivity (Deininger and Jin 2006).
Payment for ecosystem (or environmental) services (PES) schemes PES schemes are commonly defined as voluntary transactions in which a well-defined ecosystem service or a land use likely to secure that service is being bought by a (minimum of one) service beneficiary from a (minimum of one) service provider if – and only if – the service provider guarantees service provision. PES are widely understood as market-based solutions by which markets are set up (through the allocation of property rights) for ecosystem services to be traded in order to reach socially optimal conservation levels (Engel, Pagiola and Wunder 2008; Muradian et al. 2010). According to Zilberman, Lipper and McCarthy (2008), there is an important difference between 'land-diversion' PES schemes, in which agricultural land use is reduced, and 'working-land' programmes, in which a specific agricultural practice within an agroecosystem is sought (see also FAO 2011c).	The world's largest PES project targeting farmlands is China's Grain for Green Program (also called Sloping Land Conversion Program), which seeks to reduce soil erosion. It is aimed at 40-60 million smallholder households, setting aside about 15 million ha of cropland on steep slopes (Xu et al. 2004; Uchida, Jintao and Rozelle 2005; Bennett 2008). A payment scheme in Kenya's Amboseli Park compensates farmers for not cropping lands that cross elephant migration routes (Bulte et al. 2008).
Market chain development A means to integrate smallholders into the market by increasing the value added of smallholder products at different stages of the food value chain (production, processing, trading) (Poulton, Kydd and Dorward 2006; Will 2008). Niche markets for traditional crops grown under traditional, non-intensive practices could play an important role in creating pro-poor market opportunities (Will 2008; Gruère, Giuliani and Smale 2009; Hermann and Bernet 2009). If consumers are willing to pay a premium price for products from eco-friendly smallholder production, then eco-labelling, certification or origin schemes could generate substantial demand for smallholder products (Daniel and Dudhade 2007; Gruère, Giuliani and Smale 2009; Krishna, Pascual and Zilberman 2010).	With active export promotion by the Bolivian Government of quinoa, a traditional Andean grain, poor farmers in the High Andes are now benefiting from high price premiums for a few certified varieties (Hellin and Higman 2003; Del Castillo 2008). (Nevertheless, a caveat has to be noted, as more intensive production and expansion of quinoa production have reportedly also led to a number of negative social and environmental outcomes for Bolivian smallholders.)

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IFAD

International Fund for Agricultural Development
Via Paolo di Dono, 44 - 00142 Rome, Italy
Tel: +39 06 54591 - Fax: +39 06 5043463
E-mail: ifad@ifad.org
www.ifad.org
www.ruralpovertyportal.org
ifad-un.blogspot.com
www.facebook.com/ifad
www.twitter.com/ifadnews
www.youtube.com/user/ifadTV

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