Chapter III
Towards a truly green revolution for food security

Summary

- The recent food crises have revealed deep structural problems in the global food system and the need to increase resources and foster innovation in agriculture so as to accelerate food production. Food production will have to increase between 70 and 100 per cent by 2050 to feed a growing population. With current agricultural technology, practices and land-use patterns, this cannot be achieved without further contributing to greenhouse gas emissions, water pollution and land degradation. The consequent environmental damage will undermine food productivity growth.
- Achieving sustainable food security would provide a long-term solution to the challenge of combating hunger and malnutrition, mitigating food price volatility and protecting the environment. It will require, however, a radical change in existing policies—a change that would result in a strengthening of currently fragmented systems of innovation and an increase in resources for agricultural development and sustainable resource management.
- The main challenge is to improve incentives so that they promote and lead to the development of sustainable agriculture by small farm holders. Evidence has shown that, for most crops, the optimal farm is small in scale and it is at this level that most gains in terms of both sustainable productivity increases and rural poverty reduction can be achieved.

The global food crisis

The recent global food crises laid bare long-term threats to food security

The increase in prices underlying the 2007-2008 food crisis and the new food price spikes in 2011 have exposed the presence of serious threats to the sustainability of the global food system and its capacity to provide adequate and affordable access to food. Meeting the challenge of expanding food production to feed the world population over the coming decades requires a major transformation in agriculture. The so-called green revolution of the 1960s and 1970s helped boost agricultural productivity worldwide, but did not conduce to a sustainable management of natural resources, nor to food security for many of the world's poor. The world now needs a truly green revolution in agriculture—one conducive to the kind of technological innovation that aims to radically improve the productivity of small farm holdings through environmentally sustainable natural resource management embedded in broader developmental agricultural support measures.

Persistent food insecurity

Almost 1 billion people are undernourished worldwide…

The dramatic food price increases in 2007–2008 and the ensuing economic crisis saw the global number of undernourished people surpass 1 billion in 2009, signalling a threat to world economic, social and political stability. Although the number and proportion of hungry people, particularly in Asia, declined in 2010, amid signs of economic recovery, those figures remain above pre-crisis levels, leaving 925 million people undernourished (Food and Agriculture Organization of the United Nations, 2010a) (figure III.1).

… with two thirds living in seven countries

The World Food Summit Plan of Action (Food and Agriculture Organization of the United Nations, 1996) considered food security as existing "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (para. 1). Based on this definition, undernourishment is thus a key indicator of food insecurity. The overwhelming majority (98 per cent) of the world's undernourished people live in developing countries, with two thirds of them concentrated in seven nations (Bangladesh, China, the Democratic Republic of the Congo, Ethiopia, India, Indonesia and Pakistan). Most hungry people (578 million) reside in Asia and the Pacific, although the highest share (30 per cent, or 239 million people) are found in sub-Saharan Africa (figure III.2).

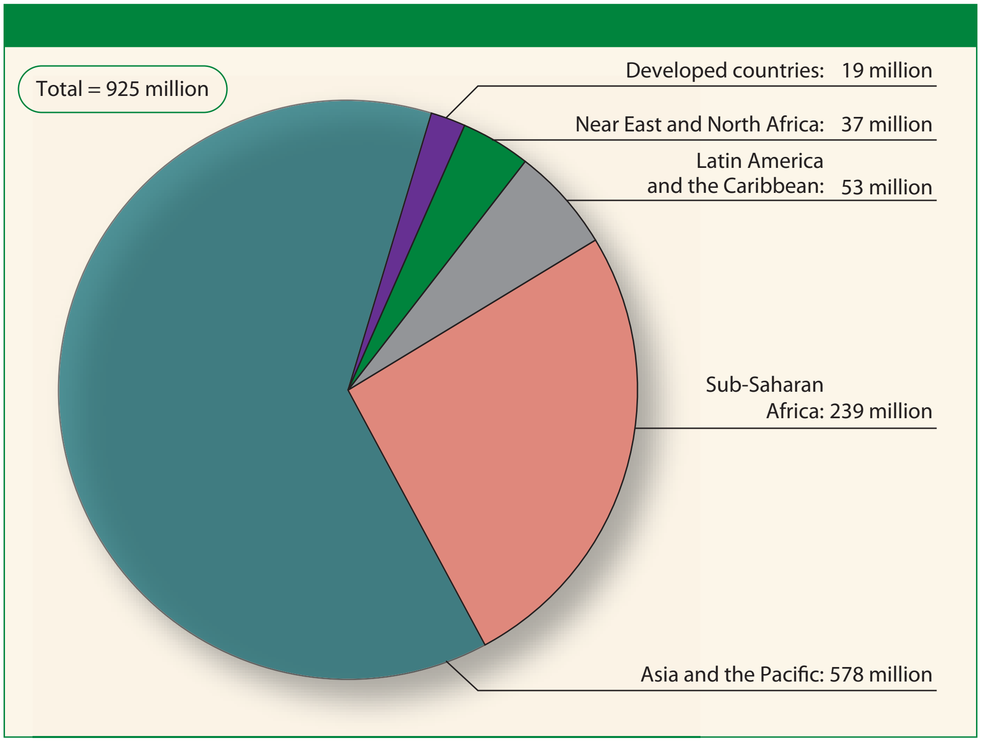
While progress varies from country to country, developing countries as a group have not moved closer to the food security targets established at the World Food Summit: the number of undernourished people increased by almost 10 per cent between 1990–1992 and 2010.[1]

Figure III.1
Undernourished population worldwide, 1969-2010

Source: Food and Agriculture Organization of the United Nations (2010a).
Note: Undernourishment exists when caloric intake is below the minimum dietary energy requirement, which is the amount of energy needed for light activity and a minimum acceptable weight for attained height. It varies by country and over time depending on the gender and age structure of the population.

1 Commitments agreed to at the 1996 World Food Summit included the call for at least halving the number of undernourished people in the world by the year 2015 (Food and Agriculture Organization of the United Nations, 1996, para. 7).

Figure III.2
Undernourished population by region, 2010



Source: Food and Agriculture Organization of the United Nations (2010a).

The 22 countries regarded as facing a "protracted food security crisis" are home to over 165 million undernourished people (about 20 per cent of the world's total). The proportion of undernourished people ranges from under 15 per cent in Côte d'Ivoire to almost 70 per cent in the Democratic Republic of the Congo (Food and Agriculture Organization of the United Nations, 2010a).

Impact of the 2007-2008 world food price spike

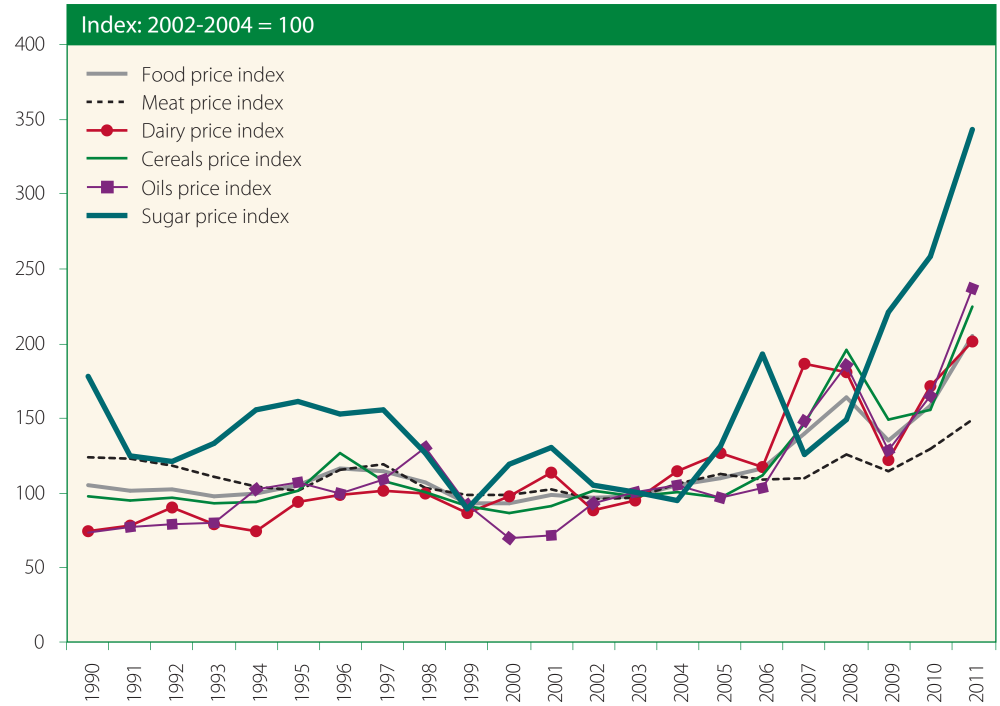
Following the 2007-2008 food price crisis, the number of people living in poverty increased by an estimated 100 million

World food prices increased dramatically in the period 2007–2008. Prices for corn, wheat and rice more than doubled between 2006 and 2008. While prices declined in late 2008, food prices have since rebounded, attaining new record highs in February 2011 (figure III.3). Despite conflicting evidence, it would appear that recent price rises have also been accompanied by higher volatility, which increases uncertainty, thereby hindering investment in human and physical capital, technology and innovation (Food and Agriculture Organization of the United Nations, 2009a) (figure III.4).

Global food prices have rebounded to record highs in 2011

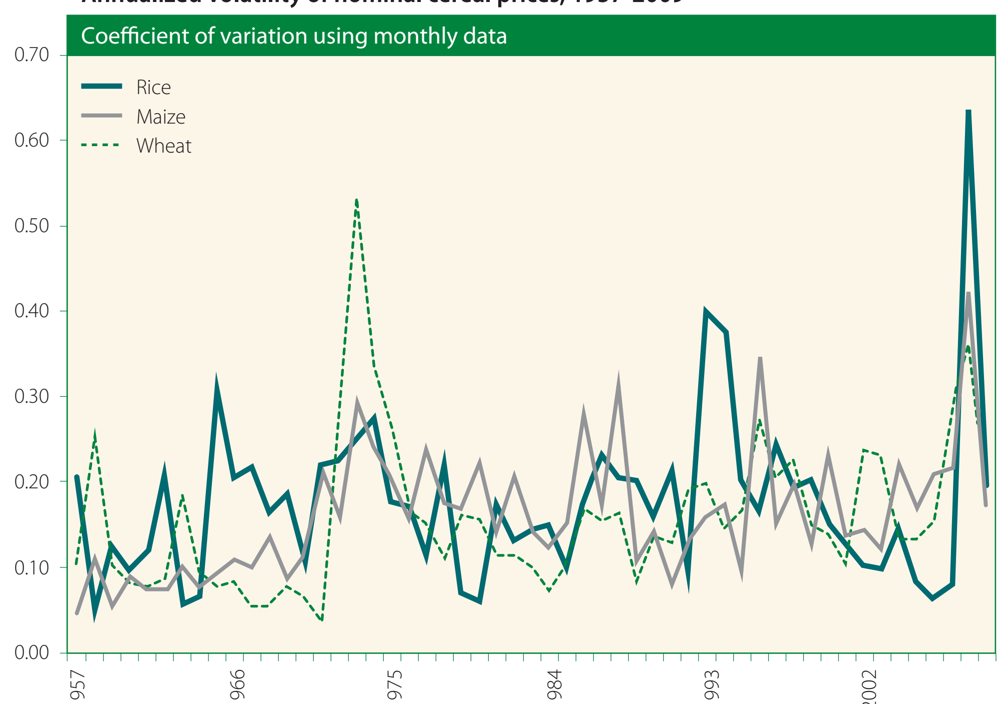
The severe impact of the 2007-2008 food crisis on living conditions was attested by the riots that broke out in over 30 countries. Evidence shows that 41 countries lost between 3 and 10 per cent of gross domestic product (GDP) to rising energy and commodity prices in 2007-2008 (World Bank, 2008a). Increasing food prices have had a particularly negative impact on the poor who spend 50-70 per cent of their income on food (von Braun, 2009). Higher food prices are estimated to have pushed a further 100 million people into poverty in 2007-2008 and nearly 50 million in the latter half of 2010 (World Bank, 2008b; 2011).

Figure III.3
Real food price indices, annual averages, 1990-2011



Source: Food and Agriculture Organization of the United Nations. Available from http://www.fao.org/worldfoodsituation/wfs-home/foodpricesindex/en.

Figure III.4
Annualized volatility of nominal cereal prices, 1957-2009



Sources: Organization for Economic Cooperation and Development and Food and Agriculture Organization of the United Nations (2010).

The nature of the impact of price rises depends on countries' economic structure, sectoral linkages, trade position, poverty levels and diet diversification (Rapsomanikis, 2009). Although higher prices provide incentives to increase production, many small farm holders are unable to respond owing to lack of access to finance, agricultural inputs, markets and technology (United Nations, 2008a). Nevertheless, in developing countries with a large share of net producing households, high food prices boost demand for rural labour and incomes (Chant, McDonald and Verschoor, 2008). While countries like India, China and Indonesia have limited the domestic impact of higher international food prices through export restrictions on rice and other crops (Timmer, 2009), evidence from the latest price spikes (2010-2011) points to greater convergence of trends in national and international food prices, which is a cause for concern, given the recent steep upward trajectory of global prices (Ortiz, Chai and Cummins, 2011).

Causes of the food price crisis

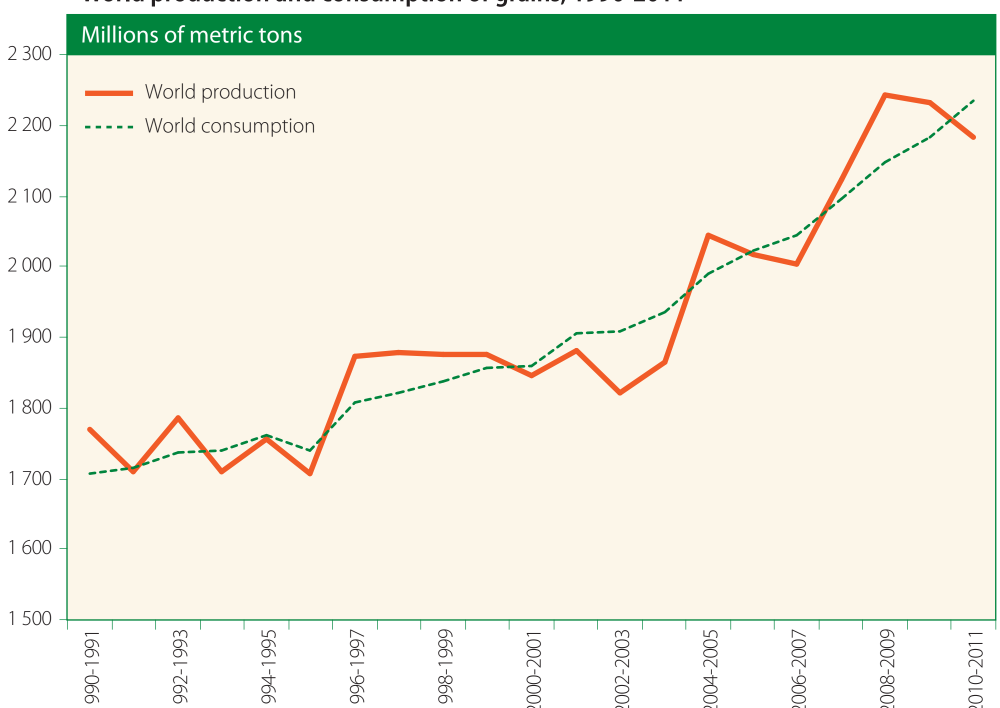
The world food crisis was the result of overlapping demand and supply crises (in 2006-2008, for example, world grain production fell short of consumption (figure III.5)).

Demand-side causes

Food prices have been pushed up by growing and wealthier populations, commodity speculation, trade policies and United States dollar depreciation

Over the past 20 years, continued global population growth, principally in developing countries (see figure O.1(a)), and rising incomes, particularly in South-East Asia, have not only raised food consumption, but also altered dietary patterns, as reflected in a greater demand for animal protein (and hence food grains). Meat consumption in China and

Figure III.5
World production and consumption of grains, 1990-2011



Source: United States Department of Agriculture (USDA) Production, Supply and Distribution (PSD) database.

India rose by about 25 per cent and 140 per cent, respectively, in the last decade (HM Government, 2010).

The significant depreciation of the United States dollar in 2008, in which most food commodity prices are denominated, also contributed to higher prices. The Food and Agriculture Organization of the United Nations (FAO) estimates that for each 1 per cent depreciation of the United States dollar, agricultural commodity prices increase by between 0.3 and 0.8 per cent (Sarris, 2009). In addition, attempts by Governments to insulate domestic markets from escalating international food prices and prospective shortages through trade protection measures further increased the level and volatility of global prices. The persistence of high and volatile food prices has also been attributed to a notable recent increase in financial speculation in commodity futures markets (Gilbert, 2008; United Nations, 2011).

Supply-side causes

Competition for land, climatic conditions, biofuel policies, high energy prices and structural problems in agricultural production and investment were supply-side factors

Land available for food cultivation has been shrinking owing to degradation and competition for other uses such as urban development and production of non-food crops. Deforestation is mainly driven by competition for agricultural land, be it for subsistence farming in Africa or for establishment of large-scale cattle and soy plantations in Latin America (Stern, 2007). In addition, increased purchases of farmland by foreign investors has resulted in the favouring of exports over domestic food production. An estimated 56 million hectares of land in developing countries were bought by foreigners in 2009, a 10-fold rise from the previous decade, with two thirds of these sometimes controversial “land grabs” occurring in Africa (Deininger and others, 2010).

Adverse weather conditions in 2005-2006, including drought in Australia, possibly related to climate change, resulted in poor harvests and exerted upward pressure on prices (Food and Agriculture Organization of the United Nations, 2008). Similarly, harmful climatic phenomena in the Russian Federation and Ukraine, particularly the recent heatwaves, are thought to be the main drivers behind the most recent international price spikes (World Bank, 2011).

Perhaps the most important contributing factor to the 2008-2009 food crisis, albeit still subject to debate, is the diversion of food commodities to biofuel production (Mitchell, 2008; Food and Agriculture Organization of the United Nations, 2009a). In 2007, three quarters of the annual increase in world maize use was absorbed by ethanol plants alone, accounting for 12 per cent of total maize production. In the United States, one third of the domestic use of corn supply was for ethanol production and the biodiesel sector accounted for about 60 per cent of the rapeseed oil output of the European Union (EU) (Food and Agriculture Organization of the United Nations, 2009a). United States and EU biofuel production has been supported by State subsidies and tariffs, which cost developed countries $11 billion in 2007 (United Nations, 2008a). Studies that attempt to explain the impact of biofuel demand on world food prices exhibit marked differences in their findings, which suggest that demand could explain anywhere from 15 to 70 per cent of the 2007-2008 food price hike. Direct competition between food and fuel has led to calls for support for a new generation of biofuels that do not compete with food (Vos, 2009).

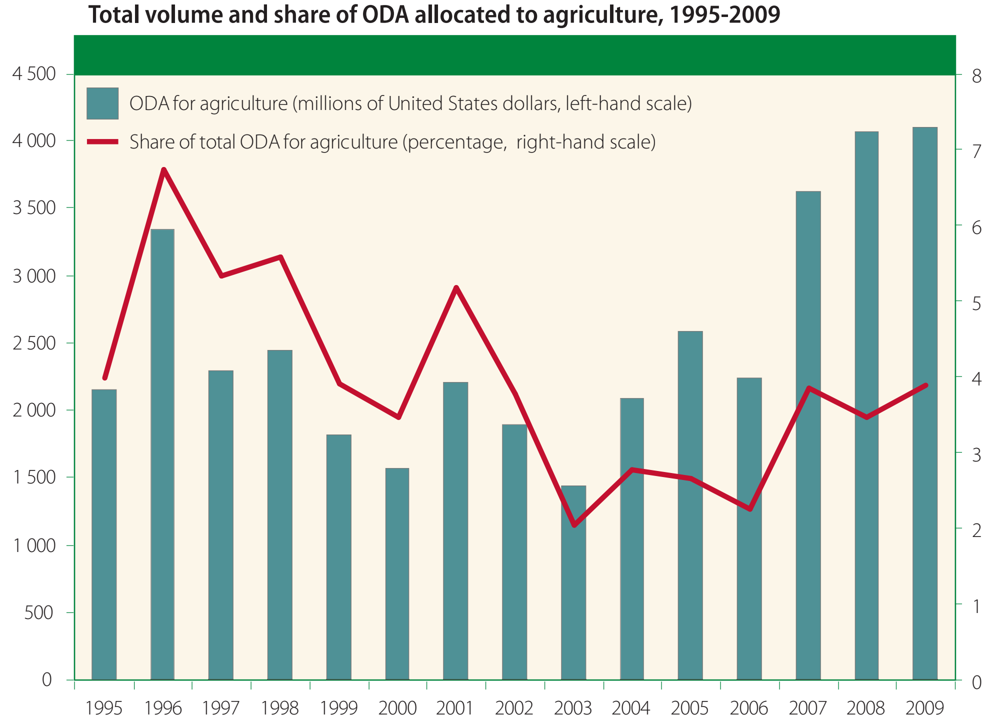
In 2007-2008, oil price rises positively impacted the level and volatility of food prices by raising fertilizer, freight and other food production costs, as well as by creating incentives for biofuel expansion (United Nations, 2008a).

A number of structural impediments to the expansion of food production have been identified, including declining agricultural investment, partly owing to lower public investments and earlier low food prices (United Nations, 2008a). The share of total overseas development assistance (ODA) allocated to agriculture fell from a peak of 18 per cent in 1978 to 4 per cent in 2009, with ODA earmarked for agriculture having decreased significantly in the 1990s (United Nations, 2008a) (see figure III.6). In this context, the International Monetary Fund (IMF), the World Bank and other institutions have been criticized for providing foreign aid conditional on the implementation of policies (such as abolishing fertilizer subsidies and favouring cash crops) that have undermined food self-sufficiency and raised imports (Stiglitz, 2002). At the same time, donor nations have continued to engage in provision of distortionary agricultural subsidies to producers and consumers (amounting to $376 billion of Organization for Economic Cooperation and Development (OECD) expenditure in 2008), undermining the ability of farmers in developing countries to compete (United Nations, 2010b).

The world faces a proliferation of instances of localized chronic food insecurity

The intertwined factors examined above contributed to the global food crisis. In this context, the fact that the number of undernourished people worldwide (1 billion) is matched by the number of those who are overfed and obese, and that hunger in the world has continued to increase in recent decades despite continuous agricultural productivity growth and, generally, low food prices, calls poignantly into question the effectiveness of the global food distribution system (Godfray and others, 2010a). Yet, between 75 and 90 per cent of staple foods are produced and consumed locally, which suggests that the world faces the prospect of a proliferation of cases of localized chronic food insecurity (United Nations Conference on Trade and Development, 2010).

Figure III.6
Total volume and share of ODA allocated to agriculture, 1995-2009



Source: OECD StatExtracts.

Policy responses to the food crisis

Escalating global food prices prompted an international commitment of $20 billion in external assistance

The food price surge induced prompt policy reactions at both national and international levels. For instance, at the G8 Summit in Hokkaido Toyako in 2008, donors pledged to provide $10 billion in ODA to fight hunger (Group of 8, 2008); and, at the G8 Summit in L'Aquila, Italy, in 2009, $20 billion over three years to address food insecurity in a sustainable manner (Group of 8, 2009).

At the national level, countries responded differently, with a wide range of mainly short-term policy measures including import tariff reductions, price controls, export restrictions, stock reductions, food programmes, new biofuel policies, and commodity futures markets regulation (Organization for Economic Cooperation and Development and Food and Agriculture Organization of the United Nations, 2010). A study evaluating such responses in 10 emerging economies revealed the importance of providing targeted safety nets for the poor as emergency responses to food shortfalls. While trade protection and building food inventories may enhance national food availability in the short run, such measures may at the same time prove to be costly in terms of expenditure and contribute to keeping food prices high by restricting food supply in international markets (Jones and Kwiecinski, 2010).

Unsustainable natural resource management as a threat to both food security and the environment

Technology in use in agriculture has led to adverse environmental outcomes …

A range of fundamental natural resources (such as land, water, air and biodiversity) provide the indispensable base for the production of essential goods and services upon which human survival depends. During the past half-century, shrinkage in the availability of natural resources occurred more rapidly than in any comparable time in history, driven in great part by human intervention in the environment in the form of agricultural activities. Although vital to the production and supply of food, feed and fuel, these have had negative environmental and socio-economic consequences, such as land degradation, water pollution, climate change, biodiversity loss, reduced long-term productive capacity, poverty, migration and ill health (International Assessment of Agricultural Knowledge, Science and Technology for Development, 2009).

Environmental impacts

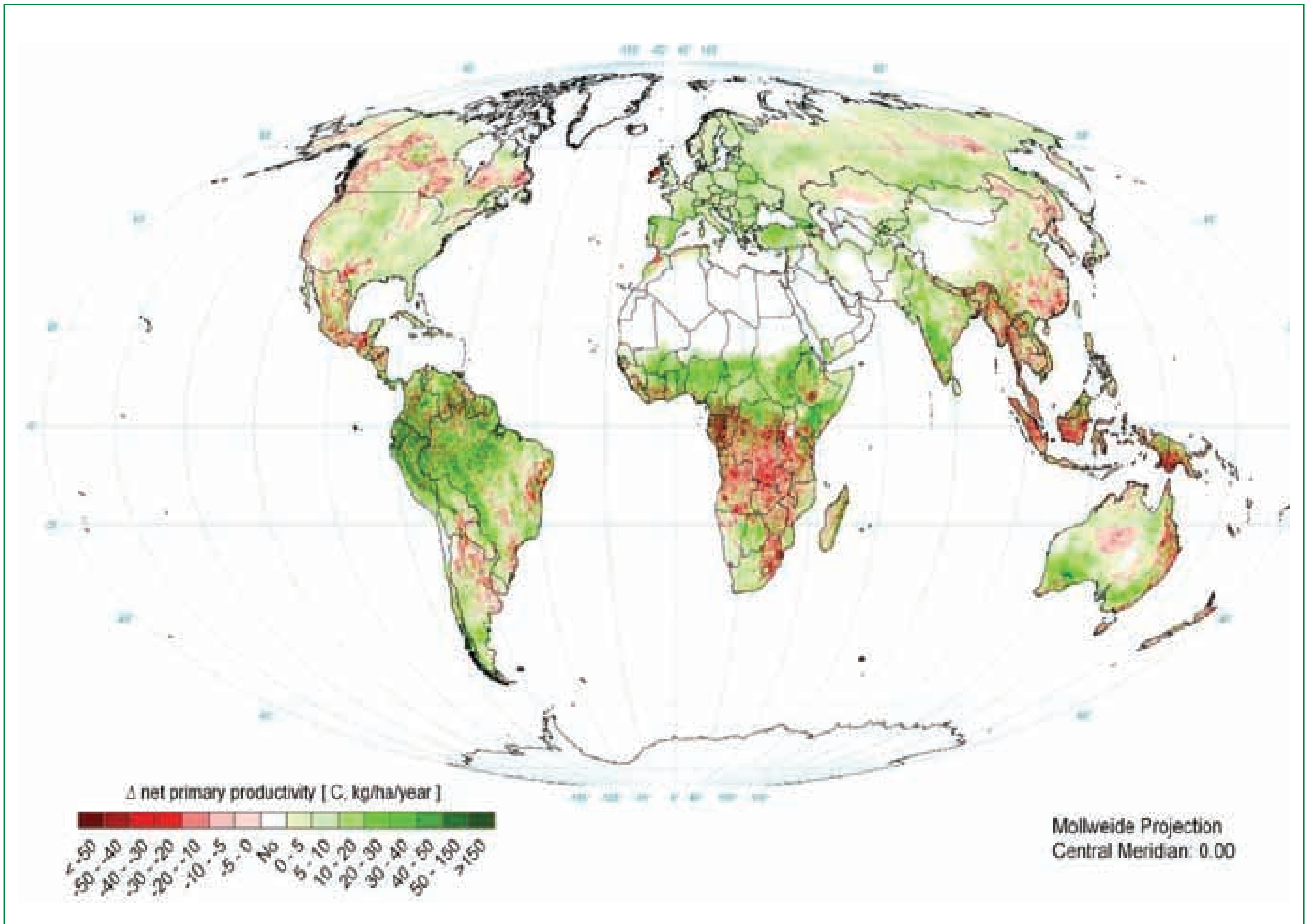
… including severe depletion of natural resources

Land degradation is among the world's greatest environmental challenges, with the potential to destabilize societies, endanger food security and increase poverty (Millennium Ecosystem Assessment, 2005). Defined as a long-term decline in ecosystem function and productivity, land degradation is driven mainly by poor land and water management, including over-cultivation, overgrazing, deforestation and inadequate irrigation (Berry, Olson and Campbell, 2003).

Almost half of the world's surface has been degraded

Land degradation is increasing, in severity and extent, in many parts of the world, with about 40 per cent of the world's land surface degraded (25 per cent has been degraded over the past quarter-century alone) and with an estimated 1.5 billion people directly dependent on agriculture (Bai and others, 2008). Figure III.7 depicts global change in land productivity (in terms of carbon dioxide (CO_2) fixation) over the period

Figure III.7
Global change in net primary productivity, 1981-2003



Source: Bai and others (2008), figure 2.

1981-2003.[2] Degrading areas are mainly in: the part of Africa that is south of the Equator, in South-East Asia and southern China, in north-central Australia, in the pampas and in swathes of boreal forest in Siberia and North America (ibid.).

Agriculture is a cause as well as a casualty of climate change

Land degradation has negative effects on climate, biodiversity, water ecosystems, landscape and other ecosystem services (see table III.1). While agriculture contributes significantly to the problem of climate change, it is also vulnerable to its effects. Climate change impacts agriculture in many ways, with changes in temperature, precipitation and climatic variability affecting the timing and length of growing seasons and yields and thereby exacerbating land degradation and contributing to water scarcity (Agrawala and Fankhauser, eds., 2008; and table III.2). Notably, in this regard, with temperature rises, crop productivity is forecast to increase at mid-high latitudes and decrease at lower

2 Land degradation is measured by the change in the normalized difference vegetation index (NDVI), scaled in terms of net primary productivity (NPP). NPP is the rate at which vegetation fixes CO_2 from the atmosphere less losses through respiration; deviation from the norm is used as an indicator of land degradation or improvement. As a proxy, the remotely sensed NDVI, which has been shown to be related to biophysical variables that control vegetation productivity and land/atmosphere fluxes, is also used to estimate vegetation change (Bai and others, 2008).

Table III.1
Global environmental impacts of land degradation

Environmental component or process	*Bases of impact of land degradation*
Climate change	• Land-use change, deforestation in particular, is a critical factor in the global carbon cycle • Soil management changes can result in the sequestration of atmospheric carbon • Agriculture is a major source of methane (CH_4) and nitrous oxide (N_2O) emissions • Land surface change (for example, as regards albedo and roughness) plays an important role in regional and global climate change • Human activities accelerate the occurrence of sandstorms • Biomass burning contributes to climate change
Biodiversity	• Deforestation leads to loss of habitat and species • Land-use change and management, including fragmentation and burning, lead to loss of habitat and biodiversity • Non-point pollution from crop production damages aquatic habitats and biodiversity
Water resources	• Agricultural activities are a major source of water pollution • Land-use and cover change alters the global hydrologic cycle • Atmospheric deposition of soil dust damages coral reefs
Persistent organic pollutants (POPs)	• Soil contains a major pool of POPs • Biomass burning produces POPs

Source: University of East Anglia, Overseas Development Group (2006).

latitudes (Intergovernmental Panel on Climate Change, 2007a). For instance, it is estimated that, in Southern Africa, yields could fall by up to 50 per cent between 2000 and 2020 (Intergovernmental Panel on Climate Change, 2007b); and that, by 2080, 600 million additional people could be at risk of hunger as a direct consequence of climate change (United Nations Development Programme, 2007, overview, p. 9).

There are important feedback mechanisms, however, as agriculture activity and land degradation generate greenhouse gas (GHG) emissions and thus contribute to climate change. They also impact land-surface albedo so as to engender adverse weather patterns (University of East Anglia, Overseas Development Group, 2006). Notwithstanding significant uncertainty in estimates, agricultural activities account for about 30 per cent of emissions of greenhouse gases (carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)) (Baumert, Herzog and Pershing, 2005). Agriculture is a significant emitter of CH_4 (50 per cent of global emissions) and N_2O (70 per cent) (Bhatia, Pathak and Aggarwal, 2004). Emissions from cattle and other livestock account for just over one quarter of CH_4 emissions.

There is much interest in the climate change mitigation potential of the reverse of this process, carbon sequestration, in both vegetation (forests in particular) and soil. Table III.3 summarizes the contribution of agriculture to greenhouse gas emissions.

Globally, agriculture is the main source of depletion and pollution of water resources

Access to sufficient and safe water is crucial for food production, poverty reduction and human health. However, increasing and competing demands for water have

Table III.2
Projections of climatic changes and corresponding impacts on agriculture

Projected change	*Likelihood of future trends based on projections for the twenty-first century*	*Projected impacts on agriculture*
Warmer and fewer cold days and nights; warmer and more frequent hot days and nights over most land areas	Virtually certain	Increased yields in colder environments; decreased yields in warmer environments
Warm spells/heatwaves: frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress at key development stages; increased danger of wildfire
Heavy precipitation events: frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to water-logging of soils
Area affected by drought increases	Likely	Land degradation; lower yields/ crop damage and failure; increased livestock deaths; increased risk of wildfire
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow of trees
Increased incidence of extreme high sea level	Likely	Salinization of irrigation and well water

Source: Intergovernmental Panel on Climate Change (2007a), table 3.2.

Table III.3
Contribution of agriculture to global greenhouse gas and other emissions

Greenhouse gas	Carbon dioxide	Methane	Nitrous oxide	Nitric oxide	Ammonia
Main effects	Climate change	Climate change	Climate change	Acidification	Acidification Eutrophication
Agricultural source	**Land-use change, especially deforestation**	Ruminants (15)	Livestock (including manure applied to farmland) (17)	**Biomass burning (13)**	Livestock (including manure applied to farmland) (44)
		Rice production (11)	Mineral fertilizers (8)	Manure and mineral fertilizers (2)	Mineral fertilizers (17)
		Biomass burning (7)	**Biomass burning (3)**		**Biomass burning (11)**
Agricultural emissions as a proportion of the total emissions from anthropogenic sources (percentage)	15	49	66	27	93

Source: Food and Agriculture Organization of the United Nations (2003).
Note: Sources of land degradation are in bold. Percentage contribution of each type of emission to total global emissions appears in parentheses.

led to serious depletion of surface-water resources (Smakhtin, Revenga and Döll, 2004). Agricultural irrigation accounts for some 70 per cent of all water withdrawals.

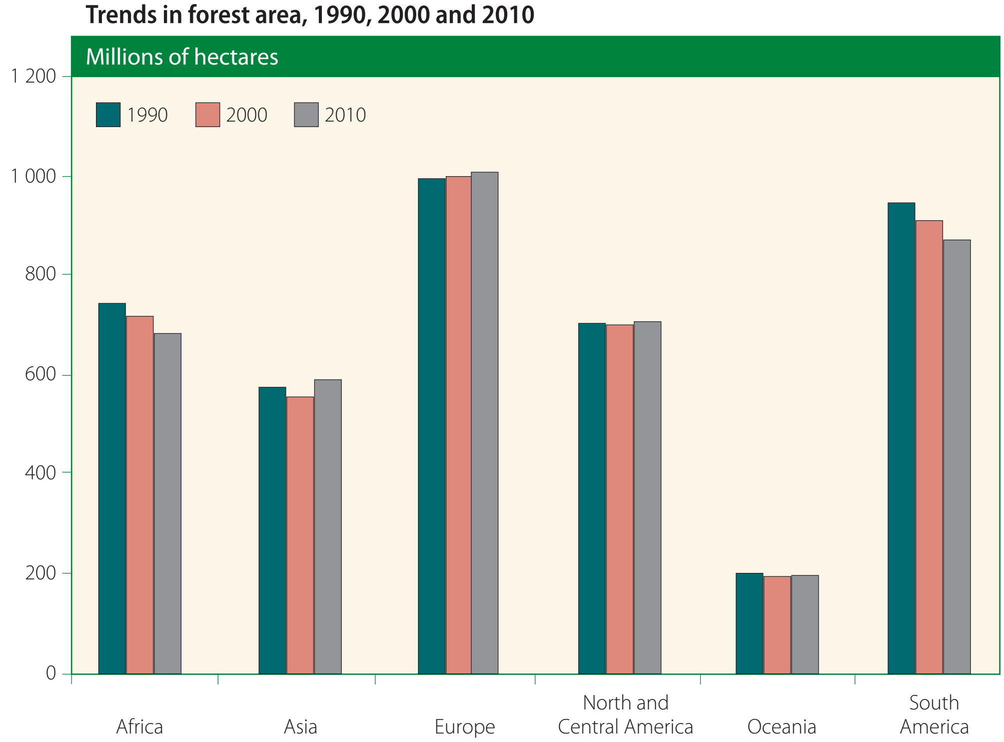
Moreover, it appears that water quality has been degraded partly owing to intensive agriculture, which has become the main source of water pollution in many developed and developing countries, rendering it unsustainable and a source of risks to human health (Molden and de Fraiture, 2004). Intensive livestock production is probably the largest sector-specific source of water pollution (Steinfeld and others, 2006). Excessive use of agrochemicals (pesticides and fertilizers) also contaminates waterways. The capacity of coastal and marine ecosystems to produce fish for human harvest is highly damaged by overfishing and loss of wetlands and other water habitats.

Deforestation is a major cause of biodiversity loss

Biodiversity underpins agriculture and food security through the provision of the genetic material needed for crop and livestock breeding, and raw materials for industry, and other ecosystem services (International Assessment of Agricultural Knowledge, Science and Technology for Development, 2009). The past century has seen the greatest loss of biodiversity through habitat destruction, primarily through the conversion of forests for agriculture.

While the last quarter-century has witnessed an increase in forest area in industrialized countries, developing countries have experienced an average decline of about 10 per cent (Food and Agriculture Organization of the United Nations, 2007) (figure III.8). The problem of deforestation is particularly severe in the humid tropics (Moutinho and Schwartzman, eds., 2005). Africa and South America suffered the largest net loss of forests from 1990 to 2005, with Africa accounting for over half of recent global losses, even though the continent hosts just over 15 per cent of the world's forests (University of East Anglia, Overseas Development Group, 2006). Habitat destruction and degradation

Figure III.8
Trends in forest area, 1990, 2000 and 2010



Source: Food and Agriculture Organization of the United Nations (2010b).

is the major global threat to birds and amphibians, affecting almost 90 per cent of threatened species (IUCN, Species Survival Commission, 2004). This is particularly evident in the case of tropical forests, which cover less than 10 per cent of the earth's land area, yet harbour 50-90 per cent of the planet's terrestrial species (Millennium Ecosystem Assessment, 2005).

The spread of industrial agriculture has also promoted the simplification of agro-ecosystems, with reductions in the number of and variety of species. Further, production of monocultures increases environmental risks by reducing biodiversity, ecosystem functions and ecological resilience (International Assessment of Agricultural Knowledge, Science and Technology for Development, 2009). In addition, over-exploitation of marine resources is so severe that an estimated 20 per cent of freshwater fish species have become extinct (Wood, Sebastian and Scherr, 2000), while certain commercial fish and other marine species are threatened globally (International Assessment of Agricultural Knowledge, Science and Technology for Development, 2009).

Socio-economic impacts

Unsustainable natural resource management has negative socio-economic consequences …

Unsustainable natural resource management also has adverse socio-economic consequences. In particular, land degradation can lead to substantial productivity losses, thereby posing risks to food security (Sanchez, 2002). While productivity impacts vary largely by region, the areas mostly affected are those whose populations are already suffering from poverty and hunger (Oldeman, 1998). The productivity of some lands has declined by 50 per cent owing to soil erosion and desertification (Dregne, 1990). Globally, the annual loss of 75 billion tons of soil costs about $400 billion per year, or approximately $70 per person per year (Lal, 1998). Soil compaction has caused yield reductions of between 40 and 90 per cent in West African countries (Kayombo and Lal, 1994). Nutrient (nitrogen, phosphorus, and potassium) depletion also has a severe global economic impact, especially in sub-Saharan Africa. In South Asia, annual economic loss is estimated at $500 million from waterlogging, and at $1.5 billion due to salinization (Food and Agriculture Organization of the United Nations, 1994). Deforestation can also exacerbate food insecurity, as forests provide food, inputs and services that support crop and livestock production (Food and Agriculture Organization of the United Nations, 2006). In a case-study analysis of seven developing countries, Berry, Olson and Campbell, (2003) estimated that problems of sustainable land management reduced agricultural GDP by between 3 and 7 per cent.

… including reduced long-term productive capacity, poverty, migration and ill health

There is often a strong association between the distribution of poor people reliant on agriculture and fragile environments. Poor people are likely to be farming steeper land and drier, less fertile soils and in more remote areas (World Bank, 2003). Sub-Saharan Africa and South Asia experience the highest intensity of soil degradation, population growth and food insecurity (Bai and others, 2008; Food and Agriculture Organization of the United Nations, 2010a). In Mexico, land degradation contributes to migration (Berry, Olson and Campbell, 2003). Deforestation will likely have a particularly adverse impact on many of the 1.5 billion persons who depend on forests for their livelihoods, especially as they represent 90 per cent of those living in extreme poverty (World Bank, 2004).

Natural resource degradation may also exacerbate gender inequalities by increasing the time requirement for fulfilment of female responsibilities such as food production, fuelwood collection, and soil and water conservation. For instance, in rural

Rajasthan, India, approximately 50 person-hours per month are required for households gathering fuelwood (Laxmi and others, 2003). In Malawi, women spend between 4 and 15 hours per week collecting firewood (Rehfuess, Mehta and Prüss-Üstün, 2006).

Agricultural production systems can further adversely affect human health. Water pollution from inorganic fertilizers and livestock waste undermines the safety of drinking water and aquatic food. Pesticides negatively affect the health of farm workers (World Water Assessment Programme, 2003). Transportation of agricultural products has also promoted the cross-border spread of pests and diseases (International Assessment of Agricultural Knowledge, Science and Technology for Development, 2009). In addition, desertification-induced dust storms can cause respiratory disorders, including bronchitis (Millennium Ecosystem Assessment, 2005).

Drivers of unsustainable natural resource management

Natural resources degradation is driven by poor land and water management practices

In explaining the unprecedented global degradation and depletion of land, water and biodiversity, a combination of natural and human-induced factors can be identified, including *indirect* factors such as population pressure, and *direct* factors, such as land-use patterns.

Deterioration of natural resources are most commonly caused by poor land and water management practices in a process driven by socio-economic and political factors (Bai and others, 2008). Land fragmentation and limited farm size contribute to inappropriate livestock management, resulting in land degradation. In addition, human-induced climate change aggravates resource degradation through floods, droughts, fires, soil changes and biodiversity loss. On the other hand, people can be a major asset in reversing resource degradation through reforestation and other sustainable land, water and forest management practices and technologies (Eswaran, Lal and Reich, 2001).

Underlying unsustainable management of natural resources are numerous interconnected economic and socio-political drivers, including poverty, inequality, demographic trends, national resource allocation, land distribution and rights, political stability, governance and institutions, societal perceptions of and values on land, and behavioural consumption and production patterns. For instance, poor small-scale farm holders can over-exploit natural resources, particularly when facing population pressure and scarcity of suitable land, as is the case in the *minifundias* in the Andean highlands of Latin America. On the other hand, large-scale farming can also be a cause of land degradation through the excessive use of chemicals and the engagement in unsustainable land management practices in order to increase productivity and profits.

Food security and small farm holders

Small farm holders are at the heart of the battle against poverty and hunger

To the extent that most food is locally produced and consumed, small farm holders are at the heart of the food security challenge. The majority of the extremely poor and about half of the undernourished people in the world live in a total of 500 million farms in developing countries (almost 90 per cent of farms worldwide), each comprising less than two hectares (ha) of land (International Food Policy Research Institute, 2005).

The scale of farming varies by region, with the average farm size ranging from 1.6 ha in Africa and Asia to over 120 ha in North America (table III.4). There is evidence to suggest that average farm size among small farm holdings is decreasing owing to population pressure and land scarcity. The bottom 25 per cent of rural agricultural households

Table III.4
Approximate average farm size by world region

Region	Average farm size (hectares)
Africa	1.6
Asia	1.6
Latin America and the Caribbean	67.0
Europe[a]	27.0
North America	121.0

Source: von Braun, 2009.
a Data for Western Europe only.

in several African countries farm, on average, less than 0.1 ha of land per capita (Jayne and others, 2003).

Women make up almost half of the rural workforce …

Small farm holders dominate agriculture in developing countries, where the presence of women is highly significant, typically in subsistence farming. In Africa and East and South-East Asia, women make up over 40 per cent of the agricultural workforce (Food and Agriculture Organization of the United Nations, 2011). Estimates of the share of female employment in that work force range from 36 per cent in Côte d'Ivoire and the Niger to 60 per cent in Lesotho. However, female farmers have less access to land, credit, markets and technology: Only 5 per cent of landholders in North Africa and West Africa are women, only 15 per cent in sub-Saharan Africa and only 25 per cent in a sample of countries in Latin America; furthermore, the average farm size is significantly smaller (ibid.).

… but they have restricted access to land, credit, markets and technology

In low-income countries, there are 3 billion people in rural areas; 2.5 billion are involved in agriculture and 1.5 billion make a living from small farms (Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development and International Labour Organization, 2010; Foresight, 2011). Countries and communities based mainly on small-scale farming are not only among the poorest, but also among the most threatened by ecosystem degradation (United Nations Environment Programme, 2002). For instance, in countries such as China and India (which, despite having invested heavily in rural development, are home to most of the world's undernourished people), the areas most vulnerable to food insecurity often contend with poor natural conditions and fragile ecologies (Xiao and Nie, 2009; M S Swaminathan Research Foundation and World Food Programme, 2008).

With small-scale farms likely to dominate the agricultural landscape in the foreseeable future, addressing the particular challenges they face is vital to combating poverty and hunger (Dixon, Gibbon and Gulliver, 2001). While there is an emerging consensus among international organizations regarding the importance of strengthening the role of small farm holders in order to ensure the achievement of greater food security, effective policies need to be in place to secure the viability of small farm holders, particularly in view of intensification of international competition and strengthening of marketing chains and quality standards, and natural resource degradation (Hazell and others, 2010).

Small-scale and diversified farming has advantages in terms of productivity, food production and environmental protection …

Most of the findings presented in the literature dealing with agricultural development in low-income countries indicate that small farm units tend to show higher productivity than large-scale farms. Small farm holders not only tend to make more intensive use of land and labour but also face lower transaction costs for labour. These advantages may disappear, however, for certain crops whose cultivation benefits from significant economies of scale and input-intensive technologies, or when conditions critical for efficient farming—like marketing opportunities, quality assurance, and access to inputs, markets, credit and information—are lacking for small farm holders.

… but without proper support it may lead to unsustainable use of natural resources

Poverty among small farm holders may create incentives for more intensive non-sustainable resource extraction as a short-term survival strategy (Lutz, ed., 1998). In northern Zambia, for instance, labour-rich households have higher incomes but they also cause the most deforestation (Holden, 1991). Nevertheless, Altieri (2008) notes that small-scale and diversified farming continues to have significant advantages over large-scale monoculture systems in terms of productivity (20-60 per cent higher yields), food production and environmental protection (including climate change mitigation).

Notwithstanding recognition of the challenges faced by small farm holders, these findings reinforce the view that they should be assigned a prominent role in food security strategies. Female farmers play a particularly important role; in Africa, for example, they account for more than half of the agricultural output (Mehra and Rojas, 2008). Small farm holders in developing countries often experience undernourishment themselves, while remaining the main suppliers of food to urban areas. Hence, improving food security and even economic growth will critically depend on removing the barriers faced by small farm holders and expanding their productive capacity, while paying particular attention to the needs of female farmers.

Towards a true green technological revolution in agriculture

A radical transformation in agriculture is needed …

The preceding analysis makes clear that combating hunger and malnutrition in a sustainable manner and guarding against high and volatile food prices will require a radically different approach addressing the structural constraints on food production within a wider framework of sustainable natural resource management. This would entail both the establishment of a comprehensive national framework for sustainable use of resources, and a harnessing of the technology and innovation needed to increase the productivity, profitability, stability, resilience and climate change mitigation potential of rural production systems and forests. Water conservation, soil protection and biodiversity enhancement need to form part of an integrated approach of sustainable land and forest management,[3] which must also integrate biophysical with sociocultural, institutional and behavioural variables, while recognizing the multifunctional nature of agriculture.

… to build synergies between increased food production and sustainable natural resource management…

A holistic, cross-sectoral approach should, for instance, consider trade-offs and build on synergies between the forests and agriculture sectors. In view of their competitive land uses, many solutions, involving difficult choices, will be reached through open and inclusive discussion and negotiation. On the other hand, the aforementioned synergies among the sectors (resulting, inter alia, in reduced land degradation and increased productivity; sustainable water supply; and green energy infrastructure and buildings) present important "win-win" options through better resource management facilitated by an enabling institutional environment.

3 Sustainable land management is defined as "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while ensuring the long-term productive potential of these resources and the maintenance of their environmental functions" (United Nations, 1993). Although there is no universally agreed-upon definition for sustainable forest management (SFM), the United Nations Forum on Forests (UNFF) states that "sustainable forest management, as a dynamic and evolving concept, aims to maintain and enhance the economic, social and environmental value of all types of forests, for the benefit of present and future generations" (United Nations Forum on Forests, 2007).

… within a comprehensive national framework for sustainable resource use

An appropriate institutional setting is also crucial in respect of supporting small-scale farming so as to increase agricultural investment and productivity and preserve natural resources. The State has an important role to play in building rural infrastructure (including roads, storage facilities and irrigation systems); improving market access (including for credit, inputs and insurance); providing extension services and technological capacity-building; encouraging coordination among multiple stakeholders; and securing property rights (including land redistribution).

Sustainable agriculture should also be a priority in developed countries to ensure more efficient use of energy and a reduction in use of chemical fertilizers and pesticides. Large subsidies to agriculture in OECD countries, including subsidies for the production of biofuels (entailing a shift in production away from food crops), have led to severe imbalances in the economics of agricultural production and consumption worldwide.

An agricultural innovation system approach can help accelerate the new green revolution

Government policies to stimulate a new technological revolution in agriculture will have to build on the rich experiences associated with innovation in the last 30 years. The recent literature on innovation in agriculture is using the concept of agricultural innovation systems to "denote the network of economic and non-economic actors, and the linkages amongst these actors (to) enable technological, organizational and social learning of the kind needed to devise context-specific solutions" (United Nations Conference on Trade and Development, 2010, sect. 1.6). We propose to utilize the concept of a sustainable agricultural innovation system (SAIS) to focus on developing a comprehensive policy framework for innovation which can respond to the double challenge of increasing productivity in food production and environmental sustainability. The SAIS constitutes the agricultural pillar of the larger concept of greening the National Innovation System (G-NIS), as discussed in chapter V.

After a brief overview of the SAIS framework, the present section identifies existing processes linked to technological innovation in agriculture and management of natural resources, including a brief review of recent experiences of innovation in sustainable agriculture compared with the experience of the green revolution of the 1960s and 1970s. Against this background, four critical objectives are singled out whose attainment requires strategic policy support to effect the transformation to sustainable agriculture, namely: (a) improved access to the whole range of technological options; (b) better access to supportive services, including removal of the political obstacles that prevent faster productivity growth among small-scale farm holders; (c) gender sensitivity in agricultural innovation processes; and (d) strengthening cooperation and partnerships to accelerate innovation.

The sustainable agricultural innovation system framework

All actors, institutions and processes, within the whole food chain must be part of the policy innovation framework …

The SAIS perspective facilitates the recognition of the multiplicity of actors that produce and use global knowledge (including universities, research institutions, firms, farmers, extension workers, civil society organizations and private foundations), their interests, the institutional contexts within which interactions occur in the innovation process, and the dynamics of learning and institutional change (Spielman, 2005). The SAIS perspective also serves to underline that innovation is important, in relation not only to production, but also to improving processes, products and marketing, and strengthening organizations and partnerships within different parts of the system through the engagement of different actors.

An innovation systems perspective enables the recognition of the evolutionary nature of innovation—its achievement through the cumulative effect of interactions between agents on the supply and demand sides of the system, within a framework of formal and informal institutions, supportive policies and stakeholder involvement, as illustrated by the cases presented in box III.1 (Brooks and Loevinsohn, 2011).

Box III.1

Innovation in agriculture

The development of agricultural research and experimentation has not been weak, even in the most challenged regions in Africa (United Nations Conference on Trade and Development, 2010), although they have lacked appropriate support to ensure widespread benefits. The two successful experiences discussed below illustrate the contribution of multiple stakeholders to achieving rapid improvement in the productivity of small farm holders with environmentally sustainable practices. Direct participation of small farm holders in a process of continuous learning and adaptation was a key factor of success.

The System of Rice Intensification (SRI)

Rice is the single most important staple of the poor, especially in Asia. Under current practices of the continuous flooding of fields and the heavy use of inorganic fertilizers, rice production is one of the main sources of methane gas emissions and one of the main causes of the contamination of land and water. It is estimated that 24-30 per cent of the freshwater utilized worldwide is for the production of rice.

With support from Africare, Oxfam America, the WWF-ICRISAT Project and the World Bank, an innovation known as the System of Rice Intensification (SRI) has been successfully tested in 40 countries with impressive results. With simple changes in the management of crops entailing transplantation into non-flooded fields of fewer seeds at a younger age and with wider spaces between them, in addition to broader use of organic fertilizers and integrated pest control management, crops become more resistant to climate variations, pests and diseases. Depending on local conditions, yields may increase by up to 50 per cent. Water savings have ranged between 25 and 50 per cent; input cost savings per hectare are estimated to be 23 per cent, due mainly to the use of fewer agrochemicals; and farmers' incomes have increased substantially.

According to Brooks and Loevinsohn (2011, p. 11): "In India, which appears to have the largest area under SRI, 'learning alliances' have been formed that exchange experiences and take the lead in interactions with government … (especially at local level) … notably in Andhra Pradesh, Tamil Nadu and Tripura." However, the involvement of formal research institutions has been more marginal, with some positive experiences in China and Indonesia. The Governments of Cambodia, China, India, Indonesia and Viet Nam have endorsed these innovations and included them as part of their national strategies for food security (Africare, Oxfam America and WWF-ICRISAT Project, 2010, p. 3).

The Farm Field School approach

Prompted by widespread environmental pollution and occupational poisoning in South-East Asia as a result of heavy use of pesticides, research institutions have developed the underpinnings of an integrated approach to improving pest control management through the conservation of beneficial insects (spiders and planthoppers, among others) and better management of the ecology of farmers' fields. Farmer Field Schools (FFS), which were developed over 10 years in the Philippines and Indonesia, have provided an opportunity for farmers to learn through observation and experimentation in the field.

With support from the Government of Indonesia, the United States Agency for International Development and the Food and Agriculture Organization of the United Nations, the FFS approach has spread to other developing countries (namely, Bangladesh, Cambodia, China, India, the Lao People's Democratic Republic, Nepal, the Philippines, Sri Lanka, Thailand and Viet Nam) and been adapted to various farming systems. The range of management skills has been extended to include the production of vegetables, cotton, potatoes, tree crops, fruits, maize, poultry and dairy cows, soil fertility management, land and water management, groundwater management, conservation agriculture, land degradation management, agroforestry, community forestry, fishing and preservation of biodiversity.

The agricultural innovation system that emerged from the experiences of integrated pest management and the Farmer Field Schools was made possible through active participation of multiple stakeholders. National and international research institutions in the Philippines and Indonesia have provided scientific knowledge to the Farmer Field Schools while non-governmental

Box III.1 (cont'd)

organizations in Indonesia have developed the pedagogic process needed to facilitate adult learning. Bilateral donors and international organizations (such as FAO) were critical in supporting the creation of Farmer Field Schools in other countries through financial contributions, provision of information and advocacy.

There are now FFS projects operating in 87 countries in Asia, sub-Saharan Africa, Latin America and the Caribbean, East and North Africa, Central and Eastern Europe, the United States of America and Western Europe. The FFS approach has contributed to the development of improved skills among farmers, a greater demand for information and a greater flexibility in the managing of their crops.

Sources: Brooks and Loevinsohn (2011); Braun and Duveskog (2008); and Africare, Oxfam America and WWF-ICRISAT Project (2010).

… so as to be able to support the design of effective mechanisms for enhancing innovation in sustainable agriculture

The policy challenge is how to move beyond the recognition of a multiplicity of innovative experiences towards the design of interventions and policies capable of stimulating and supporting the innovative capacity of the actors (farmers, civil society organizations and corporations) that are part of the food production system. The literature identifies two trajectories for fostering and supporting innovation: the "orchestrated trajectory" induced by policy and the "opportunity trajectory" triggered by market signals. Brooks and Loevinsohn (2011) extends this framework by adding an "endogenous" trajectory which emerges in local contexts.

These parallel trajectories intersect in each country at the point where knowledge and innovation are generated. Policies should aim to strengthen interactions among the various processes so as to ensure that innovation contributes simultaneously to poverty reduction, food security and environmental sustainability. Those objectives are not served if innovation is driven merely by profit motives, as is the case for most agricultural activities. Further, traditional public-private partnerships have not been very successful in directing innovation efforts towards achieving the objectives set out in a sustainable development agenda (Hall, 2010).

Policy must support local innovations

The challenge for policymakers is how to identify and support promising innovation trajectories in a context where the adoption of new technology and crop management practices has a mixed record of successes and failures and where many contentious issues are not easily resolved. Questions about what constitutes effective interventions persist, including: should the priority be building technical capacity of farmers or promoting established technological practices and products (Brooks and Loevinsohn, 2011); and should the strategy be one of strengthening farmers' organizations or improving their links with input suppliers. In order to respond to these questions, the management of rural development programmes needs to undergo a deep transformation of its own. The application of public policy and project management tools (logical frameworks and monitoring and evaluation systems) needs to become less rigid and more flexible and adaptive so as to be able to move beyond a narrow focus on *outcomes* and towards the strengthening of innovative *processes* (Berdegué, 2005). The very common practice, for example, of focusing on the replication (or scaling up) of successful innovative experiences may be too narrow to stimulate experimentation and learning, which would necessarily include the capacity to learn from failure.

A policy agenda with the capacity to stimulate innovation demands radical changes in the institutions and mechanisms that presently support agricultural development. A process of learning and innovation needs to unfold within public institutions—one that facilitates the adoption of a strategic focus on innovation and nationwide institutional changes in support of a techno-institutional agenda for food security under which local innovations can prosper (Leeuwis and Hall, 2010).

Building on existing approaches to technological innovation in agriculture and natural resource management

Local innovation in sustainable agriculture

Local communities and farmers are constantly innovating in response to shocks …

Local farmers and communities have shown great capacity to innovate in response to weather and other shocks. There are thousands of successful experiences of localized enhanced pest and weed management, water efficiency and biodiversity, including stories of highly successful innovation in the most challenging circumstances characterized by a poor natural resource base and widespread poverty (World Bank, 2007a, 2008c; Thapa and Broomhead, 2010; Spielman and Pandya-Lorch, 2009; Africare, Oxfam America and WWF-ICRISAT Project, 2010; Pretty and others, 2006).

… and many of their innovations entail the adoption of environmentally sustainable practices …

Pretty and others (2006) assessed 286 sustainable innovation experiences in 57 poor countries encompassing 37 million hectares.[4] In four years, and with wide variations across the 12.6 million farms evaluated, there were large and significant increases in crop yields (79 per cent on average), greater water efficiency, evidence of carbon sequestration and a reduction in pesticide use of 70.8 per cent associated with an average yield increase of 41.6 per cent.

… but they often lack the resources to expand production and apply their experiences beyond the local context

Most often, innovation experiences among local farmers and rural communities are part of their survival strategies in response to soil depletion, water scarcity, HIV/AIDS, catastrophic events and other negative factors; however, typically, the conditions needed to utilize these experiences on a larger scale are lacking. While indigenous female workers have experience in the management of biodiversity and traditional knowledge for sustainable agriculture, poor access to land, inputs and credit has often prevented the expansion of that successful experience (World Bank, 2009).

Large-scale efforts in sustainable agriculture intensification …

Nevertheless, there are several well-known examples of innovations with large-scale impacts. The integrated pest management (IPM) approach, proliferating Farm Field Schools and the System of Rice Intensification (SRI) are good examples of creative innovation that achieved large-scale impacts through highly effective collaboration among multiple stakeholders (see box III.1).

Other large-impact innovations encompass the networks of millers and politicians that popularized the use of NERICA (New Rice for Africa) in Africa, the handmade paper industry in Nepal, the organization of small-scale producers to export mangos in India, the diffusion of micro-irrigation in Bangladesh (Hall, Dijkman and Sulaiman, 2010) and watershed management in India (box III.2), among many others.[5]

4 Agricultural sustainability centres on the adoption of technology and practices designed to increase food production without negative environmental impacts. The projects evaluated encompassed 3 per cent of cultivated area in developing countries.

5 The World Bank (2007a) documented eight case studies in Asia, Africa and Latin America; and more recently, Juma (2011) published several case studies from around the world. However, there are many more case studies in the literature, including on the practice of national and international non-governmental organizations, some of which are available from http://www.fara-africa.org/; http://www.fodderinnovation.org/; http://www.cos-sis.org/; http://www.papandina.org/; http://www.oxfam.org/en/search/apachesolr_search/food%20security%20oxfam%20programs; http://www.worldvision.org/content.nsf/learn/ways-we-help-foodsecurity?Open&lpos=bot_txt_Food-Security#response; http://www.agra-alliance.org/; http://www.sristi.org/cms/; and http://www.prolinnova.net/.

Box III.2

Watershed development in India

In India, watersheds—namely, land drained by a common watercourse—have been the focus of increasing development efforts in recent decades. These areas of intense poverty and food insecurity tend to be characterized by eroded slopes and degraded pastures and forests.

Early watershed restoration projects had focused on the physical symptoms of degradation by building infrastructure designed to retain water and slow erosion, as well as by banning grazing and harvesting of forest products on the ridges. While these projects achieved striking visual results and benefited farmers in the lower reaches, they nevertheless negatively impacted women and landless and marginalized peasants who depended on fodder and forest products from the upper parts.

In the 1970s, a number of innovative village-level projects were initiated, granting landless people, including women, rights to use the additional surface water that was generated, in exchange for their collaboration in conserving soil and vegetation in the upper watershed. They were then able to sell the water to farmers or use it on rented land.

The substantial environmental and socio-economic benefits conferred by these projects inspired further efforts by both Governments and non-governmental organizations, including the expansion of employment opportunities based on natural resources and local opportunities outside agriculture. When well conceived and executed, such programmes can result in significant gains in farm output, ecological protection, employment for the landless, gender parity and female empowerment.

Overall, watershed development in India highlights the importance of the participation of diverse actors and attention to local contexts in harnessing environmental innovations that can produce multiple, equitable and sustainable benefits.

Source: Brooks and Loevinsohn (2011).

The adoption of sustainable practices in agriculture is supporting the application of the emergent concept of "sustainable agriculture intensification", also known as the "agroecological approach", "ecologically intensive agriculture" and "low-external input technology" (International Fund for Agricultural Development, 2011). Those practices have several points in common:

… are based on explicit support from Governments, multilateral and civil society organizations, and donors working directly with local farmers

- Successful experiences have been based on direct involvement of farmers in learning and innovation aimed at adapting knowledge, technology and management practices to the local context
- Active participation by various actors including Governments, non-governmental organizations, and multilateral organizations has been critical not only to scaling up innovations, but also to disseminating knowledge, building capacity among farmers, fostering trust and reducing the risks associated with new technology and agricultural practices
- Adjustments in the rules, norms and values of the institutions governing agricultural research and development (R&D), and practices, have also been important in inducing behavioural change among farmers (to encourage them to adopt new practices), redefining the role of women and establishing closer interacting networks

Successful innovative experiences with large welfare gains for small-scale farm holders, rural communities and the poor are those where technical knowledge is made relevant and accessible to farmers and is accompanied by an enabling environment within which they can overcome the constraints that they face in respect of adopting new technology and agricultural practices (Berdegué, 2005).

Agricultural research and development during the green revolution of the 1960s and 1970s

As in the original green revolution, sustainable agriculture for food security needs long-term research support, adequate investments for rural development, and institutional reform

Not too long ago, developing countries and donors had responded to widespread poverty and food insecurity with policies that induced a profound transformation of the rural economy. The so-called green revolution of the 1960s and 1970s brought new technology and innovation to farmers in Asia and Latin America as part of an effort to increase food production at a time when close to one third of the world's population (1 billion people) were vulnerable to hunger and malnutrition (Spielman and Pandya-Lorch, 2009).

Technological innovations were based on breeding new crop varieties, mainly wheat, rice and maize that were more resistant to pests and disease and more responsive to chemical nutrients and that allowed double- and even triple-cropping (International Food Policy Research Institute, 2002). In Asia, cereal production increased from 313 million to 650 million tons per year between 1970 and 1995; and countries in Asia and Latin America saw higher calorie intake per person and a substantial increase in real per capita income, with subsequent poverty reduction (Hazell, 2009).

The technological innovation and diffusion triggered by the green revolution were facilitated by a large and interconnected system of international research centres, coordinated by the Consultative Group on International Agricultural Research (CGIAR) and sustained with adequate funding from developed and developing countries and private donors. These centres sustained research operations, gene banks and nursery programmes in an environment of open and free exchange of information and plant genetic materials (Dubin and Brennan, 2009). The budgets available to CGIAR centres grew from $15 million in 1970 to $305 million in 1990 (Pardey and Beintema, 2001).

Governments expanded rural roads, irrigation and electrical power facilities, and improved storage facilities. Basic education, agricultural research and extension services to support farmers also improved, and international lending for agricultural development was prioritized.

Unfortunately, the "technical package" that accompanied the green revolution was not replicable in regions with different agroecological conditions in terms of climate, soil, weeds and pests, most notably sub-Saharan Africa, and where the consumption of staples was more diversified so as to include millet, sorghum, and cassava, of which improved varieties would come much later. Also, the technology arising from the green revolution was based on intensive use of fertilizers, chemical pesticides and water, which had negative environmental impacts.

Three lessons can be learned from the first green revolution

Three important lessons derived from the experience of the green revolution are relevant to the discussion of a new wave of transformations in agriculture, namely, that: (a) the development of new technology requires long-term financial support for R&D and effective and free flow and dissemination of information; (b) the adoption of new technology requires an enabling institutional framework and large investment in infrastructure, and capacity development among farmers, as well as access to inputs, credits and markets; and (c) innovations in agriculture require long-term commitments from national Governments and other international stakeholders. Going forward, the environmental impact of agriculture is a major concern. New technology and a radical reform in agricultural practices will be needed to reduce greenhouse gas emissions, land degradation, and overexploitation and contamination of water tables, and to increase the carbon sequestration capacity of agriculture and forestry.

Multiple technological options need to be made available in response to multiple challenges

There is no one technology that fits all …

In contrast with the experience of the green revolution, which relied on the adoption of a "technical package" on a large scale, achieving food security in today's context will require faster productivity gains among a large number of small-scale producers in very different agroecological regions. There is no single "technical solution" to simplify the quest for more rapid productivity and environmental sustainability gains. Instead, a whole range of technical options need to be made available to farmers.

… but a wide range of technology options need to be made available to meet farmers' specific needs …

An extensive menu of technologies and a wealth of sustainable practices in agriculture are available to spearhead the radical transformation required to increase food production without a major expansion of cultivated areas and a further depletion of natural resources. A recent study found that important productivity gains, of the order of a two- to threefold increase in average yields in Africa, for example, can be achieved through better use of existing knowledge and technology (Foresight, 2011). Similarly, FAO (2011) estimates that with better access by women to land, external inputs and technology, agricultural production in developing countries could increase by as much as 2.5-4.0 per cent, and the number of undernourished people could decline by between 12 and 17 per cent (that is, 100 million-150 million people could be free of hunger).

… including traditional knowledge and practices

Traditional technologies and practices have proved their relevance to increasing productivity and ensuring environmental sustainability: for example, low-tillage farming, crop rotation and interplanting, water harvesting and recycling, water-efficient cropping, green manure utilization, agroforestry and integrated pest management have been successfully adopted with large productivity gains.

The technology that emerged from the green revolution will continue to play an important role in the development of new crop breeding and higher-yielding varieties with substantial productivity gains, although continuing innovations will be needed for reducing the use of external inputs and increasing efficiency of water so as to reduce negative environmental impacts.

While modern developments in biotechnology, genetic engineering, food irradiation,[6] hydroponics and anaerobic digestion promise to improve the resistance of food crops to pests and extreme weather, increase their nutritional value, and reduce food contamination and greenhouse gas emissions, appropriate incentives to expand research on crops and processes of relevance to the poor need to be put in place.

There is very little that can be said, in general, about the choice of technologies that respond to the specific needs of farmers in diverse agroecological regions except that making those technologies available as options to small farm holders requires a new policy framework and additional investments in rural development. In Asia and some countries in Latin America, where the technologies derived from the green revolution led to overuse of agrochemicals and the depletion of water tables, Governments may need to reconsider whether to continue subsidizing the use of fertilizers and pesticides or to facilitate access to sustainable technology in order to increase the use of organic fertilizers and efficient water management. In sub-Saharan Africa, where small-scale farm holders generally use a fraction of the recommended levels of external inputs, decreasing food insecurity may require

6 Food irradiation is a physical process that exposes foods to a highly penetrating form of energy—gamma rays or high-energy electrons—which can uniformly deactivate the DNA of unwanted microorganisms without changing the basic nature of the treated food. It is a safe and cost-effective way to eliminate food contaminants.

the devising of new incentives to increase the use of chemical inputs in combination with sustainable technology and practices.

A radical rethinking of policy objectives and tool design is required …

From a policy perspective, the problem is how to increase awareness and stimulate the adoption of sustainable technology and crop management practices. The policy challenge becomes ever more complicated when there are trade-offs between increasing food production and halting environmental degradation, as in the case of the extensive provision of subsidies to agrochemicals so as to increase food production in spite of their negative environmental impact. In many developing countries, reconciliation of these two objectives—food security and environmental sustainability—will require a radical transformation of current policy objectives, including a wider dissemination of information and technical support to small-scale farmers through adequate extension services, the removal of political constraints and appropriate incentives for building stronger partnerships with a multiplicity of stakeholders, as discussed below.

Expanding support services and land reform and overcoming political obstacles to agrarian change

… along with increased investments in rural infrastructure and expanded access to credit and technology

In the context of food-insecure countries, striking a delicate balance between large productivity gains and environmental sustainability will require additional investments and improved capacities to implement national strategies for food security that lead to: an increase in access of small farmers to technology; an increase in investments aimed at expanding the rural road infrastructure and crop storage facilities; secure land tenure and improved rental agreements; expansion of rural credit and innovative mechanisms for weather-based crop insurance; and improved access to information and information and communications (ICT) technology.

To the extent that innovation is strongly associated with risk-taking, risk-reduction mechanisms need to be introduced to avert devastating losses of income of small farm holders. Grants, tax incentives, innovative insurance policies and new forms of venture capital may be able to provide this kind of protection (Leeuwis and Hall, 2010).

The institutional failures that perpetuate poverty also need to be removed

The policy challenge resides in how to mobilize the resources needed to expand the range of supportive services that are critical to improving the capacity of small farm holders to innovate and to compete in dynamic markets. Increasing investments for rural development and shifting the focus of attention towards support of small-scale farm holders will require, in many contexts, overcoming the obstacles put in the path of change by prevailing power relations (Spielman, 2005). Rural poverty and food insecurity are frequently the result of "institutional failures" (including coordination failures, land insecurity, gender discrimination and marginalization of indigenous populations), which prevent the development of more dynamic food production systems.

One of the most contentious issues in most counties is land distribution. To a large extent, low income and food insecurity among small-scale farm holders can be traced back to the lack of adequate access to land. Traditional land reform designed to improve access to land and provide support to different forms of association among farmers would help to effect economies of scale in production and, most importantly, in the marketing of food crops. However, changing land distribution practices, securing property rights and creating incentives that benefit small farm holders often require the formation of political coalitions that might challenge the status quo.

In countries like Brazil, China and India, whose Governments had chosen to prioritize poverty reduction and food security, dynamic innovation systems emerged in support of agricultural development. In other instances, the scaling up of innovative practices—inter alia, for rice intensification, for farmers' training and in the case of India, for the watershed initiative mentioned above—was possible through the endorsement by international organizations, national non-governmental organizations and local governments of new practices in support of dissemination of knowledge, greater participation by and capacity development of farmers, building of missing infrastructure and improving access to credit, information and other supportive services.

National strategies for food security and sustainable agriculture need to explicitly recognize the politico-economic obstacles to inducing a radical transformation in agriculture that is focused on improving the productive capacity of small-scale food producers.

Gender-sensitive agricultural innovation

Innovation for sustainable food security must incorporate a special focus on women

Unless policies to promote innovation in agriculture have an explicit gender focus, women will continue to be disadvantaged with respect to accessing new technologies and supportive services. Women in rural areas face major labour constraints as a result of their multiple responsibilities: besides providing traditional family care, rural women are typically responsible for fetching water and firewood, tending animals and farming the house garden and often engage in wage employment. Simple labour-saving tools (including green cooking stoves and appropriate tools for planting and weeding) and better access to water for house consumption would help ease their time constraints.

It is important in fostering the creation of a dynamic innovation system that addresses women's needs, to grasp the impact of the institutions and local values that define their role. Very often, the creation of gender-sensitive systems of innovation in agriculture will also require a radical transformation of the institutional constraints that prevent better access by women to secure land tenure, credit and technical assistance.

Innovative partnerships

Successful innovation experiences in the last 30 years demonstrate the importance of building partnerships among multiple stakeholders so as to strengthen the capacity of small-scale farm holders to access technology, inputs and larger markets. While the corporate private sector has played an increasingly important role in accelerating innovation in agriculture through a variety of mechanisms, the risk of excluding small-scale farmers is also large. Through appropriate regulation to prevent monopolistic practices in food markets, and better access to information, credits and risk insurance, small-scale farm holders would be in a better position to engage in mutually beneficial partnerships with the corporate private sector.

Appropriate regulations, technical assistance and better access to supportive services are needed to prevent inequitable partnerships

Perhaps one of the most important drivers of change in recent years lies in the transformation in food retailing. The emergence of large supermarket chains, which control between 40 and 50 per cent of the food market in Latin America, about 10 per cent in China, 30 per cent in South Africa and 50 per cent in Indonesia, has concentrated the purchase of large quantities of food subject to strict quality standards, a phenomenon that has led to the displacement of traditional wholesalers and small retail shops. For small farm holders, participating in these markets depends on their capacity to meet strict quality standards and to achieve concerted commercialization of their products through cooperatives and other forms of association. The risk of exclusion, however, is large, especially for farms in remote and difficult to access areas (Berdegué, 2005). Technical assistance to farmers in meeting with quality standards would help to expand their opportunities for participation in larger markets.

Voluntary standards and certification programmes, payments for ecological services and production value chains …

The proliferation of ethical and environmental certification processes in recent years is opening new opportunities for creating value chains that link small farm holders to larger exporting markets. For instance, voluntary standards and certification programmes in the banana industry address a wide range of issues including environmental protection, labour rights, safety and health at work, social equity and the welfare of local communities.[7] These can have substantial benefits for participating producers and traders by providing price premiums; improving market access and stability; helping to rationalize production, reduce costs, improve labour management and enhance the morale and participation of workers; improving the company image; and even aiding in the conservation of productive natural resources. Nevertheless, other types of standards aimed at food safety, quality, traceability and good agricultural practices, which are mainly developed by large firms in major markets, tend not to ensure price premiums, and may thus harm small-scale banana growers by significantly raising the costs they incur (Food and Agriculture Organization of the United Nations, 2008).

… can increase the productivity of small-scale farmers practising sustainable agriculture

Payments for ecological services with resources from businesses interested in protecting hydrologic services and Governments can play an important role in increasing the incomes of poor rural communities and maintaining ecological diversity (box III.3). However, new mechanisms for expanding payments for environmental services (PES) to small farm holders for the protection of natural resources, to conserve biodiversity and to increase carbon sequestration in agriculture and forestry need to be in place.

Box III.3

Payment for ecosystem services in Costa Rica

One approach to encouraging the conservation and restoration of forest ecosystems is to pay private landowners directly for conservation (Ferraro and Simpson, 2000). Payments for reforestation, forest management and conservation lead to improvement of the livelihoods of individuals and communities engaged in forestry.

In Costa Rica, alarming rates of deforestation in the 1970s led to the pioneering of a national-level payments for environmental services (PES) programme, facilitated by the recognition of ecosystem services in forest protection legislation in 1996. In this market-based system, landowners receive direct payments for environmental services provided by forestry ecosystems, including (a) mitigation of greenhouse gas emissions; (b) hydrologic services; (c) biodiversity conservation; and (d) provision of scenic beauty for purposes of promoting recreation and ecotourism (Malavasi and Kellenberg, 2002).

The national PES scheme is credited with having stopped the destruction of the Costa Rican rainforest and recapturing over one quarter of the country's land mass-to-forest cover in the period from 1987 to 2000. The scheme has also enhanced social development by rewarding more than 7,000 small- to medium-scale private landowners for the environmental services their property provides (Pax Natura, 2011).

In 2008, the programme's budget was close to $13 million for an area of 652,000 hectares. The programme receives funds from businesses interested in protecting hydrologic services, which are matched by government funding from a fossil fuel tax, and multilateral loans and grants (Ecosystem Marketplace, 2010).

Source: UN/DESA.

7 Among the most common standards in the banana industry are those associated with organic agriculture, the Rainforest Alliance and the fair trade movement, along with SA 8000 and ISO 14001.

Civil society organizations play an important role as intermediaries between small-scale farm holders and other groups

Civil society organizations and private philanthropies are becoming important players in the area of agricultural innovation. Most of the recent stories of innovation characterized by pro-poor and positive environmental impacts have entailed the active participation of international and national civil society organizations, which engage in different activities depending on the context: advocacy and lobbying for pro-poor institutional change in rural areas; serving as intermediaries between research and agricultural practices; capacity-building among farmers and the dissemination of information and good practices; facilitating collective action and creation of farmers' organizations for the purchase of inputs and marketing of food; aiding in the creation of value chains so as to help reduce transaction costs; protecting against risk through creation of informal safety nets for farmers; strengthening the capacity of women to participate in marketing production and innovation; and, in the case of private philanthropies, directly funding research, capacity-building and access to technology.

Each type of activity has its own dynamic which does not necessarily interlock with others. Each actor will also have its own special interests whose pursuit may not always translate into improved welfare and enhanced innovative capacity of small farm holders.

Government regulations are important for strengthening fair and dynamic partnerships

Government policies have an important role to play in enhancing the contribution of the multiple stakeholders that are part of the Sustainable Agricultural Innovation System and creating a regulatory framework to "promote trust and cooperation, delimitation of contributions and rewards, timely information on compliance of obligations, enforcement of agreements, recognition and protection of the rights of each party" (Berdegué, 2005, p. 21). While any Government's policy will have to respond to the specific context of its own country, building stronger partnerships within an SAIS will require participants to collaborate in developing a clear-cut strategy directed towards achieving the objectives of agricultural reform while ensuring that there are resources adequate for expanding rural infrastructure and supporting provision of services to small-scale farmers.

National strategies for support of education, science and technology in addressing food security

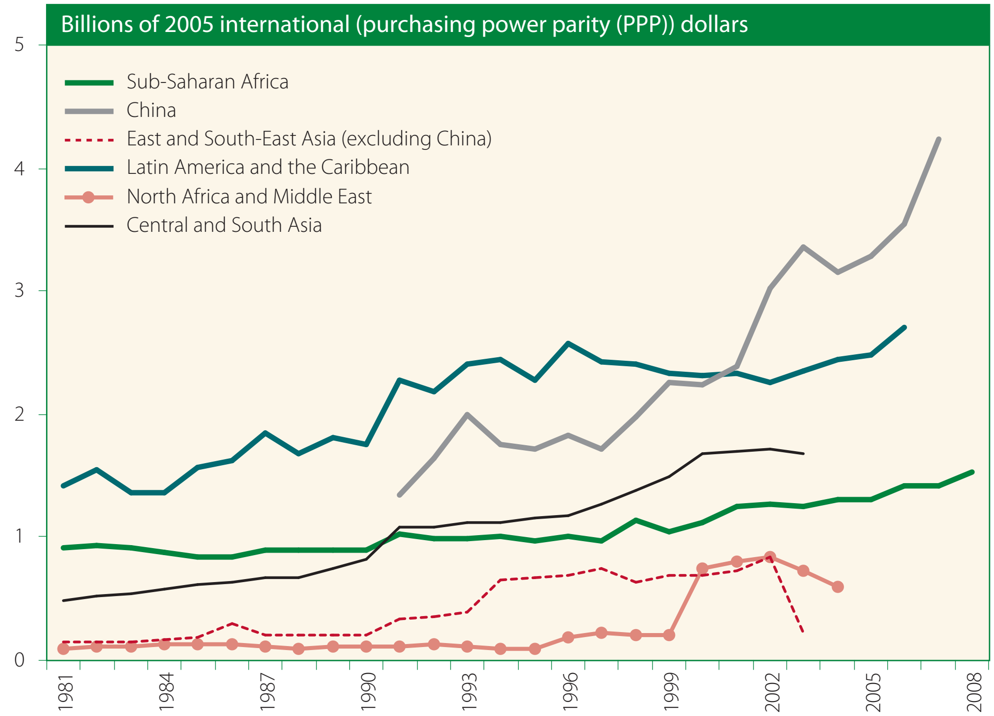
Reviving agricultural R&D

Resources for agricultural research and development are limited and highly concentrated

At the heart of the food security problem is insufficient investment support for, and public attention focused on, small-scale farmers whose food production is mostly for local consumption. Since the 1980s, international support for agricultural research has decreased and national agricultural research centres have scaled back their programmes for the production and distribution of seeds (Dubin and Brennan, 2009). Expenditures for agricultural R&D in Africa, East and South-East Asia (excluding China) and the Middle East remain low (figure III.9).

Moreover, agricultural R&D investment is largely concentrated in a few countries. In 2000, developed countries accounted for 57 per cent of total public agricultural R&D. Among developing countries in Asia and the Pacific, China and India were responsible for 67 per cent of such investments; and in Latin America, Brazil alone accounted for 45 per cent of the total. In sub-Saharan Africa, annual agricultural R&D investment had grown by 0.6 per cent in 1981-2000, contracting slightly during the 1990s (Beintema and Elliott, 2009).

Figure III.9
Public agricultural R&D investment trends in developing countries, 1981-2008



Source: UN/DESA estimates, based on Agricultural Science and Technology Indicators (ASTI), facilitated by the International Food Policy Research Institute (IFPRI) (http://www.asti.cgiar.org/data/).

While the corporate private sector has become a substantial player in agricultural R&D, especially in the production of agricultural chemical inputs, machinery and biotechnology, its focus has been centred largely on profitable research targeted towards meeting the demands of wealthy consumers and on intermediate inputs for large farmers (Ervin, Glenna and Jussaume, 2010).

National strategies for education, science and technology in agriculture need a larger supply of stable resources

While current agricultural knowledge and technology provide a range of alternatives for achieving sustainable agriculture, the adoption of new practices and technology requires additional investment in research and development to ensure adaptation to the diversity of agroecological conditions in which small-scale farm holders operate. In addition, rapidly changing climate patterns and food markets require continuous research and the development of new technology and crop management. Explicit national education, science and technology strategies are essential to accelerating productivity growth and environmental sustainability and there are three areas of development that need to be addressed by any national science and technology strategy for food security: agricultural research and development, including through the private sector; improved technical assistance to small-scale farm holders, mainly through extension services; and improved education of farmers, including innovative mechanisms for peer learning.

Agricultural research and development for food security

In drafting a national strategy for education, science and technology, it is important to have a clear picture of the agricultural research architecture so as to be able to identify the institutions currently involved, their interests, and the type of research that those institutions undertake. Such a perspective will facilitate the design of appropriate incentives to facilitate effective collaboration among scientists, farmers, the corporate private sector and non-governmental organizations. A clear mapping of the relationships among objectives, actors and resources will help to leverage existing capacities so as to facilitate the process of building dynamic Sustainable Agricultural Innovation Systems.

Public agricultural R&D for food security

Research whose goal is sustainable food security has the characteristics of a public good …

Agricultural research should consider climatic, soil and water conditions of the relevant agroecological region; technology and know-how are not easily transferable across regions without additional investment in adaptation (Pardey and Beintema, 2001). Hence, adaptation of technology to particular farming conditions should be central to the agenda of public research institutions in developing countries.

Agricultural R&D is the classic example of a public good: in the absence of public sector involvement, underinvestment in agricultural R&D will continue, especially in those areas where markets are small and consumers poor (the case of staples in developing countries is particularly relevant in this regard). The importance of farmers' capacity to innovate and adapt technology to their particular needs is widely recognized, but this has to be complemented—and is often guided—by formal agricultural R&D.

… and, as such, it requires adequate and stable financial support from Governments

Public institutions will continue to be the major source of formal agricultural R&D in developing countries; the significant economies of size, scale and scope that are achievable in agricultural research cause even private research to rely on the basic research and innovation originating in public institutions (ibid.). With few exceptions, national research institutions in developing countries lack adequate resources to operate efficiently through appropriate infrastructure, competitive salaries and research funds. Instability in operational budgets compromises their independence and capacity to operate efficiently. Agricultural research is cumulative and has long maturity cycles; discontinuity in funding and poor documentation of processes exacerbate permanent loss of knowledge. The development of a new variety of wheat, rice or corn, for example, requires 7-10 years of breeding (ibid.).

Regular allocations of public resources are important for maintaining research infrastructure and adequate salaries for scientific personnel. Funds generated internally from the sale of products and services (such as seeds and laboratory services) are becoming important in countries like Chile, China and Indonesia and may complement regular budgets. Yet the competition aimed at securing resources from different sources, which are often driven by commercial interests or by donor preferences, rather than by social and environmental concerns, leads to fragmentation of research objectives. Careful evaluation of funding sources helps to prevent diversion of research away from its focus on public goods (Echeverria and Beintema, 2009).

In addition to stable financial resources, public research institutions also require a radical change in their current linear hierarchic model of operation so as to improve their responsiveness to the needs of farmers, including through joint experimentation and learning.

In this regard, multidisciplinary teams comprising agronomists, water engineers and nutritionists are essential

Public research institutions also need to expand their traditional disciplinary approach to encompass an interdisciplinary focus in response to wide-ranging farmer demands. Transformation of diverse agroecological rural economies requires the expertise of biologists, agronomists, water engineers, nutritionists, economists and social and political scientists (Lipton, 2010). Participation of women, especially in sub-Saharan Africa where women constitute a large proportion of the agricultural labour force, will also be critical to enhancing their low levels of representation and decision-making in agricultural research and extension services and to addressing their specific needs.

Building the capacity of national public research centres is a long-term process requiring substantial and sustainable investments and radical changes in their organizational culture. Much of agricultural R&D resources in developing countries are concentrated in a few countries—Brazil, China and India—which have developed dynamic systems of innovation with capacity to engage in frontier research. In the case of small and poor countries, pooling resources to strengthen regional research agendas is perhaps the most effective option for improving their collective capacity. Promising experiences of regional and South-South agricultural cooperation include, for instance, agreements between research institutions of Brazil and China and African institutions.

Private sector research in climate-resistant crops

Through biotechnology, it may be possible to develop crops of great utility to the poor …

Rapid technological innovation for achieving food security and tackling climate change will require closer collaboration with the private sector towards expanding research in frontier areas. While the corporate private sector has increased its role in the development of technology in agriculture, we have chosen to focus attention below on private research in biotechnology, which remains controversial.

… but the research agenda needs to be expanded to include consumption crops in poor countries

Biotechnology has the potential to improve crop varieties grown by the poor, by making them herbicide-resistant, less dependent on chemical pesticides and more resilient to water stress and by conferring on them a greater nutritional value. Biotechnology may therefore be able to respond to the variety of agroecological conditions in poor and food-insecure regions, provided the current research agenda can be expanded to reflect the challenges faced by small-scale farm holders. So far, private research in biotechnology has concentrated on the development of products that can be easily protected by patents and focused mainly on building resistance to weeds and insects in profitable plants (mainly soybeans, corn, cotton and canola), which are of interest to large-scale farmers.

While it is technically feasible to expand the research agenda to better contribute to food security, independent assessments of the larger impacts of this technology are urgently needed. Biotechnology has not fully responded to concerns about long-term environmental impacts and possible spillover effects to wild plant varieties. Bt cotton[8] and corn, for example, use less herbicides and pesticides, but if these crop varieties develop resistance to the less toxic chemical herbicides and pesticides, future more toxic inputs may be required.

In addition, recent research has found that the problem of gene flow, the spread of genes from genetically engineered (GE) crops into non-GE ones, is a more serious phenomenon than was originally thought. In this case, adoption of transgenic crops could have large negative ecological implications if "GE crops are adopted more widely in developing countries where domesticated crops have wild relatives" (Ervin, Glenna and Jussaume, 2010, p. 7).

Going forward, better understanding of the consequences of transgenics based on full disclosure of information, including rigorous assessments on a case-by-case basis, will be critical to informing decisions about the deployment of this technology on a larger scale in developing countries.

One legitimate concern in exploring the potential of biotechnology to contribute to food security and sustainable agriculture is the concentration of research and products in two large firms: DuPont Pioneer and Monsanto, which account for the largest

8 Bt cotton is a genetically modified variety that is resistant to insects.

proportion of the genetically modified crop acreage in the world (Ervin, Glenna and Jussaume, 2010). The cost of seeds and inputs may discourage use of this technology by small farm holders, especially if the market continues to be dominated by a few large companies which exert influence over prices.[9]

Research in biotechnology demands closer and more direct collaboration among public research institutions, the private sector and small-scale farmers …

Yet, biotechnology can still be an effective instrument for facilitating the transformation of agriculture in poor agroecological regions with low productive capacity under current technology (namely, in parts of Africa, Central America and Asia with degraded natural resources). However, the structure of incentives and governance of innovation in this area require radical changes, which ensure, inter alia, that (a) the objectives of food production and environmental sustainability become central to the research agenda in biotechnology; (b) all stakeholders, but especially small farm holders, can actively participate in shaping the research agenda; (c) scientific researchers consider the needs of small farm holders, consumer tastes and the characteristics of local markets and contexts; (d) there is full disclosure and an open flow of information; (e) peer reviewing to assess the possible unintended environmental consequences of biotechnology is practised; and (f) effective antitrust regulation is put in place (Wright and Shih, 2010).

… through innovative partnerships, including patent buyouts, prizes, joint ventures, co-financing and advance-purchase agreements

While there are no simple answers in this regard, publicly funded research should maintain an explicit focus on strategic priorities for food security, including improving yields and resistance of staples, improving the nutritional value of crops, facilitating sustainable use of natural resources and/or reducing the use of external chemical inputs. Innovative mechanisms designed to engage the private sector need to be explored: results-based performance contracts—for the development, for example, of improved seed or crop varieties with higher water-stress tolerance and greater responsiveness to fertilizers—granted on a competitive basis may be one means of stimulating private research. Patent buyouts, prizes and proportional prizes may be other means of doing so (Elliot, 2010; Bhagwati, 2005). Use of more traditional subsidies, co-financing arrangements and joint ventures should also be explored, within a framework of appropriate protocols for maintaining the public-good nature of research products (Pardey and Beintema, 2001).[10]

While it still needs to be tested in agriculture, the 2010 Advanced Market Commitment mechanism for the production of vaccines, whereby donors made a large advance purchase at a predetermined price in order to induce participation by large pharmaceutical companies, may offer significant lessons relevant to the effort to stimulate private research and technological innovation for food security.[11]

More generally, building partnerships with the corporate private sector is important, but in the specific case of food security, Governments and public research institutions in developing countries need to be fully involved in setting the research agenda, including comprehensive risk assessments and suitable regulations on the use of new technologies (Lipton, 2010).

---

9 Seed prices have increased by 30 per cent since 1996 when GE seeds were introduced, a price increase higher than that for any other input (Ervin, Glenna and Jussaume, 2010).

10 One of the problems connected with current associations between private companies and public universities is that the research products are often protected by the copyrights held by the private companies that have co-financed the research.

11 The Governments of Canada, Italy, Norway, the Russian Federation and the United Kingdom of Great Britain and Northern Ireland and the Bill and Melinda Gates Foundation signed an agreement with GlaxoSmithKline and Pfizer, Inc., by which the firms committed to supplying 30 million doses of vaccines each year for 10 years at a reduced price for developing countries, provided donors made additional payments for 20 per cent of the doses. See http://www.gavialliance.org/media_centre/press_releases/2010_03_23_amc_commitment.php (accessed 6 February 2011).

Technical support and extension services

The second pillar of an effective strategy for promoting education, science and technology in agriculture is the dissemination of information and technology, which during the green revolution, was mainly carried out by agricultural extension workers. In the current context, a larger number of actors (civil society organizations, the private sector, farmers and multilateral organizations) contribute towards this end.

Large-scale extension services in agriculture are important for effective technological adaptation

A survey conducted by the Global Conference on Agricultural Research for Development (GCARD) estimates that about one half billion agricultural extension workers exist globally, most of them being public workers. Although the number appears large, the general perception is that it is inadequate, especially when measured against the needs of small-scale farm holders who, for the most part, have been deprived of the services of such workers (Lele and others, 2010). Agricultural extension workers who have no particular interest in promoting the use of commercial products are still an important vehicle for the transmission of knowledge, information and training for small farm holders, provided that they have adequate training themselves, a clear mandate and appropriate incentives to perform their job.

… with special attention to female farmers

Exclusion of women from technical support needs to be explicitly addressed. In Africa, women receive 7 per cent of agricultural extension services and less than 10 per cent of credit offered to small-scale farm holders.[12] Moreover, inasmuch as educational curricula tend to exclude topics with particular relevance to women (such as nutrition, sanitation, hygiene, gender-specific tools and management), gender analysis and targeted initiatives must be incorporated in agricultural education, research and extension services (Davis and others, 2007).

In Ethiopia and Mozambique, for example, inadequate resources for expanding research and training facilities and retaining faculty members have compromised the quality of education received by students. Graduate education is more conceptual in nature than managerial and practically oriented and has thus failed to nurture innovative capacity among farmers in the range of services required to improve production and marketing, including their capacity for collective action (ibid.).

In India, a country with a long tradition of promoting agricultural R&D, Hall and others (1998) found little interaction occurring between scientists and extension service providers, or between production and post-harvest scientists. Institutional segregation by discipline and highly centralized management obscure the relevance of technical support to farmers and the building of partnerships among public agricultural R&D institutions, the private sector, farmer associations and civil society organizations. Scientists and extension service workers often have fairly fragmented perspectives on production and marketing and have been unable to make practical use of research findings and knowledge.

A longer-term commitment to providing adequate funding for public research and training needs to be accompanied by a new approach to technical education—one that is more practical in nature and oriented towards problem-solving and decision-making, and with greater capacity to involve farmers and civil society organizations in finding interdisciplinary and creative solutions to new problems.

12 New Agriculturist, "Gender revolution: a prerequisite for change" (July 2008). Available from http://www.new-ag.info/focus/focusItem.php?a=493.

Basic education and peer learning

Formal and informal education and peer learning are essential for strengthening the innovative capacity of farmers

The third pillar of an effective sustainable agricultural innovation system is basic education and adult literacy and training. The ability of farmers to innovate, learn from one another and adapt to change largely depends on their capacity to access and process information including through information and communications technology. Rapid expansion of quality education in rural areas, including adult literacy and training, should receive the highest priority in any strategy aimed at strengthening farmers' responsive capacity to rapidly changing agroecological and market conditions. Flexible land management and the capacity to innovate in production, storage and marketing practices and techniques require appropriate use of information and technology as part of a continuous learning process (Davis and others, 2007).

More innovative mechanisms for the transmission of knowledge and training also need strengthening. The experience of the Farm Field Schools—operating in 87 countries—shows that innovation and flexible natural resource management can be advanced through farmer-to-farmer learning, with participation from formal and informal research institutions (see also box III.1). In-service and on-the-job training and distance education have also proved effective and are increasingly complementing extension services.

Beyond rural education

Education aimed at changing behaviour is also important in respect of reducing waste and promoting the adoption of sustainable diets and consumption practices

Education is also central to bringing about the requisite societal transformation needed to ensure food security and protect the environment. Formal and informal education, extension services, advertising and information campaigns, and political and civil society mobilization are important means of creating more sustainable food production and consumption patterns.

On the production side, farmers need to be informed and trained and stimulated to adopt more sustainable practices. However, the challenge of feeding a rising and increasingly affluent population also requires behavioural changes in terms of consumption, including dietary patterns. In particular, the livestock sector, which has grown rapidly to meet the increasing demand for meat, is a prime cause of water scarcity, pollution, land degradation and greenhouse gas emissions. This has prompted calls for support for vegetarian diets.[13] However, the nutritional importance of animal protein, particularly in developing countries, and the differences, in the context of production efficiency and environmental impact, between different types of livestock,[14] may warrant, instead, warnings against consumption of red meat and dairy products (Godfray and others, 2010b). Publicity, advocacy, education and even legislation can also be used to bring about ideological, cultural and behavioural changes so as to reduce high levels of retail and domestic food waste in the developed world.

Building new institutions that pave the way towards sustainable agriculture and food security by strengthening the multiple nodes of the SAIS and changing behaviours is

13 See David Batty and David Adam, "Vegetarian diet is better for the planet, says Lord Stern", 26 October 2009. Available from http://www.guardian.co.uk/environment/2009/oct/26/palm-oil-initiative-carbon-emissions (accessed 14 March 2011).

14 According to certain estimates, cattle (under intensive production) consume 114-125 litres of water per animal per day compared with 1.3-1.8 litres in the case of chicken; cattle require 8 kilograms (kg) of cereal per animal to produce 1 kg of meat compared with a 1 kg feed requirement for chicken (Food and Agriculture Organization of the United Nations, 2006; Intergovernmental Panel on Climate Change, 2007b). The dairy and beef sector of the United Kingdom accounted for over 24 metric tons of carbon dioxide equivalent ($MtCO_2e$) of CH_4 and N_2O emissions in 2005, compared with 2 $MtCO_2e$ from the poultry sector (Radov and others, 2007).

a long-term process requiring commitment of resources, a clear vision of the overall direction of change, and capacities to adapt to a changing environment. National strategies to achieve food security and sustainable agriculture will help Governments ensure consistency in typically decentralized agricultural innovation systems, and help guide the direction of donor resources and private sector investments. Without this minimum framework, rural structural change may not occur in time to prevent irreversible human and environmental damage to the current food production and consumption systems.

Regional and global partnerships for food security and environmental sustainability

Payments for environmental services and better regulation of commodity markets could facilitate international cooperation towards food security and environmental protection

The international community has much to contribute to a global agenda for food security and environmental sustainability. Chapter VI examines the challenges associated with international cooperation in various areas. In the case of agriculture and sustainable land management, delivering on the financial pledges made in the aftermath of the food crisis of 2007-2008 would constitute a good down payment on realizing the commitment to the goal of eradicating hunger. Other areas where international action can be expected include:

- Reform of agricultural subsidies in OECD countries, including subsidies to biofuels, and support to new-generation biofuels to reduce the diversion of agricultural land use from food production.
- Increased international investment in agricultural R&D for food security with private sector participation in development. Adequate funding for the effective functioning of CGIAR during the green revolution was critical to facilitating rapid innovation through proactive adaptation and dissemination, often with supportive and facilitative (subsidized) public provisioning of infrastructure and other needed inputs. Reconstituting the global, regional and national capacities for agricultural R&D with international financial support can result in the generation of a rapid increase in agricultural productivity.
- New financing mechanisms to expand payments to small farm holders in developing countries for environmental services (PES) that help protect natural resources, to preserve biodiversity and to increase carbon sequestration in agriculture and forestry.
- Elimination of non-tariff barriers to food trade which prevent the expansion of markets to include small-scale producers in developing countries.
- Adoption of green/ecological footprint standards.
- Effective regulation of commodity futures markets to avert speculation with food prices.

In the very short term, preventing export bans on food crops and panic buying in response to weather-related catastrophes would help to reduce large price spikes. In addition, mechanisms to protect vulnerable populations utilizing safety nets and food assistance are necessary in order to reduce the impact of increasing food prices. Building global grain reserves may be an option in responding to food emergencies but the management and deployment of assistance require closer scrutiny so as to ensure an effective emergency response and to avert longer-term negative impacts on local food production systems.