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How to Feed the World and Save the Planet

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Summary

Global food prices have more than doubled over the past decade, reaching unprecedented highs. Increased prices have made food less affordable to many and exposed deep structural flaws in the global food system. Meanwhile, the increase in food production necessary to meet the needs of a rapidly expanding population will—under current technologies and practices—lead to further environmental destruction in the form of greenhouse gas emissions (GHG), water pollution, and land degradation.

Meeting the double challenge of expanding global food production while ensuring environmental sustainability will therefore require a major technological transformation in agriculture. In this endeavor, valuable lessons can be learned from the so-called green revolution of the 1960s and 1970s, which helped boost agricultural productivity worldwide. However, the green revolution did not conduce to a sustainable management of natural resources or to food security for many of the world's poor. A “truly green” revolution in agriculture is hence needed—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 support measures.

A wealth of technologies and practices in agriculture is currently available to spearhead the radical transformation needed to increase food production in a sustainable manner. However, the current policy environment has not supported the adoption of such sustainable agricultural technologies and practices at a large scale. Instead, a much more radical, systemic and integrated policy

approach is needed to promote sustainable food production at both national and international levels.

The transformation of agriculture so as to increase its productivity, profitability, resilience, and sustainability requires long-term support by governments. Increased state funding is needed toward agricultural research and development (R&D), rural education and extension services, improved rural infrastructure, and enhanced market access, as well as better distribution of land and other productive assets.

The international community also has much to contribute to a global agenda for food security and environmental sustainability. Donors need to honor existing commitments toward food security, as well as mobilize additional resources for R&D and for climate change mitigation and adaptation in the agricultural sector. International action is also needed to reform agricultural policies in Organisation for Economic Co-operation and Development (OECD) countries, including subsidies to biofuels, nontariff measures on food trade, and regulation of commodity futures markets.

The twin perils of global food insecurity and environmental degradation

Persistent global food insecurity

The 2007–8 global food crisis, as well as the renewed increases in food prices contributing to the 2011 food crisis in the Horn of Africa, 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. As of 2012–14, a total of 805 million people, or around one in eight people in the world, were estimated to be suffering from chronic hunger—regularly not getting enough food to conduct an active life (FAO, IFAD, and WFP, 2014).

The overwhelming majority (98%) of the world's undernourished people live in developing countries, with close to two-thirds of them concentrated in seven nations (Bangladesh, China, the Democratic Republic of the Congo, Ethiopia, India, Indonesia, and Pakistan). Most hungry people (526 million) reside in Asia, although the highest share (24%, or 214 million people) is found in Sub-Saharan Africa (FAO, IFAD, and WFP, 2014).

While the estimated overall number of undernourished people has dropped since 1990, the rate of progress is insufficient to meet the international target

for hunger reduction set at the 1996 World Food Summit (WFS) of halving the *number* of undernourished people in the world by 2015. Developing countries as a group have only made modest inroads toward meeting the WFS target: the number of undernourished people declined by 20 percent since 1990–92. More encouragingly, the less ambitious Millennium Development Goal (MDG) hunger target of halving the *proportion* of undernourished people appears within reach: the share of hungry people decreased from 23 percent in 1990–92 to 14 percent in 2012–14 (FAO, IFAD, and WFP, 2014) (Figure 7.1).

Despite overall progress, marked differences across regions and countries persist (Figure 7.2). Sub-Saharan Africa remains the region with the highest prevalence of undernourishment, with some improvement in recent years. While the share of undernourished is lower in Western Asia than in most other regions, it is nevertheless the only region that has registered an increase since 1990–92. The most significant reduction in prevalence of undernourishment has occurred in Southeastern Asia, with a decline from 31 to 10 percent.

Figure 7.1 Undernourishment in the developing regions: Actual progress and target achievement trajectories toward the MDG and WFS targets

Note: Data for 2012–14 refer to provisional estimates.

Source: FAO, IFAD, and WFP (2014).

Figure 7.2 Undernourishment trends by region

Source: FAO, IFAD, and WFP (2014).

Impact of high food prices

Rising food prices, partly attributable to adverse climatic conditions, have been the main driver of the 2007–8 and 2010–11 food crises. Global food prices have more than doubled over the past decade, reaching record highs in 2007–8 and 2010–11 (Figure 7.3). International prices for corn, wheat and rice more than doubled between 2006 and 2008. While prices declined in late 2008, food prices then rebounded, attaining new record highs in February 2011. Despite conflicting evidence, it would appear that recent price increases have also been accompanied by higher volatility, which increases uncertainty, thereby hindering investment in human and physical capital, technology, and innovation (FAO, 2009).

The severe impact of the 2007–8 food crisis on living conditions was attested by the riots that broke out in over thirty countries. Increasing food prices have had a particularly negative impact on the poor who spend 50–70 percent of their income on food (von Braun, 2009). It has been estimated that higher food prices pushed a further 150 million people into poverty between 2007–10 (World Bank, 2008c; 2011).

In assessing the causes of the recent food crises, these have exposed deep structural flaws in the world food system. Although increased financial activity in commodity future markets may have amplified short-term price fluctuations, the global food price spikes have been the result of a long-term structural imbalance in the demand and supply for food. Demand for food has risen owing to continued global population growth, rising incomes, altered dietary

Figure 7.3 Food price indices (2002–4=100), annual averages, 1990–2014

Source: FAO <http://www.fao.org/worldfoodsituation/foodpricesindex/en/>.

patterns, and trade policies. At the same time, however, agricultural output has failed to keep pace with growing consumption due to competition for land, adverse climatic conditions, biofuel policies, high energy prices, and dwindling agricultural production and investment.

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

The aforementioned shortfall of agricultural supply is likely to persist, aggravated by the need to double food production by mid-century in developing countries in order to feed a rapidly expanding population (Bruinsma, 2009). Limits to the expansion of cultivated land area means that some 80 percent of the projected growth in food output in developing countries would need to derive from intensification of crop production (Bruinsma, 2009). With current agricultural technology, practices, and land-use patterns, this cannot be achieved without further contributing to environmental destruction in the form of GHG emissions, land degradation, biodiversity loss, water scarcity, and pollution. But the consequent environmental damage will, in turn, undermine long-term food productivity growth. Unsustainable agriculture and land management can thus also lead to negative socioeconomic consequences including food insecurity, poverty, migration, gender inequality, and ill health (IAASTD, 2009).

Attempting a closer look at the environmental impact of unsustainable natural resource management, the past half-century has witnessed shrinkage in the availability of natural resources, which has occurred more rapidly than in any comparable time in history.

The issue of land degradation is among the world's greatest environmental challenges. Defined as a long-term decline in ecosystem function and productivity, land degradation is driven mainly by poor land and water management, including overcultivation, overgrazing, deforestation, and inadequate irrigation (Berry, Olson, and Campbell, 2003). The phenomenon of land degradation is increasing, in severity and extent, in many parts of the world, with about 40 percent of the world's land surface degraded (25% has been degraded over the past quarter-century alone) (Bai et al., 2008).

Land degradation, driven by unsustainable natural resource management, in turn has negative effects on the climate, biodiversity, water ecosystems, landscape, and other ecosystem services. As summarized in Table 7.1, agriculture and land degradation contribute significantly to the problem of climate change, by generating GHG emissions leading to warming, as well as impacting land surface albedo and creating adverse weather patterns. Notwithstanding significant uncertainty in estimates, the agriculture, forestry, and other land use sector accounts for 24 percent of emissions of GHGs, the second largest emitter following the energy sector (IPCC, 2014a). The most important source of GHG emissions in agriculture is methane (CH_4) emissions from enteric fermentation in livestock and nitrous oxide (N_2O) emissions from synthetic fertilizer application. Deforestation and forest degradation in developing countries are the primary sources of carbon dioxide (CO_2) emissions from these countries, accounting for 35 percent of CO_2 emissions in developing countries and 65 percent in least developed countries (United Nations, 2009). GHG emissions from agriculture, forestry, and fisheries have nearly doubled over the past fifty years and are forecasted to increase by an additional 30 percent by 2050.²

In addition, increasing and competing demands for water have led to serious depletion of water resources (Smakhtin, Revenga, and Döll, 2004). Agricultural irrigation accounts for some 70 percent of all water withdrawals. Moreover, it appears that water quality has been degraded partly owing to intensive agriculture, which makes excessive use of agrochemicals (pesticides and fertilizers) and 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 et al., 2006).

Table 7.1 Global environmental impacts of land degradation

Environmental component/process	Bases of impact of land degradation
Climate change	<ul style="list-style-type: none"> • 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 (CH₄) and nitrous oxide (N₂O) emissions. • Land surface change (for example, as regards to 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	<ul style="list-style-type: none"> • Deforestation leads to loss of habitat and species. • Land-use change and management, including fragmentation and burning, lead to loss of habitat and biodiversity. • Nonpoint pollution from crop production damages aquatic habitats and biodiversity.
Water resources	<ul style="list-style-type: none"> • 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.

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

The past century has also seen the greatest loss of biodiversity through habitat destruction, primarily through the conversion of forests for agriculture. The problem of deforestation is particularly severe in the humid tropics (Moutinho and Schwartzman, 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 percent of the world's forests (University of East Anglia, Overseas Development Group, 2006). Over the 2005 to 2010 period, 3.6 and 3.4 million hectares of forest per year were lost in South America and Africa, respectively.³

The spread of industrial agriculture has also promoted the simplification of agro-ecosystems, with reductions in the number of and variety of species. Moreover, overexploitation of marine resources is so severe that an estimated 20 percent of freshwater fish species have become extinct (Wood, Sebastian and Scherr, 2000), while certain commercial fish and other marine species are threatened globally (IAASTD, 2009).

In addition to negative environmental impacts, unsustainable natural resource management also has adverse socioeconomic impacts. In particular,

land degradation can lead to substantial productivity losses, thereby posing risks to food security.

Importantly, agriculture—albeit a contributor—is also vulnerable to the effects of climate change, with changes in temperature and precipitation affecting the timing and length of growing seasons and yields (Agrawala and Fankhauser, 2008). Evidence already points to the negative impact of climate change on net global yields of maize and wheat (IPCC, 2014b). Extreme weather events also have a negative impact on agricultural production. Recent food price spikes and supply shortages caused by exceptional conditions of drought in the Russian Federation, Ukraine, and countries in East Africa, as well as floods in Pakistan, Australia, and the United States, are *prima facie* evidence of the catastrophic impacts of adverse climatic conditions, possibly related to climate change.

Looking ahead, with temperature rises, crop productivity is forecast to decrease in both tropical and temperate regions. For instance, it is estimated that in Africa and South Asia, average crop yields could fall by 8 percent and fisheries by 40 percent by 2050 (Knox et al., 2012; IPCC, 2014b). While yields may increase in some high latitude areas such as China and the UK, overall decreases are predicted to offset any increases even with only moderate warming (Knox et al., 2012). By 2080, 600 million additional people could be at risk of hunger as a direct consequence of climate change (UNDP, 2007).

Aside from food insecurity, the degradation of arable land is a predominant factor in the migration of people. Use of inorganic fertilizers and pesticides and the spread of pests and livestock diseases can further adversely affect human health (IAASTD, 2009). Natural resource degradation can also exacerbate gender inequalities by increasing the time requirement for fulfillment of female traditional responsibilities such as food production fuel wood collection, and soil and water conservation.

Current efforts to promote sustainable agriculture among small-scale farmers

The analysis thus far 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. 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.

The reality that up to 90 percent of the food consumed in developing countries is locally produced, mostly by small-scale farmers. According the latest estimates family farms produce over 80 percent of the world's food (FAO, 2014). Smallholder farmers are at the heart of both the challenge of and solution to food security and environmental sustainability. Combating poverty and hunger in a sustainable manner will therefore require not only a radical transformation in the use of technology in agriculture and the management of natural resources but also a profound change in the focus of development strategies on agriculture to improve the productive capacity and livelihoods of people in rural areas.⁴

In assessing current efforts to boost sustainable food production, while there have been some notable developments in the right direction, these have nevertheless tended to be localized in nature and far from sufficient.

The green revolution in the 1960s and 1970s

Commendable efforts responding to widespread poverty and food insecurity date back to the 1960s and 1970s, when developing countries and donors pursued policies that induced a dramatic rise in agricultural productivity and production. Nevertheless, these policies did not have universal reach and came at a cost to the environment.

The so-called green revolution policies 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 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 (IFPRI, 2002). In Asia, annual cereal production doubled 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 centers, coordinated by the Consultative Group on International Agricultural Research (CGIAR) and sustained with adequate funding from developed and

developing countries and private donors. These centers sustained research operations, gene banks, and nursery programs in an environment of open and free exchange of information and plant genetic materials (Dubin and Brennan, 2009). The budgets available to CGIAR centers 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 agro-ecological conditions in terms of climate, soil, weeds, and pests, most notably Sub-Saharan Africa, and where the consumption of staples was more diversified. Also, the technology arising from the green revolution was based on intensive use of fertilizers, chemical pesticides, and water, which had negative environmental impacts.

Local innovation in agriculture

While the technology and innovation of the 1960s–70s green revolution was underpinned by a concerted international research effort, current approaches to technological innovation for sustainable agriculture tend to be more localized in nature, arising from the capacity of farmers and rural communities to innovate in response to weather and other shocks.

Indeed, there is a wealth 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 (see, for example, Pretty et. al., 2006). Yet, prevailing conditions typically prevent the widespread use of these experiences.

Nevertheless, there are several well-known exceptions with large-scale impacts, including the integrated pest management (IPM) approach, the Farm Field Schools (FFS), the System of Rice Intensification (SRI), the networks of millers, and politicians that popularized the use of New Rice for Africa (NERICA), the diffusion of micro-irrigation in Bangladesh, and watershed management in India (Hall et al., 2010; Brooks and Loevinsohn, 2011). Common features among these widespread efforts in sustainable agriculture intensification include extensive experimentation to adapt to the variety of local contexts with explicit support from governments, multilateral and civil

society organizations, and with direct involvement of local farmers, including women, in donor-led initiatives.

In addition, contrary to the green revolution, which relied on the wide-scale adoption of a single “technical package,” in today’s context there is no single “technical solution” toward greater agricultural productivity and environmental sustainability. Instead, a whole range of technical options need to be made available to a large number of small-scale producers in very different agro-ecological regions.

A wealth of technologies and sustainable practices in agriculture is currently available to spearhead the radical transformation needed to increase food production without a major expansion of cultivated areas and a further depletion of natural resources.

The menu of existing technological options includes traditional technologies and practices which have been successfully adopted with important productivity and environmental gains. Examples include low-tillage farming, crop rotation and interplanting, green manure utilization, agroforestry, integrated pest management, water harvesting and water-efficient cropping.

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

Modern technologies such as biotechnology, genetic engineering, food irradiation, hydroponics, and anaerobic digestion also provide complementary options to improve the resistance of food crops to pests and extreme weather, increase their nutritional value, and reduce food contamination and greenhouse gas emissions. More research is needed, however, to adapt crops and processes to local conditions and to the needs of the poor.

Overall, although a wide range of sustainable agricultural technologies and practices already exist, the policy challenge is to identify and support the scaling-up of local instances of agricultural innovation and make available appropriate technical options to farmers in poor and food insecure countries and regions.

Policy responses to the food crises

The previous analysis highlights the need for an enabling policy environment to address the issues of food insecurity and environmental degradation. This requires both short-term policy responses to scale up and improve humanitarian

relief to alleviate hunger and starvation, as well as longer-term action to expand resources and foster innovation in agriculture to accelerate food production in a sustainable manner.

The recent food crises induced policy reactions at national and international levels. National governments responded to the 2007–8 global food price crisis with a range of mainly short-term policy measures including import tariff reductions, price controls, export restrictions, stock reductions, and food programs. A study evaluating such responses in ten emerging economies revealed the importance of providing targeted safety nets for the poor as emergency responses to food shortfalls.

The international community also reacted to the food crises with emergency food assistance. For instance, in the case of the 2011 food crisis and famine unfolding in the Horn of Africa, the United Nations World Food Programme (WFP) led a humanitarian response targeting about 8 million drought-affected people.

Importantly, the food crises have also prompted greater global political attention. For example, at the G8 Summits in Hokkaido Toyako in 2008 and L'Aquila in 2009, donors pledged to provide \$10 billion in Official Development Assistance (ODA) to fight hunger and \$20 billion over three years to address food insecurity in a sustainable manner (Group of 8, 2009). The 2012 G8 Summit in Camp David saw the launch of the “New Alliance on Food Security and Nutrition,” which focuses on private sector investment in production and innovation. At the 2012 G20 Summit in Los Cabos a further “AgResults” initiative was launched to promote innovation in agricultural products and systems (OECD, 2012a). In addition, the UN Secretary General has afforded top priority to eliminating hunger through the launch of the “Zero Hunger Challenge,” and he launched the “Global Alliance on Climate-Smart Agriculture” at Climate Summit in September 2014.⁵ These new donor-led initiatives complement existing ones, such as the “Alliance for a Green Revolution in Africa (AGRA),” founded by the Rockefeller and the Bill & Melinda Gates Foundations.

Despite such welcoming developments, current national and international efforts are insufficient to address the magnitude of the challenge of food insecurity and depletion of natural resources. This is to a large extent owing to the limited public investment and foreign aid directed toward agriculture in recent decades. For instance, only a handful of signatory countries have achieved the 10 percent national budget allocation to agriculture as prescribed by the 2003 Maputo Declaration on Agriculture and Food Security in Africa (Fan et al., 2009). Furthermore, foreign aid to agriculture and rural development

has fallen from almost a quarter of sector-allocable aid in the mid-1980s to less than 10 percent in 2009–10 (OECD, 2012b). Dwindling resources for agriculture has also translated in decreased international support for agricultural research, alongside the scaling back of by national agricultural research centers of their programs for the production and distribution of seeds (Dubin and Brennan, 2009). Moreover, what limited resources are allocated to agricultural research and development (R&D) tend to be concentrated in a few major developing countries (Beintema and Elliott, 2009).

More generally, past policies have failed to *jointly* address the twin challenges of food insecurity and environmental degradation. Hence, policies aimed at reducing hunger may have focused on means of increasing agricultural productivity and production, without explicitly addressing sustainability concerns. With respect to policies aimed at adapting to the impacts of climate change, such measures have tended to focus on short-term on-farm agronomic changes, with limited efforts—and a lack of research on options—for more systemic and transformational adaptation.

National strategies for food security and sustainable agriculture

The sustainable agricultural innovation system (SAIS) framework

The preceding section demonstrated that current policies to foster agricultural innovation are insufficient and piecemeal in nature, and therefore unlikely to have an impact at a large scale, at the scale required to reach the goal of achieving food security with an environmentally sustainable agriculture. Instead, a much more radical, systemic, and integrated policy approach is needed to promote sustainable food production at both national and international levels.

In this endeavor, a sustainable agricultural innovation system (SAIS)—recognizing the dynamic nature of learning and innovation and the multiplicity of actors engaged in the innovation process and the institutional contexts within which they interact—provides a useful framework for policy making.

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 they interact, and the dynamics of learning and institutional change (Spielman, 2005). The

SAIS perspective also serves to underline that the concept of innovation extends beyond technological solutions in production to also encompass innovation in processes, products, and marketing, as well as innovative partnerships, policies, and forms of governance of natural resources (for instance, by emphasizing the participation and empowerment of small-scale and poor producers).

An innovation systems perspective enables the recognition of the evolutionary nature of innovation, and hence of the need for a new technological revolution in agriculture to build on the rich experiences of innovation in the last thirty years. The policy challenge is how to move beyond the recognition of a multiplicity of innovative experiences, toward the design of policies to expand, transfer, adapt and/or disseminate the plethora of existing technological approaches so as to reduce poverty, hunger, and environmental destruction.

In designing suitable policies and incentives to stimulate innovation among small-scale farmers to increase sustainable food production, the direct involvement of farmers in learning and innovation is seminal for adapting knowledge, technology, and management practices to the local context. Moreover, active participation by various actors including governments, nongovernmental organizations, and multilateral organizations can be 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. Importantly, technical knowledge needs to be made relevant and accessible to small-scale farmers and be 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).

Some useful lessons to be learned from the past experience of the green revolution include: (a) the development of new technology requires long-term financial support for R&D and effective and free flowing 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 easy access to inputs, credits, and markets; and (c) innovations in agriculture require long-term commitments from national governments and international stakeholders.

On the whole, building new institutions that pave the way toward sustainable agriculture and food security by strengthening the multiple nodes of the SAIS and changing behaviors is 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.

National strategies for sustainable food production

National governments have a critical role in designing and implementing policies and incentives to stimulate innovation to increase food production in a sustainable manner. In particular, governments have an important part to play in pursuing food security as an integral part of their national development strategies; channeling resources toward agriculture (including investment in agricultural research and development); expanding access to technology and information (including through rural education, extension services, and technical training); improving market access (including for credit, inputs, and insurance); building and maintaining rural infrastructure (including roads, storage facilities, and irrigation systems); providing social safety nets; securing property rights (including land redistribution); and encouraging coordination among multiple stakeholders (including through public-private partnerships).

Integrated national development strategies

As mentioned, sustainable agriculture to achieve food security needs to be an explicit component of countries' national development strategies, including the identification of financial resources to expand agricultural research, rural infrastructure, and supporting services to small-scale agricultural producers.

A holistic, cross-sectoral approach should consider trade-offs and build on synergies between sectors and objectives, to prioritize and promote technically available and economically feasible options that ensure food security, poverty reduction, and environmental sustainability. For instance, an integrated national development approach should recognize conflicts and promote synergies between forests and agriculture. In view of their competitive land uses, many solutions, involving difficult choices, can be reached through open and inclusive discussion and negotiation. However, the potential synergies among the sectors (resulting, *inter alia*, in reduced land degradation and increased productivity) present important "win-win" options through better resource management facilitated by an enabling institutional environment.

Investment in agricultural R&D

Governments committed to end hunger while protecting the environment need to allocate sufficient resources toward the agricultural sector. In particular, there is a need to halt and reverse the pattern of shrinking resources for agricultural R&D, including for the adaptation of technology to local conditions.

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 R&D to ensure adaptation to the diversity of agro-ecological 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. The intensification of research efforts to breed new crops, and the development and adaptation of new technology to increase sustainable food production require significant long-term public and private funding for agricultural R&D.

In addition to sustainable financial resources, the model of operation of public research institutions also needs to become more flexible and inclusive so as to improve their responsiveness to the needs of small-scale farmers, including through joint experimentation and learning. 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 agro-ecological 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 labor 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 centers is a long-term process requiring substantial and sustainable investments and radical changes in their organizational culture. 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.

Furthermore, rapid technological innovation for achieving food security and tackling climate change will require closer collaboration with the private sector toward expanding research in frontier areas.

For instance, in the case of biotechnology, a legitimate concern relates to the concentration of research and products in few large firms (namely, DuPont Pioneer and Monsanto) that exert influence over prices. The high cost of seeds and inputs may prohibit use of this technology by small farm holders. Yet, biotechnology can still be an effective instrument for facilitating the transformation of agriculture in poor agro-ecological 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 the objectives of food production and environmental sustainability become central to the research agenda in biotechnology.

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 (Bhagwati, 2005; Elliot, 2010). 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).

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).

Provision of rural education and extension services

In addition to higher investment in agricultural research and development, increased awareness and the accelerated adoption of sustainable technologies and crop management practices will require wider dissemination of information and information and communications technology (ICT) through quality education in rural areas and adequate extension services.

The dissemination of information and technology in the rural sector has traditionally be 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 toward this end.

It has been estimated that about half of a 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 et al. 2010). Agricultural extension workers, free from any 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. It is therefore vital that governments continue to provide quality rural extension services at a large scale to address the specific needs of famers.

Exclusion of women from technical support needs to be explicitly addressed. In Africa, women receive 7 percent of agricultural extension services and less than 10 percent of credit offered to small-scale farm holders. 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).

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 toward 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.

While technical education and training is vital for the adoption of new farming methods and technologies, this needs to be accompanied by investment in basic education in rural areas, including adult literacy. 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 rural education, including adult literacy and training, should receive the highest priority in any strategy aimed at strengthening farmers' responsive capacity to rapidly changing agro-ecological and market conditions.

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

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 behavioral 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 GHG emissions. This has prompted calls for support for vegetarian diets. 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, may warrant, instead, warnings against consumption of red meat and dairy products (Godfray and others, 2010). Publicity, advocacy, education, and even legislation can also be used to bring about ideological, cultural, and behavioral changes so as to reduce high levels of retail and domestic food waste in the developed world.

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

Aside from the aforementioned emphasis on agricultural research, education, and training, achieving the goals of food security and environmental sustainability will further require complementary government policies. These include building rural road infrastructure and crop storage facilities; improving access to input and product markets; expanding rural credit and innovative mechanisms for weather-based crop insurance; securing land tenure and improved rental agreements; and ensuring adequate social safety nets.

Major policy transformations are needed to strengthen the systems of agricultural innovation and increase resources for rural development and

sustainable natural resource management. 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 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 toward 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.

A related issue concerning access to land involves the increased purchases of farmland by foreign investors, which has resulted in the favoring of exports over domestic food production. An estimated 56 million hectares of land in developing countries were bought by foreigners in 2009, a tenfold rise from the previous decade, with two-thirds of these sometimes controversial “land grabs” occurring in Africa (Deininger et al., 2010). Improved national dialogue and empowerment of communities and traditional small-scale farmers is essential in countries engaged in land leasing to foreign investors. A full evaluation of the impact of land grabbing needs to be part of any long-term contract to avoid the displacement of small-scale producers (often using land with no formal titles) and the invasion of community land used to support rural livelihoods. Additional support to countries engaged in long-term land leasing to foreigners is also important to develop the mechanisms for the enforcement of contracts, especially in areas related to employment creation, infrastructure development,

and the transfer of technology. A full evaluation of the developmental impact of land grabbing needs to be incorporated in countries' decisions and national strategies for food security in a process of open and effective consultation with potentially affected groups.

On the whole, national strategies for food security and sustainable agriculture need to explicitly recognize the socioeconomic and political obstacles to inducing a radical transformation in agriculture that is focused on improving the productive capacity of small-scale food producers. For instance, policies to promote innovation in agriculture need to have an explicit gender focus to address the institutional constraints that prevent better access by women to secure land tenure, credit, new technologies, technical assistance, and other supportive services.

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—for instance, for rice intensification and watershed management—was possible through the endorsement by international organizations, national nongovernmental 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.

Innovative partnerships

The previous analysis highlighted the critical role of governments in inducing a technological transformation in agriculture. Yet, governments need to also build partnerships with other stakeholders, including the private sector, so as to strengthen the capacity of small-scale farmers to access technology, inputs, and larger markets.

For instance, it was mentioned earlier that effective agricultural research demands closer collaboration among public research institutions, the private sector and small-scale farmers through innovative partnerships. Such partnerships could take the form of results-based performance contracts, patent buyouts, prizes, joint ventures, cofinancing and advance-purchase agreements, comprehensive risk assessments, or suitable regulatory schemes (Pardey and Beintema, 2001; Bhagwati, 2005; Elliot, 2010; Lipton, 2010).

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.

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 percent of the food market in Latin America, about 10 percent in China, 30 percent in South Africa, and 50 percent 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 an organized 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 (Berdegúé, 2005). Technical assistance to farmers in meeting with quality standards would help to expand their opportunities for participation in larger markets.

In addition to the private sector, 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 also entailed the active participation of international and national civil society organizations, which, among others, can serve as intermediaries between research and agricultural practices; facilitate collective action and creation of farmers' organizations for the purchase of inputs and marketing of food; and strengthen the capacity of women to participate in marketing production and innovation.

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" (Berdegúé, 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 the participants to collaborate in developing a clear-cut strategy directed toward achieving the objectives of agricultural reform and ensuring that there are resources adequate for expanding rural infrastructure and supporting provision of services to small-scale farmers.

International action for food security and environmental sustainability

Governments, in their capacity as coordinators of the multiple stakeholders in a SAIS, can further benefit from regional and global partnerships. The international community has much to contribute to a global agenda for food security and environmental sustainability.

Toward this end, a renewed focus of development assistance on agriculture and sustainable land management is critical. Delivering on the financial pledges made in the aftermath of the food crisis of 2007–8 would constitute a good down payment on realizing the commitment to the goal of eradicating hunger. Availability of financing for climate change mitigation and adaptation activities in the agriculture sector in developing countries is further important to spur and enable the transition toward sustainable and climate-resilient food production.

In the very short term, preventing export bans on food crops and panic buying in response to weather-related catastrophes could help to reduce large food 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 that it represents an effective emergency response and to avert longer-term negative impacts on local food production systems.

In the longer-term, foreign donors can accelerate countries' transition toward sustainable food production through increased investment in agricultural R&D. 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. There is a need to support international institutions such as the CGIAR to better globally coordinate and complement large public investments in agricultural infrastructure, as well as facilitate technological diffusion by making freely available information on agricultural processes and plant genetic materials.

International action is further needed to reform agricultural subsidies in OECD countries, which undermine the ability of farmers in developing countries

to compete. This includes rethinking subsidies to biofuels, and support to new generation biofuels to reduce the diversion of agricultural land use from food production. Nontariff measures on food trade must be reformed so that these are truly science-based and adequate assistance is provided for small-scale producers to meet them. The WTO Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) and other bilateral and regional trade agreements that incorporate TRIPS-based provisions—which introduce monopolistic and exclusive rights regimes into plants and seed varieties—may also need to be modified to permit knowledge and seed sharing in developing countries. Developments such as the signing of the International Treaty on Plant Genetic Resources for Food and Agriculture—which promotes international cooperation and open exchange of genetic resources of crops—are welcoming in this regard.

New financing mechanisms should also be developed to expand payments to small farm holders in developing countries for environmental services (PES) that help to protect natural resources, to preserve biodiversity, and to increase carbon sequestration in agriculture and forestry.

Finally, effective regulation of commodity futures markets can help minimize unwarranted price volatility, which dilutes incentives to invest and undermines the viability of poor farmers and rural workers around the world.

Notes

- 1 The views expressed in this chapter are those of the authors and do not represent the official position of the organizations where they work.
- 2 <http://www.fao.org/news/story/en/item/216137/icode/> (accessed July 1, 2014).
- 3 <http://mdgs.un.org/unsd/mdg/Resources/Static/Products/Progress2013/English2013.pdf>.
- 4 This year's flagship publication of the FAO *The State of Food and Agriculture Report 2014* is dedicated to Innovation in Family Farming, in recognition of the need to focus attention to the production conditions of small-scale farming.
- 5 <http://www.fao.org/climate-smart-agriculture/85725/en/>.

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