SUMMARY  Soil and land management are essential for a sustainable food supply and ecosystems. Healthy soils can support sustainable agricultural production, mitigation of the impacts of climate change, and other ecosystem services. Interventions that show promise for improving soil health include investment in sustainable intensification technologies, climate-smart agriculture, and ecosystem-level management.

Sustainable management of soils and land provides a global public good, supporting agricultural productivity, climate change mitigation and resilience, and a range of ecosystem services. The irreplaceable functions of soils have only recently been widely recognized, and 2015—proclaimed the “International Year of Soils” by the United Nations (UN)—could mark an important turning point for addressing soil and land degradation. The Sustainable Development Goals (SDGs) put the focus of development on agriculture, climate change, and protecting biodiversity and the environment—all of which are closely related to soil health. SDG 15 specifically calls for halting and reversing land degradation. And a global initiative called “4 per 1,000” launched at the 21st Conference of the Parties (COP21) in Paris calls for addressing both climate change and food security by sequestering 0.4 percent of atmospheric carbon in the world’s soils annually.

Evidence of the potentially tragic consequences of neglecting soil and land resources is abundant. The Dust Bowl years on the Great Plains of the United States in the 1930s were the result of rapid erosion caused by decades of continuous monocropping of shallow-rooted annual crops. In northwestern China, similar unsustainable practices led to widespread dust and sandstorms from the 1970s to 1990s. Globally, we are losing 75 billion tons of soil every year to unsustainable practices, with impacts that not only harm poor farmers but also extend far beyond the agriculture sector. Climate change impacts, including climate amelioration through agricultural practices.
temperature increases and rainfall variability, will add to the existing stress on soils and agricultural production.

Fortunately, practices and policies are being tested that show promise for averting irreversible damage to the world’s soil resources. Innovations in management, soil conservation programs, and Green Revolution practices have not only improved agricultural efficiency and productivity but have also decreased erosion. Below we review the challenges of soil and land management, lessons learned, and policy options that could help achieve the sustainability goals at a global scale.

**CHALLENGES**

While the impact of soil and land degradation on farm production has long been recognized, understanding of the off-farm and even global impacts of soil and land management is recent. Sustainable development will require healthy soils, not only for increased agricultural production as a growing global population requires more food, but also to ensure sustainability of critical ecosystem services.

Given the fundamental importance of healthy soils, how do we coordinate, promote, and monitor multi-sectoral efforts? And how do we mobilize resources to ensure long-term soil health?

**Valuing land degradation**

Robust economic evaluation of the costs and benefits of increasing sustainable management is required to mobilize large-scale investments and strengthen policy commitments. Although a growing literature has examined the global-scale costs and benefits of sustainable land management, there is little consensus. One innovative study estimated the annual cost of global land degradation at about US$300 billion (about 0.4 percent of global gross domestic product in 2007), and provided new insights into the cost of land degradation (Figure 1).\(^2\) First, more than half of the total cost is attributable to degradation of ecosystem services—primarily loss of carbon sequestration, biodiversity, genetic information, and various cultural services—that largely affects beneficiaries other than local land users. Clearly land degradation...
is not just a problem for farmers—it is everyone’s problem. Second, the rewards of action outweigh the costs. Potential returns from investment to prevent land degradation are projected to be double the cost of inaction in the first six years alone, and up to five times larger over 30 years. Third, loss of carbon sequestration accounts for a large share of the cost of unsustainable management practices, including about 75 percent of the US$57 billion annual cost of land degradation occurring on farms that grow maize, rice, and wheat globally.

Valuing soil carbon
Carbon markets have been established to create financial incentives for reduction of greenhouse gas (GHG) emissions (especially CO₂), including carbon losses from soils, through trading of emissions allowances (carbon credits) among emitters. Agricultural emissions comprise 14 percent of global GHG emissions. Creation of carbon markets was expected to create a win-win opportunity for farmers—incentives for land management would increase soil fertility while plants would absorb CO₂ from the atmosphere, mitigating climate change. However, although the global carbon market reached a value of more than US$100 billion in 2009, agriculture has been largely excluded. Obstacles to participation include high levels of uncertainty about agriculture’s mitigation potential because of measurement difficulties; concerns about permanence because sequestered soil carbon is lost rapidly when mitigation practices are abandoned; large transaction costs including those of monitoring, reporting, and verifying changes in soil carbon and emissions; and in the case of smallholders, the need to work together to generate a market-viable quantity of emission reductions. Despite growing scientific evidence of the benefits of soil carbon sequestration and economic analyses demonstrating the power of carbon markets to foster more sustainable land management, market valuation of carbon in agriculture has not fulfilled its potential.

Monitoring agricultural sustainability
Measuring the status of land and soils, especially over large areas, is difficult, but recent technological advances in estimating soil organic carbon and moisture using unmanned aerial vehicles and satellites offer potential for more effective monitoring. New monitoring frameworks attempt to devise a simple model of inherently complex agricultural systems to support actionable measures. The Africa RISING project, for example, is developing a Sustainable Intensification Index using a set of indicators across space and time: economic (income, poverty); human (education, health, nutrition); environmental (soil carbon input, erosion, water-use efficiency, on- and off-farm vegetation); social (farmer groups, social capital, gender equity); and productivity (yield, total factor productivity). The framework will be used as a monitoring tool for diverse farming systems across Africa. Another approach, developed by HarvestChoice, uses a satellite-based estimation of aboveground biomass to quantify the spatio-temporal trends in biomass appropriated by agriculture. Preliminary findings from detailed mapping across Africa south of the Sahara suggest that the method can identify hot spots of accelerating biomass harvest from crops, indicating areas of active agricultural intensification.

WHAT IS AT STAKE?
By placing goals related to soil and land management on the agenda, the UN commitment recognizes the critical role of soil and land for realizing its new goals. Beyond the direct contribution of soil health to agricultural sustainability, what is at stake?

Sustainable food supply
Management of land and soil fertility, particularly soil carbon, is essential for reliable agricultural production and resilience to external shocks, including climate change. Soil organic matter, of which about 60 percent is carbon, is critical to soils in terms of fertility, ecological processes, plant productivity, and ultimately human survival. Soil carbon plays a central role in (1) maintaining soil structure, notably increasing water-holding capacity and soil permeability, aeration, and drainage; (2) providing energy and substrate for microbial activity; (3) promoting a reservoir of available organic nitrogen, phosphorus, and other essential plant nutrients; and (4) creating a cohesive physical structure that protects against
water and wind erosion. Carbon storage in soils is also critical for climate change mitigation. Potential increases in soil organic carbon from improved agricultural practices could offset the equivalent of 5 to 15 percent of global fossil fuel emissions.6

Over the past 25 years, a quarter of Earth’s land has suffered degradation due to loss of organic matter.7 Fertilizer, in the form of either inorganic or organic amendments, is essential to maintain soil productivity. Under continuous intensive cultivation, soils lose mineralized organic nitrogen, and consequently available phosphorus becomes largely inaccessible to plant uptake. And in some soils, a further chain reaction may reduce the soil’s ability to hold on to essential nutrients. Left without replenishment of nutrients and organic material, soils can become unresponsive to fertilizer applications. In extreme cases, degradation can be irreversible. The resulting loss of agricultural productivity is likely to perpetuate poverty traps.8 The organic material’s contribution to soil fertility, therefore, cannot be understated and may determine the agricultural potential of soils.9

Ecosystem services
Complex landscapes enhance local diversity in agricultural systems and provide supporting and regulating ecosystem services critical for agriculture.10 Among other important contributions, landscape diversity provides more food sources and habitats for beneficial insects than simple or monoculture landscapes, and is correlated with greater diversity and abundance of populations of natural enemies of plant pests as well as lower incidence of plant disease.11 Further research on how landscape structure and heterogeneity influence interactions among host, pathogen, and environment may lead to practical measures to reduce the impact of plant disease.12

Landscape diversity also provides habitats for pollinators, which provide another ecosystem service critical for agricultural production. Evidence suggests that conserving habitats for wild pollinators within agricultural landscapes improves both the level and stability of pollination, leading to increased yields and income for farmers.13 These environmental services depend on on-farm management and the structure, composition, and functioning of the surrounding landscape.14

Human health
Better understanding of the soil health–human health nexus is critical to developing sustainable strategies of soil fertility management to improve human health.15 Recent studies have investigated various aspects of the nexus, including food security, human contact with various chemicals in soils, and human contact with soil pathogens.16 Researchers at the International Food Policy Research Institute (IFPRI) along with partner organizations have focused on the relationship of soil health to food security, particularly food availability and quality. To increase food availability, studies have focused on developing sustainable soil management practices to raise agricultural productivity while reducing adverse impacts on environmental and human health. The Economics of Land Degradation Initiative and related work have highlighted the importance of sustainable soil fertility management by determining the high cost of inaction in the face of land degradation.17 To enhance food quality, the transfer of nutrients from soils to plants to people has been examined. Led by IFPRI, the Research for Ethiopia’s Agriculture Policy (REAP) program introduced fertilizer blends to Ethiopian farmers for replenishing nutrient-depleted soils. Similarly, the HarvestZinc project led by HarvestPlus, a biofortification initiative, has offered a means to alleviate nutritional deficiencies by linking zinc levels in soils, plant uptake, and human nutrition.18

PROPOSED ACTIONS
Despite the challenges of managing soil and land for agricultural sustainability, interdisciplinary research and public interest surrounding the sustainable development agenda are generating unprecedented amounts of site-specific data, decision-support tools, and consensus around a sustainable food security roadmap. To provide guidance in global food policy development and implementation, we propose the following actions based on this growing knowledge.

Implement sustainable intensification technologies
Agricultural intensification—producing more food from existing farmland—is the prevailing paradigm
for meeting global food needs as the world’s population heads toward 9.6 billion by 2050. Carefully designed, site-specific sustainable intensification (SI) technologies offer a means of increasing the food supply while reducing environmental impacts and GHG emissions. Based on decades of research, a number of initiatives are proving the feasibility of SI at various scales. The Africa RISING initiative, for example, aims to identify successful SI practices in six African countries. Working closely with smallholder farmers in diverse locations and farming systems, Africa RISING uses location-specific research to ensure technologies are appropriate to local culture and agroecology. But changes in agricultural systems often entail trade-offs, which need to be taken into account by policymakers. Preliminary results from a modeling exercise using Malawi as a case study suggest that farm productivity, profitability, and soil carbon can increase if farmers use a mixture of organic and inorganic sources of nitrogen—the simulation showed a 24 percent increase in profits over a 20-year period, relative to a maize monoculture system using only inorganic fertilizer. However, while profits increase, the combination of organic and inorganic sources of nitrogen also increases the leaching of nitrogen from soils. Addressing the relative importance of trade-offs in different contexts can help in formulating effective policies for sustainable agriculture.

Scaling up adoption of SI technologies among farmers is, however, a daunting task requiring a nuanced understanding of farmers’ livelihoods, careful planning for iterative implementation, and systematic monitoring to understand environmental linkages and their effects. Because SI technologies take a “whole-farm” approach, they are more complex than other interventions for sustainability. For example, SI requires farmers to adopt a package of practices, which may need to be applied in a particular order and at specific times. The benefits, however, can be substantial. For example, evidence from the “doubled-up” legume technology tested by Africa RISING in Malawi shows that by growing an additional legume in order to supplement household nutrition and income, farmers successfully doubled both farm output and soil fertility benefits, because legume crops increase soil fertility. Similarly, in Tanzania, technologies including crop diversification through intercropping, soil fertility management, postharvest management, and integration of high-value vegetable crops have boosted farmers’ earnings by 70 percent. These cases provide a knowledge base for policies to scale up adoption of SI technologies.

Invest in perennials
Simplified agroecosystems featuring annual crops have largely replaced ecosystems dominated by heterogeneous perennial vegetation. Despite the advantages they offer for sustainable soil and land management, perennials account for a smaller share globally of farming systems, investment dollars, and plant-sourced calories than annual crops. Perennials develop long-lived, deep roots for better access to nutrients and water, enabling more resilience to harsh environmental conditions while producing more biomass both above and below ground. They are superior to annuals in terms of reducing soil erosion, transferring organic inputs to soil microorganisms, and increasing the amount of carbon stored in the soil—key for improving soil health. These organic inputs and microorganisms improve soil fertility and structure as well as increasing water infiltration and storage, all of which increase water availability to crops. By supplying soil with carbon, perennials improve the ability of food crops to utilize mineral fertilizers and potentially help farmers adapt to climate change. A variety of available perennial crops suitable for livestock forage, fruit production, agroforestry, and nitrogen fixation can be integrated into mixed-use farming systems through rotation, intercropping, and monoculture. However, there are virtually no varieties of perennial grain available on the market yet, with the exception of the pigeon pea—a semiperennial cultivated in East Africa. This lack of perennial availability limits the potential contribution these crops can make to increasing food security. Further investment is needed to scale up the development and integration of perennial crops into mixed farming systems.

Promote climate-smart soil and land management
To address future challenges to food security and achieve the SDGs, climate-smart agriculture must
be made operational. Climate-smart agriculture is an umbrella term that includes many approaches built on geographically specific solutions, such as no-till farming, fertilizer deep-placement technology, and integrated soil fertility management. The concept embraces three pillars: (1) sustainable increases in productivity, (2) enhanced resilience and adaptation of farming systems, and (3) mitigation of GHG emissions.21 One of the greatest challenges facing development practitioners is to design climate-smart soil and land management strategies that satisfy all three pillars of climate-smart agriculture.22 IFPRI researchers have developed a modeling approach that combines and reconciles the limited resolution of macro-level global economic models with detailed models of biophysical processes at high spatial resolution. This suite of models provides clear insights into the economic, productivity, and carbon-storage implications of alternative policies.

A recent application of this approach in Colombia, a country fully invested in pursuing low-emissions development strategies, reveals the importance of considering the full scope of interactions among various land uses. Results indicate that investments in increasing the efficiency and productivity of the livestock sector and reducing land allocated to pasture are preferable to policies that target deforestation alone or target a reduction of emissions in crop production. Investments in livestock productivity and land carrying capacity would reduce deforestation and provide sufficient gains in carbon stock to offset greater emissions from increased crop production while generating higher revenues.

**Manage ecosystem services at the landscape level**

A landscape perspective is necessary to understand how land use affects ecosystem services.23 The scale at which ecosystem services are rendered determines the relevant management units for supporting sustainable agriculture.24 For example, ensuring reliable ecosystem services from insect populations (including crop pollination and pest regulation) requires coordinated land-use management among local farmers, as well as judicious use of chemical insecticides to limit harm to beneficial insects. To achieve this level of coordination across farm boundaries, research and policy attention needs to move beyond the traditional field and farm scale to the agricultural landscape.25 A greater level of collaboration and public investment in research and extension are necessary. Future management and planning efforts should move toward a landscape perspective.

**Recognize soil, land, and ecosystem services as public goods**

Many ecosystem services behave as public goods.26 For example, forests on private land sequester carbon, creating a public good in that no one can be excluded from the benefit of carbon sequestration.27 In many cases, both the costs and the benefits of soil,
land, and ecosystem management by farmers largely accrue to people “off-farm.” A recent study finds that 54 percent of the cost of long-term loss of ecosystem services resulting from land degradation is borne by people off-farm. For some biomes, off-farm costs are much higher—for example, an estimated 76 percent of the cost of world deforestation is off-farm. On the positive side, this means that farmers who plant trees or adopt other sustainable land management practices create both on- and off-farm benefits. Policies and strategies for achieving SDG 15—zero net land degradation by 2030—should reflect the public goods created by on-farm practices. The trade-off (or opportunity cost) of restoring degraded lands accounted for about 94 percent of the total cost of taking action against land degradation, largely due to losses farmers incur to restore a high-value biome and foregone benefits from the low-value biome associated with land degradation.

Payment for ecosystem services (PES) programs can address these high costs by helping land users internalize some or all of the off-farm benefits generated by sustainable land management practices. A number of successful programs in countries ranked both low and high on the UN’s Human Development Index have demonstrated that PES can be successfully implemented if key preconditions are in place—regardless of the human development level. The key preconditions are strong local and national institutions that ensure land tenure and a market-based program for payments. For example, the Plan Vivo projects in Africa have implemented a number of successful PES programs rooted in community-based forest management practices. Mozambique’s Sofala Community Carbon program pays farmers for on-farm carbon sequestration, adding to the benefits of on-farm ecosystem services, including sustainable timber and nontimber forest product harvesting.

Costa Rica offers a success story of restoration of deforested lands. The country’s political constitution and its 1996 Forestry Act provide a framework for rewarding land users who provide off-farm ecosystem services through certified forest conservation. The payments are financed through fossil fuel taxes, water fees, and donor contributions. Land users engaged in forest conservation enjoy direct payments, tax breaks, and payments for carbon credits from local and international buyers. The country has invested significantly in environmental awareness, leading to changes in perceptions about ecosystem services. All of this has led to successful restoration of deforested lands and other sustainable natural resource management practices.

**GROWING EVIDENCE**

Unsustainable land management practices are driving the annual loss of 75 billion tons of soil from global cropland, with impacts that go far beyond agriculture. As soil is increasingly recognized as a limited and irreplaceable natural resource, this can change. Through global initiatives to address soil and land degradation issues, momentum is gathering to put agriculture on a more sustainable track. Research is generating data and powerful analytical tools to create a roadmap of actions for achieving the SDGs. Major challenges remain, including development of effective governance and financing strategies for sustainability. But the evidence needed for practical application of better approaches is growing. Climate-smart agriculture technologies and management practices that promote sustainable intensification, supported by landscape-level approaches and economic valuation of ecosystem services, provide reason to be optimistic about sustainable management of soil and land, and ultimately food security for future generations.