Making agricultural systems more environmentally sustainable

chapter 8

The green revolution in Asia doubled cereal production there between 1970 and 1995, yet the total land area cultivated with cereals increased by only 4 percent.[1] Such intensification of agriculture has met the world's demand for food and reduced hunger and poverty (chapters 2 and 7). By dramatically slowing the expansion of cultivated area, agricultural intensification has also preserved forests, wetlands, biodiversity, and the ecosystem services they provide.[2]

But intensification has brought environmental problems of its own. In intensive cropping systems, the excessive and inappropriate use of agrochemicals pollutes waterways, poisons people, and upsets ecosystems. Wasteful irrigation has contributed to the growing scarcity of water, the unsustainable pumping of groundwater, and the degradation of prime agricultural land. Intensive livestock systems, part of the continuing livestock revolution, also present environmental and health problems. High concentrations of livestock in or near urban areas produce waste and can spread animal diseases, such as tuberculosis and avian bird flu, with risks for human health.

In areas not affected by the green revolution, there has been little if any agricultural intensification; instead, agriculture has grown through extensification—bringing more land under cultivation. This has led to environmental problems of a different kind—mainly the degradation and loss of forests, wetlands, soils, and pastures. Every year about 13 million hectares of tropical forest are degraded or disappear, mainly because of agriculture. Some 10–20 percent of drylands may suffer from land degradation (or desertification).[3]

Onsite degradation of natural capital has direct impacts on agricultural productivity because it undermines the basis for future agricultural production through the erosion of soil and depletion of soil nutrients (table 8.1). Estimates of the magnitude and productivity impact of land degradation are debated, but in hotspots such as the highlands of Ethiopia, degradation may be high enough to offset the gains from technical change.

Problems from agricultural production extend outside of fields or pastures: water pollution, reservoir siltation from soil erosion, mining of groundwater acquifers, deforestation, the loss of biodiversity, and the spread of livestock diseases. Although farmers and pastoralists have strong incentives to address onsite problems, they have weak incentives to mitigate offsite effects. Avoiding such externalities requires regulatory mechanisms, negotiated solutions, and/or transferring payments between those causing the damage and those affected by it, possibly involving large numbers of people separated in space, time, and interests. This has proved very difficult in most poor countries because of the general weakness of public institutions and the legal system. Some problems, such as the spread of animal diseases and climate change, require cooperation at the global level (chapter 11). Negative intergenerational externalities, even less tractable, arise when farmers use resources today with too little regard for the resource heritage they leave for future generations.

Environmental problems play out in different ways in intensive and extensive agricultural systems. (See chapter 2 for definitions and mapping of the major farming systems.) Intensive systems in high-potential areas have an advantage: their natural environment is usually fairly resilient and not easily damaged. However, high external input use often makes these systems sources

Table 8.1 Agriculture's environmental problems onsite and offsite

	Onsite effects	Offsite effects (externalities)	Global effects (externalities)
Intensive agriculture (high-potential areas)	Soil degradation (salinization, loss of organic matter)	Groundwater depletion Agrochemical pollution Loss of local biodiversity	Greenhouse gas emissions Animal diseases Loss of in situ crop genetic diversity
Extensive agriculture (less-favored areas)	Nutrient depletion Soil erosion onsite effects	Soil erosion downstream effects (reservoir siltation) Hydrological change (e.g., loss of water retention in upstream areas) Pasture degradation in common property areas	Reduced carbon sequestration from deforestation and carbon dioxide emissions from forest fires Loss of biodiversity
Level of cooperation typically required	None (individual or household)	Community, watershed, basin, landscape-level, regional, or national	Global

of downstream pollution through fertilizer, pesticide, and animal waste runoff and increased water salinity levels. Conversely, the areas having extensive systems are fragile and easily damaged. Low input use means extensive systems are not a major source of pollution, but farming steep slopes and fragile soils can cause substantial erosion, damaging downstream areas.

Drivers of resource degradation

Some resource degradation in rural areas has little to do with agriculture. Logging, mining, and tourism also degrade resources through deforestation, conversion of natural ecosystems, and pollution. Moreover, many farmers and pastoralists do not degrade their land or mismanage natural resources. Much agricultural production is sustainable, and in some cases large areas have been under continuous cultivation for centuries, if not millennia. In other cases, such as the Machakos region of Kenya, areas once degraded have been restored and crop yields have recovered.[4] Even in areas thought to be mismanaged, closer analysis often reveals that farmers take a variety of conservation actions. Nonetheless, farming and pastoral activities are often the main drivers of degradation.

Overcoming environmental problems in agriculture requires a good understanding of private incentives of individual resource users and ways to manage resources more successfully from society's point of view. Many factors affect private incentives for managing resources, including information, prices, subsidies, interest rates, market access, risk, property rights, technology, and collective action (see table 8.1). Often resulting in both onsite and offsite resource degradation, these factors can be modified through policy changes and public investment, although global forces are changing the drivers of resource degradation in new ways. Global markets can leave a global environmental footprint, such as the impact of Asian demand for soybeans for livestock on deforestation in the Amazon (chapter 2). Furthermore, climate change is increasing production risks in many farming systems, reducing the ability of farmers and rural societies to manage risks on their own.

Two difficult drivers to manage are poverty and population. Poverty is more likely to drive resource degradation in less-favored regions, where poor-quality and fragile soils must support rising population densities. But even in these areas the relationship can be complex and indeterminate.[5] In other contexts poor people typically control only small shares of the total resources and so are fairly minor contributors to degradation. On its own, then, reducing poverty will seldom reverse resource degradation. Yet the poor and women are typically most affected by resource degradation wherever it occurs, because they have the fewest assets and options for coping with degradation, and they depend most on common property resources.[6]

Population pressure has mixed impacts on resource degradation, depending mainly on the available technology. As Malthus observed in 18th century England, population pressure without technological advances leads to agricultural encroachment into ever-more-marginal areas, reducing average yields, degrading resources, and worsening poverty. When suitable technologies and institutions are available, however, population growth can lead to their adoption and sustain improvements in resource conditions and yields. Because many natural resource management technologies are labor intensive (for example, terracing or contouring land, building irrigation structures), population growth can actually assist their uptake because it lowers labor costs.[7]

When population pressure is combined with high initial levels of poverty and few technology options for boosting productivity, degradation and poverty can spiral downward.[8] This is happening in some areas of Africa, where many farms are now too small to support a family, yield growth has stagnated, and job opportunities off the farm are rare. These distressed areas can become breeding grounds for civil conflict, displacing environmental refugees and disrupting efforts to reach the very poor and vulnerable.[9]

With this as background, turn now to strategies for achieving more sustainable development in intensive and extensive farming systems. The key challenges in irrigated areas are to use less water in the face of growing water scarcities; stop unsustainable mining of groundwater; and prevent the degradation of irrigated land through waterlogging, salinization, and nutrient depletion. In intensive farming areas in general (irrigated and high-potential rainfed areas), modern inputs like seed, fertilizer, pesticides, and water need to be managed to sustain high yields without damaging the environment. In intensive livestock systems, particularly in periurban and urban areas, the management of animal wastes and disease risks needs to improve. In less-favored regions with extensive farming systems, development needs to support the livelihoods of local people and still be compatible with other environmental services on a fragile resource base. In both high-potential and less-favored areas, payments for environmental services can be used when national and global social benefits exceed the opportunity cost of current land use and the management costs of the program.

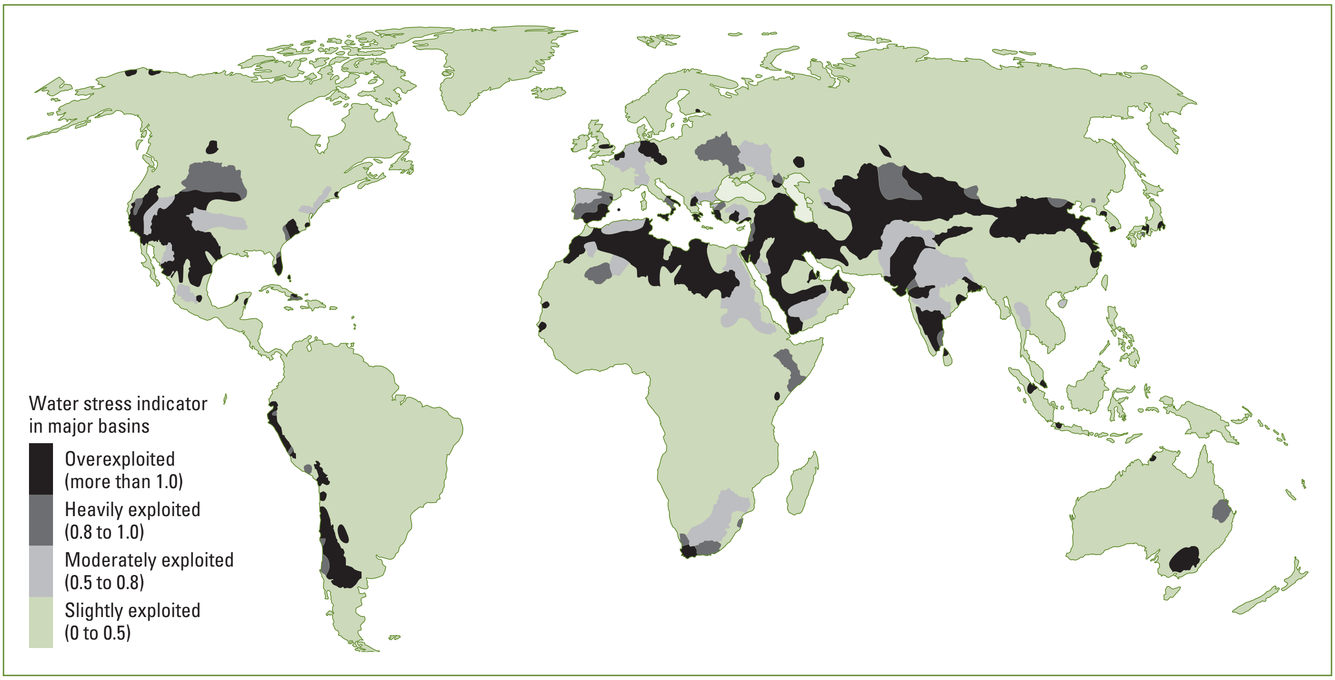
Improving agricultural water management

Agriculture uses 85 percent of water consumed in developing countries, mainly for irrigation. Even though irrigated farming accounts for only about 18 percent of the cultivated area in the developing world, it produces about 40 percent of the value of agricultural output.[10]

The continuing high productivity of irrigated land is key to feeding much of the developing world, yet future trajectories are worrisome (chapter 2). Many countries are experiencing serious and worsening water scarcities. In many river basins, freshwater supplies are already fully used, and urban, industrial, and environmental demands for water are escalating, increasing the water stress. Globally, about 15–35 percent of total water withdrawals for irrigated agriculture are estimated to be unsustainable—the use of water exceeds the renewable supply.[11] An estimated 1.4 billion people[12] live in basins with high environmental stress where water use exceeds minimum recharge levels (map 8.1). As a result of excessive withdrawals, such major rivers as the Ganges, the Yellow River, Amu Darya, Syr Darya, Chao Phraya, Colorado River, and the Rio Grande may not reach the sea during part of the year. Other well-known consequences of unsustainable irrigation are the degradation of the Aral Sea in Central Asia and the shrinking of Lake Chad in western Africa and Lake Chapala in central Mexico.

Intensive use of groundwater for irrigation rapidly expanded with the adoption of tubewell and mechanical pump technology. In the Indian subcontinent, groundwater withdrawals have surged from less than 20 cubic kilometers to more than 250 cubic kilometers per year since the 1950s.[13] The largest areas under groundwater irrigation in developing countries are in China and India. Relative to total cultivated area, reliance on groundwater is highest in the

Map 8.1 Overexploitation has caused severe water stress in many river basins



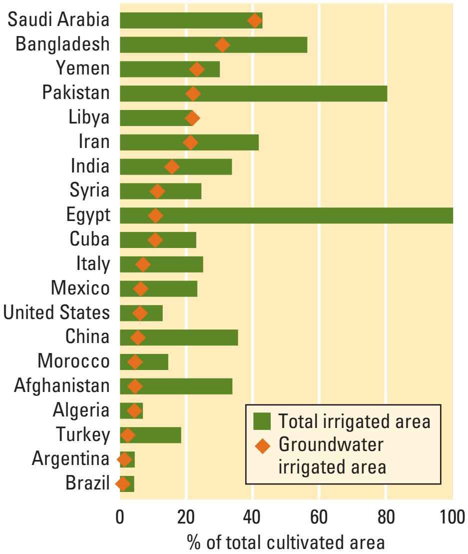
Source: Data from Smakhtin, Revenga, and Döll 2004; map reprinted with permission from United Nations Development Programme 2006.
Note: The environmental water stress indicator is the total water use in relation to water availability, after taking into account environmental water requirements (the minimum flows to maintain fish and aquatic species and for river channel maintenance, wetland flooding, and riparian vegetation).

Middle East and South Asia (figure 8.1). But because of the open-access nature of groundwater, it suffers from depletion; contamination by municipal, industrial, and agricultural users; and saline water intrusion. Where groundwater use is most intensive, aquifer recharge tends to be too small to sustain it.[14]

Groundwater resources are being overdrawn to such an extent that water tables in many aquifers have fallen to levels that make pumping difficult and too costly. Small farmers with little access to expensive pumps and often insecure water rights are most affected. Saline intrusion resulting from overpumping—the most common form of groundwater pollution—leads to losses of large agricultural land areas. In Mexico's coastal aquifer of Hermosillo, annual withdrawals three to four times the recharge rate resulted in a 30 meter drop in water tables and saltwater intrusion at the rate of 1 kilometer per year, causing large agribusiness firms to relocate to other regions.[15] Falling water tables increase the vulnerability of coastal groundwater aquifers to climate change, as saline intrusion will get worse in depleted aquifers as sea levels rise.

Poor water management is also leading to land degradation in irrigated areas through salinization and waterlogging. Waterlogging usually occurs in humid environments or irrigated areas with excessive irrigation and insufficient drainage (for example, Egypt's unmetered irrigation of the Nile valley and delta). Salinization is a larger problem in arid and semiarid areas (for example, Pakistan's large irrigation perimeters and the Aral Sea basin). Nearly 40 percent of irrigated land in dry areas of Asia are thought to be affected by salinization.[16] The result is declining productivity and loss of agricultural land. Better water management and onfarm investments, such as field leveling and drainage, can rectify these problems, but this often requires substantial public investments in off-farm infrastructure, strong water management institutions, collective action, and a good understanding of the hydrology.

Figure 8.1 Dependence on groundwater irrigation is highest in the Middle East and South Asia



Source: FAO AQUASTAT database accessible at http://www.fao.org/ag/agl/aglw/aquastat/main/index.stm and International Commission on Irrigation and Drainage database accessible at http://www.icid.org/index-e.html.

With competition for water growing, the scope for further irrigation expansion is limited (with few exceptions, such as Sub-Saharan Africa). Thus agriculture must meet future food demand through water productivity improvements in both irrigated and rainfed areas (chapter 2). Projections indicate that yield improvements in existing irrigated areas, rather than further expansion, will be the main source of growth in irrigated agriculture (chapter 2).[17] Meeting the water scarcity challenge will require integrated management of water use at river-basin levels for better water allocation across sectors, and greater efficiency in the use of water within irrigation systems. The details of policies must be adapted to local conditions, but in general they include a combination of integrated water management approaches, better technology, and institutional and policy reform.

Moving toward integrated water management in irrigated agriculture

In much of the 20th century, the emphasis was on building infrastructure to increase water withdrawals. Since then, the increasing interconnectedness among competing users of water and aquatic ecosystems has led to severe environmental stress in many basins, where the remaining flow after diversions for industry, municipal, and agricultural use has often been insufficient to maintain the health of river ecosystems and groundwater aquifers. More efficient use of water in irrigation and better water allocation are key to meeting these increasing demands.

Local interventions can have unexpected consequences elsewhere in a basin. For example, efficiency improvements, such as canal lining and microirrigation, can reduce the quantity of water available to downstream users and the size of the environmental flows because efficiency improvements often result in expansion of irrigated areas.[18] Harvesting water and using more groundwater can have similar effects on other users in the basin. To avoid misguided investments and policies, quantifying the impact of local interventions within the broader hydrology of the whole system is becoming increasingly important.[19]

Adaptive management—an approach for river restoration that explicitly recognizes the uncertainty about the response of natural ecosystems to policy interventions—can help mitigate environmental degradation and the loss of wetlands and wildlife habitats even in severely stressed basins. For example, restoration of the environmental flows has had promising results for the northern Aral Sea, despite unmatched hydrological complexity and massive environmental damage from past excessive water withdrawal for irrigation (box 8.1).

Rising climatic uncertainties and hydrological variability increase the urgency of integrated planning approaches, which is already evident in arid regions with large-scale irrigation. In Morocco, dams were designed on the basis of past rainfall patterns, but in an unusually intense period of droughts, the volume of water stored was insufficient, resulting in major water shortages.[20] Expensive irrigation schemes are thus used far below their potential, and modification to allow for water-saving technologies, such as drip irrigation, increase costs. Because changes in rainfall from climate change are expected to have a similar effect in other parts of Africa, Morocco's experience is a cautionary tale for countries planning to make new investments in irrigation in drought-prone areas. According to recent predictions, greater variability in precipitation will significantly affect surface water across a quarter of the continent.[21]

Because climate change is shrinking mountain glaciers, irrigation systems in the long term will not receive enough runoff water from glacial melt in the Andes, Nepal, and parts of China—or they may receive it at the wrong time because of early melt. Additional investments will be required to store and save water. Including climate risk in the design of irrigation systems and long-term planning can significantly reduce more costly adjustments later.

BOX 8.1 *Restoring the northern Aral Sea—by doubling the Syr Darya's flow*

Unsustainable expansion of cotton cultivation and poor water management in the Aral Sea basin produced a major environmental disaster. By the late 1980s the Aral Sea had shrunk so much that it divided in two, and by the 1990s much of the land around the northern Aral was a saline wasteland.

In 1999 Kazakhstan began to restore it. A 13-kilometer dike to the south of the Syr Darya outfall raised the northern sea's level and reduced its salinity. It was thought that it would take up to 10 years to raise the water level. However, only seven months after the dike's completion, the target level was reached, and spare water started to flow over the spillway to the south. Water levels have risen by an average of four meters. Local fisheries, crops, and livestock have begun to recover, and the microclimate may have become less arid. Economic prospects for local communities look positive again—for the first time in more than 30 years.

The key to this transformation: an integrated approach to restoring the Syr Darya River. Rehabilitating dams, barrages, and embankments along the river in Kazakhstan, which fell into disrepair following the collapse of the Soviet Union, doubled the river's flow and improved the potential for hydropower. For the northern Aral, success depended on identifying discrete national investments that would contribute to wider regional or multicountry plans.

Sources: Pala 2006; World Bank 2006q.

Improving productivity of irrigation water

Physical scarcity of water may be a fact of life in the most arid regions, but it is heightened by policies that induce higher water use and the overdevelopment of hydraulic infrastructure. In particular, the expansion of irrigated agriculture has often been at the expense of other water users, biodiversity, and ecosystem services, damaging fisheries and wetlands. Bureaucratic rigidities, subsidized pricing of water supplied to farmers, and the failure to recognize or account for externalities contribute to the problem.

Many large irrigation schemes suffer from inflexible water delivery systems that constrain farmer responses to changing markets and profit opportunities and encourage unsustainable use of ground and surface water. Modernization of these systems requires a combination of physical investments, economic incentives, and institutional change. Reengineering many canal-based irrigation schemes to facilitate more flexible water management at the field level can encourage farmers to grow a greater diversity of crops and better adjust water supplies to crop needs. With a more reliable water supply, farmers will be more willing to share the cost of services. Lessons from global experience show that decentralized governance models in the irrigation sector, usually through water users' associations, are more successful than government agencies in recovering costs. Although decentralization tends to result in better maintenance, the efficiency and productivity outcomes have been mixed.[22]

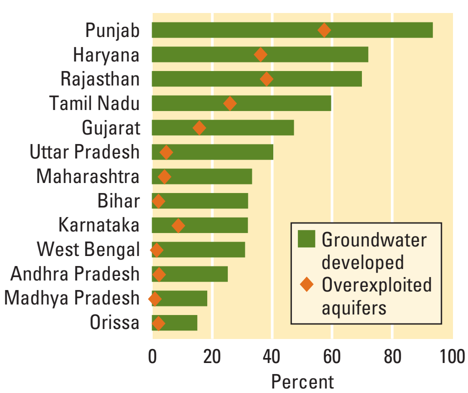
Institutional reform of large-scale irrigation schemes is a challenge everywhere, but there are some encouraging success stories. In the 1970s the Office du Niger, a large irrigation scheme in Mali, was in disarray as a result of highly centralized top-down management.[23] In the 1980s the government embarked on reforms that succeeded only when the mission of the irrigation agency was redefined—introducing strong private sector incentives in its management, empowering farmers, and building a strong coalition of stakeholders (chapter 11). The scheme's greater efficiency quadrupled yields, and overall production increased by a factor of 5.8 between 1982 and 2000. Attracted by employment opportunities, the area's population increased by a factor of 3.5, and poverty fell more than in other areas.[24]

Economic policies often create inappropriate incentives for farmers in the choice of technology and water management practices. In irrigated agriculture, energy subsidies encourage groundwater mining, and the underpricing of canal water steers farmers away from water-efficient crops.

Subsidies for canal irrigation, power, and fertilizer in India, abetted by state procurement of output at guaranteed prices, led farmers to overproduce rice, wheat, and other low-value crops, using water-intensive cultivation and making excessive withdrawals of groundwater (chapter 4).[25] More than a fifth of groundwater aquifers are overexploited in three of the four leading green revolution states, disproportionately affecting smallholders and damaging drinking-water supplies (figure 8.2). More realistic charges for water and power would not only help correct incentives to use water efficiently, they would also enable the agencies that provide these resources to better cover their operation and maintenance costs and improve the quality of service delivery.

But removing subsidies for irrigation services has proven difficult. Better pricing and cost recovery are explicit objectives of many irrigation projects and policies, but there has been little progress.[26] Applying volumetric charges for irrigation water has run into obstacles in many developing countries—exceptions are Armenia, Iran, Jordan, Morocco, South Africa, and Tunisia. Even where volumetric pricing has been accepted as a principle, cost recovery is lower than expected because of payment evasion, meter tampering, and measurement problems.[27]

Figure 8.2 Groundwater aquifers in India are being depleted



Source: World Bank 2003d.
Note: "Groundwater developed" is a percent of all available groundwater in a state. "Overexploited aquifers" is a percent of administrative blocks in which groundwater extraction exceeds recharge.

Innovative technologies can improve the quality of irrigation services and facilitate cost recovery. For example, accurately measuring water use in irrigation is now possible with canal automation[28] or satellite data. Moving from manually operated to automated channel control of irrigation, as applied in Australia, could be used in some developing countries.[29] Remote-sensing technologies can measure the amount of water from surface and groundwater schemes actually applied to the fields.[30] Although these technologies require a substantial initial investment, they can be more cost effective than other alternatives.[31]

Economic reforms outside the water sector that influence relative product prices often have a major influence on water productivity in agriculture. In India's Punjab region, well known for overexploitation of groundwater, minimum support prices for rice increase the financial attractiveness of rice relative to less-water-intensive crops. Likewise, many water-scarce countries in the Middle East and North Africa support the production of irrigated wheat, at the expense of other horticultural crops that would pay higher returns to water. More liberal trade policies could also encourage efficient specialization—products with high water requirements would be imported from places with more water, and water-scarce regions would specialize in less-water-intensive and higher-value crops. Sequencing of reforms in the water sector and broader economic reforms becomes decisively important if the broader reforms alter the constellation of political forces and generate support for otherwise stalled reforms in the water sector.

Using water markets when water rights are secure

Theoretically, markets for allocating water across sectors and within irrigation schemes are the most economically efficient instrument for improving water productivity. Local water markets have often developed naturally where social control and hydraulic infrastructure make this possible (for example, trading water turns in traditional irrigation systems in South Asia, or trading groundwater in Jordan and Pakistan). However, it is unlikely that markets will reallocate water on a large scale in developing countries in the near future.[32] So far, large water markets have been confined to countries with strong institutional frameworks and secure water rights (that is, individual or collective entitlements to water), such as Chile and Mexico. Online water trading, especially between farmers and urban users, is now possible in California.

As water becomes more scarce, interest in water markets will likely increase because they can efficiently allocate water among different users. The early experience with formal water markets shows that a variety of approaches may be needed, depending on the local institutions, cultural norms, hydrological conditions, and capacity to transfer water over long distances. The design of water markets also needs to take into account the increasing frequency of droughts as a consequence of climate change and the possibility of water rationing. A flexible water allocation process, whereby water allocations depend on actual water availability, may be needed.

Water rights that are perceived as just and responsive to the needs of all water users are a precondition for successful introduction of water markets. Inequality in water rights is often embedded in traditional water rights, the distribution of land rights, and access to irrigation. For example, women are often excluded from building and maintaining irrigation works, a common way for participants to obtain rights in the scheme.[33] With mounting pressure on water resources, securing water rights of indigenous groups, pastoralists, smallholder farmers, and women is becoming particularly important.

Conflicting interests of upstream and downstream users complicate the allocation of water rights. Local disagreements can be resolved by community approaches to governing shared resources, but reaching agreement between upstream and downstream users on a larger scale, particularly in the context of transboundary water bodies, is far tougher. Similarly, enforcing rights over groundwater is challenging because of the difficulty of monitoring extraction.

Seizing windows of opportunity and making reforms happen

Many changes in irrigation management—from allocation of water rights to the reform of irrigation agencies—are politically contentious. Past reforms have often failed or remained incomplete because of overoptimism about the willingness or capacity of local bureaucracies to carry them out and about the time and cost of needed investments. In Indonesia, Madagascar, and Pakistan, reform strategies ignoring the political reality met with slow progress.[34]

Reforming irrigation systems and water allocations is inherently a political process. For example, water management bureaucracies may oppose the devolution of responsibility and greater accountability to water users. When reforms have political as well as technical champions, they are more likely to succeed. In Chile, Mali, Namibia, and South Africa, institutional reforms in water succeeded largely because they were part of a broader package of political and economic reforms with strong political backing.[35] In Mali the president championed reform of the Office du Niger (chapter 11). In Morocco the leadership of the ministries of finance and economic affairs were instrumental in building consensus and creating a window of opportunity for pursuing reforms.[36] Even centralized states with limited mechanisms for accountability in the sector (Algeria, the Arab Republic of Egypt, and the Republic of Yemen, for example) are beginning to release information to the public, involve citizen groups, and enact changes to increase the accountability of publicly managed irrigation systems.[37]

An adequate legal framework and a clear division of responsibility between the public sector and water users are essential to successful devolution of management to water users, including the ability to set budgets, define what services to provide, and collect payments.[38] Representation of women farmers in water user's associations and gender training of association staff can improve performance of water user's associations. Reliance on women's nongovernmental organizations (NGOs) and women's participation in construction and rehabilitation works has helped achieve active participation of women in water users associations in some successful cases, such as the Dominican Republic.[39]

Greening the green revolution

A remarkable shift to high-input farming is behind agriculture's intensification in irrigated and high-potential rainfed farming areas in transforming and urbanized countries. Exemplified by the green revolution, high-input farming typically involves monocropped fields and a package of modern seed varieties, fertilizers, and pesticides.

Despite its success in dramatically increasing food production and avoiding the conversion of vast amounts of additional land to agriculture, high-input farming has produced serious environmental problems. The mismanagement of irrigation water was just discussed. Additional offsite problems arise from the injudicious use of fertilizers and pesticides: water pollution; indirect damage to larger ecosystems when excess nitrates from farming enter water systems; and inadvertent pesticide poisoning of humans, animals, and nontargeted plants and insects.[40] Fertilizer nutrient runoff from agriculture has become a major problem in intensive systems of Asia, causing algal bloom and destroying wetlands and wildlife habitats.

Equally alarming has been mounting evidence that productivity of many of these intensive systems cannot be sustained using current management approaches. There is growing evidence that soil-health degradation and pest and weed buildup are slowing productivity growth. These trends are best documented in the intensive rice-wheat systems of South Asia (box 8.2).

High-input farming has also reduced biodiversity in local landscapes and genetic diversity in the crops grown.[41] Modern crop varieties often carry similar sources of genetic resistance to production stress, although this is being counteracted by more rapid turnover of varieties and by spending more on breeding approaches that broaden the genetic base or adapt materials to keep ahead of ever-evolving pests and diseases (chapter 7).[42] Preservation of crop and animal genetic resources through ex situ gene banks is supported through global initiatives (chapter 11) and has become an even higher priority because of the need to adapt to climate change.

Faced with these resource-related problems, farmers need assistance to fine-tune their cropping systems and crop management practices to local conditions. More diversified systems can often reduce the need for chemical fertilizers and pesticides (for example, mixed legume-cereal systems), but power, fertilizer, and output subsidies discourage a shift to alternative cropping patterns, as in India's Punjab.[43] Complementary investments in market infrastructure and institutions and dissemination of research and knowledge will also be needed where environmental benefits from diversification would tilt the balance in favor of alternative cropping patterns.

The environmental cost of pollution by fertilizers and pesticides can be reduced by better management of these inputs without sacrificing yields. Integrated pest management that combines agroecological principles with judicious use of pesticides can increase yields and reduce environmental damage (box 8.3).[44] Other knowledge-based improvements in management that are win-win for farmers include using pest-resistant varieties, better timing and application of fertilizer and water, precision farming (using geographic information systems [GIS]), and low-tillage farming (chapter 7).[45]

BOX 8.2 *Resource degradation in rice-wheat systems of South Asia*

The rice-wheat system covers 12 million hectares in the Indo-Gangetic Plain of India and Pakistan, providing a significant share of marketed food grains in India and Pakistan. But intensive and continuous monoculture of rice (summer season) and wheat (winter season) has led to serious soil and water degradation that has negated many of the productivity gains from the green revolution. Soil salinization, soil-nutrient mining, and declining organic matter are compounded by depletion of groundwater aquifers and buildup of pest and weed populations and resistance to pesticides. In India's Punjab, extensive use of nitrogen fertilizer and pesticides has also increased concentration of nitrates and pesticide residues in water, food, and feed, often above tolerance limits. Results from long-term experiments in India and econometric analysis of productivity data over time and across districts in Pakistan's Punjab reveal that soil- and water-quality degradation may have negated many gains from adoption of improved varieties and other technologies.

Sources: Ali and Byerlee 2002; Kataki, Hobbs, and Adhikary 2001.

Despite the promise of integrated management practices, farmers have been slow to take them up. One reason is the subsidies on water and fertilizer that some governments still provide in intensive systems. By making inputs less costly, subsidies encourage farmers to be more wasteful in their use. Another reason is that many of these improved practices are knowledge intensive and require research and extension systems that can generate and transfer knowledge and decision-making skills to farmers rather than provide blanket recommendations over large areas.[46] Farmers will also need greater ecological literacy to better understand interactions in complex ecosystems—an objective of many farmers' field schools on integrated management approaches (chapter 7). A third reason is the negative externality of much environmental damage in high-input farming systems. By driving a wedge between the private interests of farmers and the larger social value of the environmental services they degrade, the systems can lead to significant offsite degradation unless incentives are changed, by taxing pesticides or effectively regulating pollution, for example.

But new forces are at work inducing many farmers to use intensive systems more sustainably. There is a rapidly expanding demand for organic and other environmentally certified products (chapter 5). The high health, quality, and environmental standards of emerging supply chains and supermarkets also compel farmers to shift to better and more sustainable farming practices. Decentralized governance allows greater access to local information and use of local social capital in regulating externalities. Civil society has the capacity to provide technical assistance and help organize farmers and communities to meet the more stringent environmental standards. Community organizations and producer cooperatives were at the heart of the recent expansion of organic export production in East Africa.[47]

BOX 8.3 ***Integrated pest management to control the Andean potato weevil in Peru***

A late blight and the Andean potato weevil are major threats to potato production, reducing yields by a third to a half. To help farmers, the International Potato Center and Peruvian partners started adaptive onfarm research in two potato-growing communities in the Andes in 1991.

The research introduced several integrated pest management practices:

- Chemical control, with selective insecticides
- Agronomic control, adjusting harvest time, soil management, and tillage after harvest
- Mechanical control, such as covers for transport, ditches around potato fields, vegetative barriers, and the elimination of volunteer plants
- Biological control, with the fungus *Beauveria*
- Handpicking adult insects and using chickens to eat larvae.

Although farmers did not adopt all the practices, a before-and-after study showed that farmers could substantially reduce damage and increase their net income on average by $154 per hectare. A cost-benefit analysis using survey data showed an internal rate of return of 30 percent, with all research and development costs included and a service life of 20 years.

Sources: TAC's Standing Panel on Impact Assessment SPIA 1999; Waibel and Pemsl 1999.

Managing intensive livestock systems

Driven by the growth in demand for meat, milk, and eggs, intensive livestock systems are burgeoning in the developing world, a direct consequence of rising per capita incomes and urbanization (chapter 2). This intensification has been assisted by technological change, particularly in animal breeding, nutrition, and health. The results—more productive animals; larger production units that capture economies of scale; and greater integration within the market chain, improving quality and lowering the costs of marketing and transport.

Livestock intensification has also produced environmental problems linked to the move from dispersed production in rural areas to specialized livestock units in urban and periurban areas, now happening on a grand scale in much of Asia. The major environmental threats are the pollution of water and soil with animal waste, especially nitrogen, phosphorous, and highly toxic heavy metals such as cadmium, copper, and zinc. Dense livestock populations also add significantly to the risks of spreading animal diseases and high economic losses. Some of these diseases are also a threat to humans, especially where dense populations of animals and humans come in close contact.

Strategies to manage the environmental and health problems of intensive livestock systems need to alter this pattern of urban concentration. Areas that can absorb higher livestock densities can be identified with GIS technology, superimposing current farming systems and their nutrient balances on ecologically sensitive areas, prevailing human population densities, and infrastructure.[48] Inducing enterprises to relocate to an environmentally more suitable area requires both "command and control" and "market-based" instruments. Command and control measures might include limiting the size of livestock farms (Norway), limiting the livestock density per farm (Germany), and introducing minimum distances between farms (Spain) or between farms and the nearest waterway (Brazil). Market-based instruments include tax rebates for relocation (Thailand, box 8.4), environmental taxes on urban livestock farms, and investment support for onfarm infrastructure to reduce nutrient leaching (countries of the Organisation for Economic Co-operation and Development [OECD]). Tradable manure quota systems, with a government buy-back system to reduce overall animal pressure, have worked in the Netherlands.[49]

One cause of recently emerging diseases such as avian flu is the mix of traditional and intensive production systems in areas densely populated by both people and livestock, as occurs in urban and periurban areas (see focus H).[50] Although the epidemiology of avian flu is not yet fully clear, its spread in East Asia seems accelerated by that mix. The traditional backyard poultry systems concentrated around urban areas allows the continuing—albeit low-level—circulation of the virus, while larger, intensive operations near urban areas, with considerable movement of feed, animals, and people, enable the virus to scale up and spread.

Reversing degradation in less-favored areas

Many less-favored areas have gained little from past agricultural successes in raising yields. Less-favored areas include lands with low agricultural potential because of poor climate, soil, and topography; they also cover areas that may have higher agricultural potential but are underexploited because of limited access to infrastructure and markets, low population density, or social and political marginalization (chapter 2). Less-favored areas account for 54 percent of the agricultural area and 31 percent of the rural population of developing countries (chapter 2). Many of these areas are either hillside and mountain regions (uplands) or arid and semiarid zones (drylands). They are mostly characterized by extensive agriculture, resource degradation, and poverty. Settlement areas in tropical forests, although smaller in their extent and population, are another important category from an environmental perspective, with deforestation contributing to reduced global carbon sequestration and climate change.

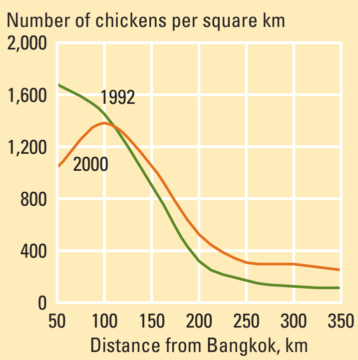
Less-favored regions encompass a broad array of low-input farming systems, including migratory herding in arid areas; agropastoral systems in dryland areas; integrated crop, tree, and livestock production in hillside and highland areas; and managed secondary forest-fallow cultivation at forest margins.[53] Many are environmentally fragile, their soils, vegetation, and landscapes easily degraded. Some, especially upland and forest areas, also protect watersheds, regulate water flows in major river basin systems, sequester large amounts of carbon above and below ground, and are host to a rich array of biodiversity. Few of these environmental benefits are valued in the market place.

BOX 8.4 *Managing poultry intensification in Thailand*

Thailand, as an important player in the global poultry meat market (more than 500 million tons of exports in 2003), has controlled many of the disease risks. A zoning and tax system significantly reduced the concentration of poultry in periurban areas in less than a decade (figure at right). Poultry farmers close to Bangkok had to pay high taxes, while farmers outside that zone enjoyed tax-free status.[51]

Highly pathogenic avian influenza was also controlled, although it has not been fully eradicated. Following an outbreak in late 2003, the Thai government developed disease-free zones with 24-hour movement control and high biosecurity—with thousands of inspectors going door to door to search for diseased animals.[52] The large exporters shifted to cooked meat. The incidence of highly pathogenic avian influenza fell, but two outbreaks in August 2006—in village poultry and a small commercial unit with poor biosecurity—emphasize the need for vigilance.

Thailand is shifting the concentration of poultry away from Bangkok



Source: Steinfeld and others 2006.

Land degradation and deforestation in less-favored areas reduce agricultural productivity and cause the loss of other valuable ecosystem services, including biodiversity habitats. Land degradation is most severe in such hotspots as the foothills of the Himalayas; sloping areas in the Andes, southern China, and Southeast Asia; rangelands in Africa and Central and West Asia; and the arid lands of the Sahel. Most land degradation is the result of wind and water erosion.[54] Soil-nutrient mining resulting from shortening of fallows and very low use of fertilizer is endemic across much of Sub-Saharan Africa. Overgrazing and degradation of pastoral areas are widespread in much of the steppe of North Africa, the Middle East and Central Asia, and the Sahel.

Estimates of the global extent of soil degradation and its productivity impact are scarce and debated. In Sub-Saharan Africa, estimates of productivity losses are generally in the range of 1 percent a year or less,[55] but in extensive areas in Kenya, Ethiopia, and Uganda, they are higher. According to near-infrared spectrometry data, about 56 percent of the land is moderately to severely degraded in the Nyando River Basin in Kenya.[56] On a national scale, costs of land degradation in Kenya may translate into losses of 3.8 percent of gross domestic product (GDP).[57] Soil degradation tends to be a greater problem in upper watershed areas with steep slopes. Intensive grazing has led to gully erosion and the loss of 5 percent of productive area in Lesotho over the course of about 30 years,[58] and in Turkey's Eastern Anatolia region, erosion affects more than 70 percent of cultivated land area and pastures.

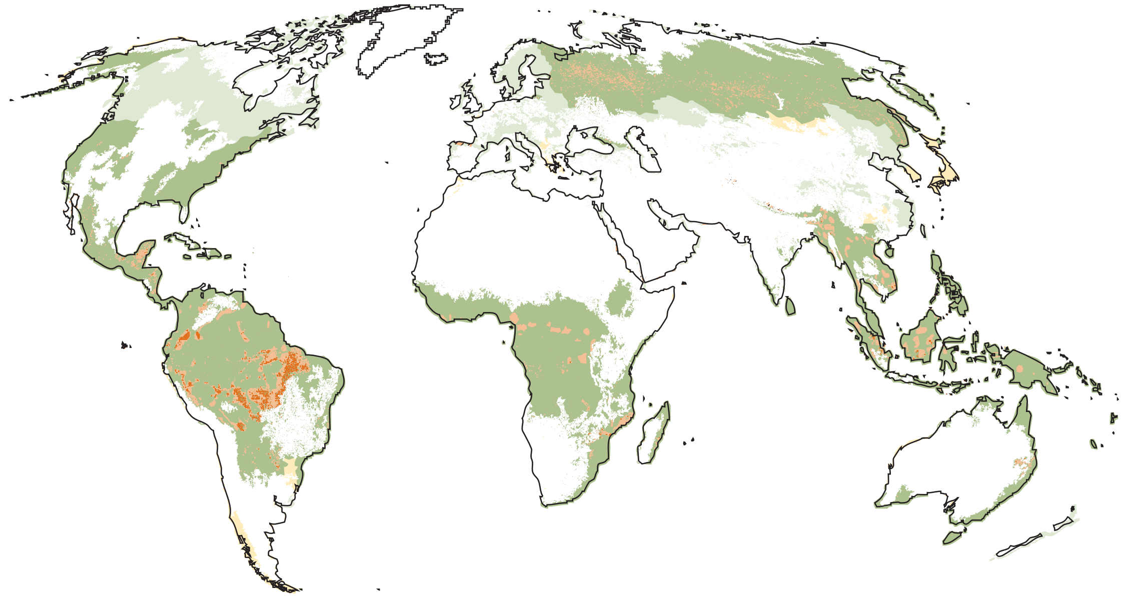
Soil erosion in upper watersheds causes downstream sedimentation and secondary salinization (through salts in irrigation water) in many irrigated areas. For example, in the Tigray region of Ethiopia, soil erosion in upper catchments halved the storage capacity of reservoirs within five years of construction. In Morocco, soil erosion reduced storage capacity of 34 large reservoirs by about 0.5 percent per year. According to one set of estimates, the replacement cost of the storage capacity lost from sedimentation globally could reach $13 billion a year.[59]

The expanding agricultural frontier is the leading cause of deforestation, even though not all conversion and degradation of forest cover is associated with extensive agriculture. Deforestation is occurring most rapidly in the remaining tropical moist forests of the Amazon, West Africa, and parts of Southeast Asia (map 8.2). Deforestation in mosaic lands[60] (where small clumps of forest are embedded in otherwise intensively cultivated agricultural systems, often in close proximity to urban centers) is a small contribution to the overall forest loss, but these forests are important biodiversity habitats and biological corridors.[61]

Because more than half of all species exist primarily in agricultural landscapes outside protected areas, biodiversity can be preserved only through initiatives with and by farmers. This dependence of biodiversity on agricultural landscapes is explicitly recognized in the concept of ecoagriculture (an integrated approach to agriculture, conservation, and rural livelihoods within a landscape or ecosystem context).[62]

In many less-favored regions, population growth is placing enormous pressure on the natural resource base. Until a few decades ago, natural resources were commonly abundant and, once used, could recover through fallows and shifting cultivation. Many of the more fragile lands were not farmed at all or were grazed by nomadic herders. Sparsely settled forests provided hunting and gathering livelihoods for tribal peoples. Today, many of these lands support moderate to high population densities, providing food, fuelwood, water, and housing. Without adequate increases in land or animal productivity to secure their livelihoods, farmers expand their crop areas by shortening fallows and clearing new land—much of which is environmentally fragile and easily degraded—and add livestock to already-overstocked pastoral areas. Sometimes intensification can help reduce this pressure (box 8.5). In transforming and urbanized countries, out-migration is an important livelihood option, but two consequences are an increase in women farmers and a general aging of the farm workforce in many of these areas (chapter 3).

Map 8.2 Many deforestation hotspots are in tropical areas



Source: Lepers and others 2005. Reprinted with permission, © American Institute of Biological Sciences.
Note: Areas are defined as hotspots when deforestation rates exceed threshold values, as estimated from either available deforestation data or from expert opinion.

Strategies for less-favored areas

Public policy interventions to reduce poverty and preserve the environment are warranted in many less-favored regions. Many such interventions have been neglected because of the perception that rates of return on public investments are better in high-potential areas—as was true during the early phases of the green revolution in Asia and as may be true in Africa today. But public investments in roads, education, irrigation, and some types of research and development (R&D) can produce competitive rates of return[63] and positive outcomes for poverty and the environment in less-favored areas. However, some policy interventions aimed at reducing poverty can result in important tradeoffs between poverty and the environment—new road development is a major cause of deforestation.[64]

The form of policy interventions should depend on the type of less-favored region targeted and on the national economic context. The diversity on both counts is considerable. Options include encouraging more out-migration, promoting income diversification into nonfarm activities, increasing recurrent expenditure on safety nets, supporting more intensive agricultural development where it is profitable to do so, and introducing payments for environmental services. Nonagricultural options are generally more viable in transforming and urbanized countries with dynamic nonagricultural sectors—and less so in poor agriculture-based countries with stagnant economies.

Agricultural development in less-favored regions is constrained to varying degrees by fragile, sloped, and already-degraded soils; erratic and low rainfall; poor market access; and high transport costs. Typically a shift to more intensive agricultural production systems that can raise productivity and reduce or reverse the need for further crop area expansions is required. The challenge is to do this profitably while ensur-

BOX 8.5 ***Four trajectories: disappearing or rebounding forests, misery or growth***

Expansion of the agricultural frontier into forested areas has been triggered by several factors, including population pressure, poverty, market conditions, road construction, and off-farm employment opportunities. Major new roads are another powerful driving force of deforestation. Intensifying agriculture can help reduce pressure on forest cover, but the outcome depends on how these factors play out. Sometimes market opportunities make it profitable to continue expansion into forest areas despite intensification in existing fields. Four trajectories are possible.

Deforestation with intensification. Intensification can help slow deforestation if geography or tight labor markets prevent further expansion into forest areas. For example, intensification of rice farming in the valleys in the Philippines absorbed excess labor from hillside farms, allowing forests to recover.[65] But deforestation can continue even with intensification. Forest area dwindled in the Indian Terai where the green revolution increased the value of putting land into agriculture, until a 1980 ban on cutting forests for agriculture. The expansion of soybean cultivation in the Brazilian forest margins is another example of global economic forces at work.

Deforestation with impoverishment. When land use proves unsustainable—soil fertility declines and agricultural incomes collapse—natural regrowth of forests may not occur. Consequently, people leave the land, as with millions of hectares of *imperata* grasslands in Southeast Asia and large areas of apparently abandoned pastures near Belem, Brazil. If this type of unsustainable land use combines with high population pressure, the result is impoverishment and immiseration, as in Madagascar.

Reforestation with intensification. Reforestation is likely to accompany intensification when forest depletion leads to wood scarcity, raising the value of forests, and better tenure makes it possible for households and communities to manage forests. The result: a mosaic of croplands and managed forests, as in parts of Kenya, Tanzania, and the Sahel.

Reforestation with abandonment of rural areas. Forests are rebounding in some regions combined with out-migration (western Europe, Japan, North America, and more recently Eastern and Central Europe). Several developing countries appear to be making this transition from conversion to agriculture to forest regrowth, including parts of Asia (China, the Republic of Korea, peninsular Malaysia, and possibly parts of India and Vietnam), Central America (Costa Rica and the Dominican Republic), Cuba, and Morocco.[66]

Source: World Bank 2007i.

ing the sustainable use of resources at local levels and avoiding negative environmental externalities at higher scales.

Strategies for these areas need to be based on two key interventions: (1) improving technologies for sustainable management of land, water, and biodiversity resources; and (2) putting local communities in the driver's seat to manage natural resources. Both approaches need a supportive policy environment to succeed.

Improving technologies for sustainable resource management. The low productivity of most less-favored areas requires major new technology breakthroughs to secure profitability, reverse resource degradation, and improve livelihoods. After years of neglect, less-favored regions have recently attracted more agricultural R&D attention from public, nongovernmental, and private agencies (chapter 7). Initial efforts targeted natural resource management practices that conserve scarce water, control erosion, and restore soil fertility while using few external inputs (fertilizer). Many of these practices are complex and site specific.

Plant breeding has focused on varieties that are more tolerant of drought and poor soil conditions and that have greater pest and disease resistance. These improvements can produce significant gains in productivity and will be more important as farmers try to adapt to climate change. Improved pest and disease resistance is particularly important to stabilize yields and make farming systems more resilient.

Integrated soil and water management in watersheds has received insufficient policy attention, even though it can result in remarkable improvements in agricultural productivity in many less-favored areas.[67] Better water, soil, and crop management can more than double productivity in rainfed areas with currently low yields.[68] Investments in water harvesting and small-scale irrigation are in many circumstances catalytic—reducing the barriers to adoption of otherwise costly soil and crop management practices by increasing their profitability.

The advent of tubewell and treadle-pump technology in the 1990s was behind the successful transformation in South Asia's poverty triangle—Bangladesh, eastern India, and Nepal's Terai region. Small farmer-controlled irrigation using simple low-cost technologies—river diversion, lifting with small (hand or rope) pumps from shallow groundwater or rivers, and seasonal flooding—also enjoys local success in Africa, especially for high-value horticulture (in Burkina Faso, Mali, Niger, and Tanzania, for example). However, these projects require social capital and community action.

Farmer user groups were key to the success of Nigeria's Second National Fadama Development Project, which invested in irrigation equipment, other farm assets, rural infrastructure, and advisory services. Incomes of the participants of this community-driven project have increased by more than 50 percent on average, between 2004 and 2006. In the dry savannah zone, where farmers invested mainly in small-scale irrigation, average incomes increased by nearly 80 percent.[69]

Incorporating trees into farming systems (agroforestry) is another promising approach that has already had far-ranging impacts in many hillside and agropastoral areas in Africa. New market opportunities have led to an expansion of fruit and nut production by smallholder farmers. In Kenya, fruit trees contribute about 10 percent of total household income regardless of wealth, and about 60 percent of all firewood and charcoal comes from farms. Agroforestry-based soil fertility systems (mainly through rotational fallow or a permanent intercrop of nitrogen-fixing trees) have more than doubled yields and increased net returns on land and labor in the southern African region (chapter 7).

Livestock intensification using integrated agroforestry-livestock production systems in less-favored areas is another approach with high potential payoffs. The common constraint on intensifying traditional livestock systems is the lack of feed.[70] To address that, farmers are improving pasture management (area rotation, silvopastoral systems), producing leguminous fodder crops, and using crop residues and industrial subproducts (feedblocks in northern Africa, cottonseed in West Africa, and fodder trees in Niger). High-quality fodder shrubs that are easy to grow and that generate net returns of $40 per cow per year have already been adopted by about 100,000 East African smallholder dairy farmers; there is potential to expand this to another 2 million smallholders.[71] In Niger, agroforestry parklands have led to a remarkable recovery of degraded soils and provided livestock feed on about 5–6 million hectares (box 8.6).

Conservation farming is another sustainable land management technology that has been adapted to a wide range of conditions (chapter 7). In the Sahel, tree planting and simple and low-cost stone bunding (putting stones around the contours of slopes to keep rainwater and soil within the farming area) retain soil nutrients and reduce erosion, leading to higher and more stable yields and incomes.[72] In the steep hillsides of the Chiapas region in Mexico, the combination of conservation tillage and crop mulching has increased net returns on land and labor.[73]

The uptake of these various practices has been mixed.[74] Some natural resource management practices simply do not offer enough gains in land and labor productivity to make the investment worthwhile.[75] Many are labor intensive and incompatible with seasonal labor scarcities, aging populations, and the increasing role of women farmers. Fallows, terracing, and green manures (dedicated crops grown for their organic matter and nutrients, which are

BOX 8.6 *Agroforestry parklands in Niger turn back the desert and restore livelihoods*

A series of Sahelian droughts in the 1970s and 1980s coupled with strong population growth led to severe land degradation and the loss of trees, animals, and livelihoods in Niger. The ecological and economic crisis triggered a search for solutions involving authorities, technical experts, and communities, with astonishing results. Tree and shrub density has increased 10–20 times since 1975 in several surveyed villages in Niger's Maradi, Tahoua, and Zinder regions. In the past 20 years, tree cover has increased on about 5–6 million hectares without resorting to expensive large-scale tree plantations. (At the previous cost of $1,000 a hectare, agroforestry parklands of this scale could have cost $5–6 billion.)

Key to this transformation was the transition from state ownership of trees to de facto recognition of individual property rights. Instead of chopping down trees in their fields, which in the past belonged to the state, farmers started treating them as valuable assets. Integrated agroforestry parklands (crop-fuelwood-livestock production systems) have developed, including Gao (*Faidherbia albida*), baobab, and other trees and bushes.

Villagers report improvement in soil fertility and livelihoods despite the country's weak economic performance. Sheep and goats increased in number thanks to the fodder from Gao foliage. Women have been the main beneficiaries because they own most of the livestock. Time spent collecting fuelwood, traditionally women's task, has fallen from around two-and-a-half hours a day to half an hour. In villages where livestock herds did not grow, water availability—not the lack of feed—is the main reported constraint. Sales of wood have become an important income source in rural areas in the surveyed villages, especially for the poor.

Sources: Larwanou, Abdoulaye, and Reij 2006; Polgreen 2007; McGahuey and Winterbottom, personal communication, 2007; Reij, personal communication, 2007.

plowed into the soil rather than harvested) also keep land out of crop production, and composting and manuring compete with household needs for energy from scarce organic matter. Natural resource management is also knowledge intensive, and farmers may not have access to appropriate agricultural extension or training. Learning from neighbors turns out not to be very effective for complex natural resource management practices.[76]

Investments in natural resource management, unlike those in single-season inputs such as fertilizer and improved seed, are long term, requiring secure long-term property rights over resources. Farmers will be reluctant to plant trees, for example, if they are uncertain of being able to retain possession and reap the eventual rewards (as in Niger). Communities are more likely to invest in improving common grazing areas and woodlots if they have secure rights to use those resources and can exclude or control outsiders (as in the Tigray Highlands of Ethiopia).[77] Formalizing individual or community land rights is important, as is access to credit for longer-term investments (chapter 6).

Putting local communities in the driver's seat. Adoption of many natural resource management practices requires collective action at community or higher levels. There has been a veritable explosion of community organizations for natural resource management in recent years, driven largely by NGOs that have become active in many less-favored regions. They have also been encouraged by some international development agencies (such as the International Fund for Agricultural Development [IFAD]) to empower poor people, particularly poor women, and to ensure that they participate in new growth opportunities, as in the very successful Southern Highlands Project of Peru.[78] Some governments have also turned to local communities to take over roles formerly fulfilled—usually very inadequately—by the state, such as managing forests in India, rangelands in the Middle East and North Africa, and pastures during the transition from central planning in Mongolia.

Participatory approaches involving farmers and communities are especially important for natural resources management because of the enormous agroecological diversity in less-favored areas and the need to select and adapt technology to fit local needs and conditions. Community approaches can provide the secure property rights and collective action for improving natural resource management. They can also help manage local externalities and mediate between local people and the project activities of governments, donors, and NGOs.

Community organizations that represent the interests of a diverse group of stakeholders, including pastoralists, women and indigenous groups, tend to be more effective at resolving conflicts over natural resource use than central authorities.[79] Some of the more successful community organizations are led by women. Active engagement by women is important because they tend to be more dependent on natural resources in communal areas as farmers and collectors of fuelwood, fodder, and water.[80] Women's participation in community organizations to manage natural resources improves their effectiveness. Survey results of 33 rural programs in 20 countries found higher levels of collaboration, solidarity, and conflict resolution in community organizations that included women.[81]

Collective action for resource management often needs to be at landscape levels, requiring cooperation by groups of farmers or even entire communities.[82] For example, contouring hillsides to control soil erosion and capture water requires a coordinated investment and water-sharing arrangements by all farmers on the same hillside. Watershed development requires cooperation among all the key stakeholders in a watershed, and this may involve one or more entire communities. But ensuring broad participation and sustainable outcomes is challenging because watershed management programs often have winners and losers. Conservation interventions, such as rangeland closure, can cause income losses at least in the short term, particularly for the poor (as in Turkey, box 8.7).

The growth of community organizations is proving a challenge for government ministries responsible for agriculture and natural resources, because they seldom have the

BOX 8.7 *Two tales of community-driven management, watersheds, and pastures*

Environmental sustainability and income trade off in Eastern Anatolia

Soil erosion is one of the most serious problems affecting the sustainability of agriculture in Turkey because as much as a third of the cultivated land and extensive areas of rangelands and mountain pastures have steep slopes. About 16 million hectares, or more than 70 percent of the cultivated and grazed land area in Turkey, are affected by erosion, especially in the upper watershed of the Euphrates River in Eastern Anatolia. Extensive livestock systems are a main culprit. Poor rangeland management has led to extensive soil degradation, limiting the scope for natural forest regeneration, and contributing to greatly increased soil sedimentation.

The Eastern Anatolia Watershed Rehabilitation Project, with strong community involvement, has helped slow soil and forest degradation in the region. It closed forest grazing. It terraced and reforested degraded hillsides. It intensified livestock production and horticulture in the valley. And it compensated for the loss of income from extensive livestock systems. Without taking into account the eventual benefits of reduced sedimentation downstream, the project had an estimated rate of return of about 16 percent and is widely judged successful.

Many households have seen their incomes rise, but the poverty impact of the project has been ambiguous. The main beneficiaries from small-scale irrigation are households with access to springs, the main source of water in the project area. The majority of the livestock are owned by wealthier households with more land and greater ability to switch to intensive livestock systems. Immediate project benefits have been linked to land and water-source ownership, while forest income from fuelwood collection and timber sales—from which the poor could benefit to the same degree—will be received only in the long term, after the restoration of forest cover on the hillsides.

Reconciling environmental sustainability with income generation for the poor has been difficult because of uncertainty about the size and timing of eventual conservation benefits, and unequal access to productive resources in areas of intensive cultivation. After the initial willingness of the communities to agree to forest closures in return for the immediate compensatory benefits, pressure to reopen closed areas for grazing is expected to escalate.

Comanagement of pastures raises herder incomes in Mongolia

Mongolia has the largest remaining contiguous area of common pastureland in the world—home to 172,000 herding families. Pasturelands have never been privately owned, but customary rules governed the traditional pasture management system prior to the period of central planning. With transition to a market economy, private livestock ownership was reintroduced but no longer was governed by traditional institutions. Rapid growth in the number of herder families (more than doubling between 1992 and 1999) and livestock (by about 30 percent) has caused severe pasture degradation. Overgrazing and desertification may affect about 76 percent of pastureland. A successful comanagement approach between state and communities has received active government and NGO legal and technological support (using GIS systems and community mapping) and has begun to fill the institutional vacuum in pasture management.

Adoption of community-based pasture management practices tends to be higher in areas with limited pasture capacity, far away from cities and market centers, and in herder communities with strong social relations. The most problematic issue is resolution of disputes between the herders from different communities. As suggested by a survey of selected sites, incomes have risen between 9 percent and 67 percent during the three years since the beginning of the project. Improvement and protection of community hayfields, establishment of hay and fodder funds, and preparation of additional fodder for the winter are reported to have helped reduce animal losses by an average of 6–12 percent.

Sources: World Bank 2004f; Ykhanbai and Bulgan 2006.

organizational culture or human resources to support participatory approaches. New specialist structures may have to be created, cutting across disciplines and relevant ministries. Alternatively, organizations from the private sector and civil society could be contracted to link central policies and procedures with practices on the ground.

Training and leadership support from outside actors (NGOs) have often succeeded in filling a void in leadership and technical skills in the community and government ministries, even within the context of an institutional vacuum in the trasition period in Mongolia (as in Mongolia, box 8.7).

Sometimes well-intentioned interventions to redress poverty in less-favored areas may backfire and undermine traditional ways of managing common property natural resources. For example, government attempts to help pastoral communities manage droughts and grazing areas in the agropastoral systems of the Middle East and North Africa ended up further degrading farmland and rangeland (box 8.8).

So, despite their promise, community approaches are not a panacea on their own. Acute resource loss, irreconcilable social conflict, a lack of capacity, or simply the absence of a valid community often requires more centralized interventions or at least support from outside agencies. Resolving conflicting interests between pastoralists and agriculturalists in many dryland areas (as in Sudan, Lebanon, and Mongolia), or managing and controlling water resources beyond the immediate watershed, may demand more than what community approaches can deliver. Much remains to be learned about the conditions for them to succeed and be scaled up.

Given the large externalities in less-favored regions, promoting sustainable farming and reducing poverty do not always

BOX 8.8 *Managing drought and livestock in pastoral areas of the Middle East and North Africa*

Most of the agricultural land in the Middle East and North Africa receives less than 400 millimeters of annual rainfall and is devoted to barley-sheep systems that use the available cropping land and the vast grazing areas of the steppe. Agropastoral societies have their own strategies for coping with drought, long a significant factor in the region. Mobile or transhumant grazing practices reduce risks of having insufficient forage in any one location. Reciprocal grazing arrangements with more distant communities provide access to their resources in drought years. Flock sizes and stocking are adjusted to match available grazing resources. Extra animals can be easily liquidated in a drought, either for food or cash. Barley farmers and shepherds diversify into crop farming and nonagricultural occupations, particularly through seasonal migration for off-farm employment.

These traditional risk strategies have managed drought shocks and enabled pastoral societies to survive for many centuries. The interplay between drought and traditional management systems has also helped to keep total flock sizes in equilibrium with the productivity of the pastures, avoiding the long-term degradation of grazing areas. However, the ability to manage drought shocks has declined with population growth, as more people seek to earn a livelihood from the meager resources in these areas, and by more frequent and prolonged droughts associated with global warming. Droughts now bring significant losses of livestock, push many farmers and herders into poverty, and hold back investments in better natural resources management.

Governments throughout the region have intervened to help manage drought losses, but usually on the basis of crisis relief once the drought has set in and without much thought to the longer-term consequences. The most important interventions are feed subsidies for livestock and debt forgiveness, both degrading resources.

Feed subsidies (mostly for barley) have been quite successful in protecting livestock numbers and production during droughts. But they have also accelerated rangeland degradation in the long term by undermining the traditional process of adjusting flock size to interyear climatic variations. Flock sizes have increased sharply in recent years, and grazing practices have changed; many of the animals no longer leave the steppe during the dry season but have their feed and water trucked in. This leads to overgrazing during the dry season, reduces the natural seeding of annual pasture species, disturbs the soil, and contributes to wind erosion, particularly in areas near water and feed supply points. High government procurement prices for barley have also encouraged the mechanized encroachment of barley cultivation onto rangelands, where it cannot be sustained.

While systematic rescheduling of credit for farmers provides some short-term relief to herders and small-scale farmers, this approach has proved of greatest benefit to larger farms—and contributed to the chronically poor debt-collection performance of the region's agricultural development banks. Better alternatives, which need to be explored, would be simple forms of drought insurance, early warnings of drought, and safety nets for the poor.

Source: Hazell, Oram, and Chaherli 2001.

stem environmental degradation. There are few technological or community-driven approaches to resolve the tradeoffs that frequently occur between reducing poverty and environmental degradation—solutions require much more effective mechanisms for managing environmental externalities, including payment for environmental services.

Payment for environmental services

Agricultural landscapes in both less-favored and high-potential areas produce a wide range of valuable environmental services, such as sequestering carbon, harboring biodiversity, regulating water flows, and providing clean water downstream. Farmers receive no compensation for providing these services, however, and so they tend to be underproduced. Many approaches to increasing environmental services are based on demonstrating to farmers the "right thing to do"—forgetting that it's the "right thing" for others and not necessarily for the farmers. Other approaches have attempted to regulate what farmers can and cannot do. Neither approach has worked well nor been sustained over time. Occasionally, win-win technologies can generate both high returns for farmers and high levels of environmental services, but these are few and far between, and may not remain win-win over time as prices change.[83]

The bottom line is that if society wants farmers to undertake natural resource management practices that have benefits outside the farm, society needs to compensate them. This has been attempted at small scales by providing concessionary loans for investments, using food-for-work programs for conservation activities such as tree planting, and supplying key inputs like seedlings without charge. These efforts usually provide only short-term rewards, however, and the incentive they create ends as soon as the rewards end. The benefits of these short-term programs have usually been temporary at best. The emerging approach of payment for environmental services (PES) aims to address this problem.

PES is a market-based approach to conservation based on the twin principles that those who benefit from environmental services (such as users of clean water) should pay for them, and those who generate these services should be compensated for providing them.[84] In a PES mechanism, service providers receive payments conditional on their providing the desired environmental services (or adopting a practice thought to generate those services). Participation is voluntary. The PES approach is attractive in that it (1) generates new financing, which would not otherwise be available for conservation; (2) can be sustainable, as it depends on the mutual self-interest of service users and providers and not on the whims of government or donor funding; and (3) is efficient if it generates services whose benefits exceed the cost of providing them.

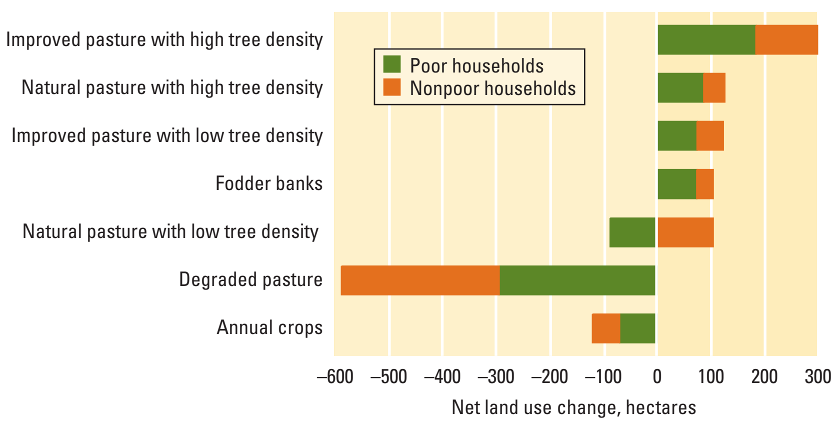
There has been very strong interest in PES programs in recent years, particularly in Latin America. Costa Rica has the oldest program, created in 1997, which at the end of 2005 was paying for forest conservation on about 270,000 hectares, or about 10 percent of forest area. Mexico created a similar program in 2002, and at the end of 2005 it was paying for the conservation of about 540,000 hectares (or about 1 percent of forest area).[85] Most PES schemes in developing countries have focused on retaining forest, but interest is growing in applying the approach to agricultural areas. A pilot project on degraded pastures in Colombia, Costa Rica, and Nicaragua has induced substantial changes in land use, with degraded pastures transformed into silvopastoral systems (where trees and livestock are produced together) (figure 8.3).[86] Despite the expensive and technically challenging practices, poor households are actively participating.

Water users are the most significant current source of funding for PES schemes, mainly through decentralized, watershed-specific schemes, but also through nationwide programs (as in Mexico). Water users paying for watershed conservation through PES mechanisms are domestic water supply systems, hydroelectric power producers, irrigation systems, and bottlers. The potential for watershed payments can significantly expand with a better understanding of the effects of upstream land-use changes on downstream water services.

Carbon payments—under the Clean Development Mechanism or the voluntary (retail) market—are another large potential source of funding for PES (chapter 11). Small-scale farmers can benefit from carbon sequestration payments, but this requires strong local community organizations capable of developing adequate monitoring and verification systems. The *Scolel Té* project in Mexico's Chiapas region mobilized local community and farmer organizations to commercialize carbon through agroforestry. Of the sale price of $3.30 per ton of carbon dioxide, 60 percent went directly to farmers, raising families' local incomes by an average of $300 to $1,800 per year.[87] But many obstacles, including high transaction costs (40 percent in this case) and the need to coordinate the activities of many small farmers to generate meaningful amounts of carbon sequestration, limit participation of small farmers in this market.

If payment schemes are to be used more widely, they will have to ensure that the funding base is sustainable for the long term, directly linking service users and providers. This is easier when there are just one or two large service users with fairly clear actual or potential environmental threats—and when the causes and effects between farm activities and environmental outcomes are fairly well understood. Small

Figure 8.3 With PES, degraded pasture has been converted to sustainable land use in Nicaragua



Source: Computations from Silvopastoral Project GIS mapping data by Pagiola and others (forthcoming).
Notes: Land use changes by poor and nonpoor Silvopastoral Project participants in Matiguás-Río Blanco, Nicaragua (2003–05). Areas converted to other uses with net land-use change of less than 30 hectares are not shown. The poor are defined as households below the national poverty line, using household survey data on income from all sources.

watersheds with a downstream hydropower plant (usually most vulnerable to sedimentation) or domestic water suppliers (affected by contamination and sedimentation) are good candidates. Large basins with multiple users, where downstream impacts are the cumulative impact of myriad upstream uses, are poor candidates. Using PES for biodiversity conservation is also difficult because of the lack of stakeholders with strong financial interests.

Conclusions

Since the 1992 Earth Summit in Rio, it is generally accepted that the agriculture and environment agendas are inseparable. Degradation of natural resources undermines the basis for agricultural production and increases vulnerability to risk, imposing high economic losses from unsustainable use of natural resources. The agriculture-for-development agenda will not succeed without more sustainable use of natural resources—water, forests, soil conservation, genetically diverse crops and animal varieties, and other ecosystem services. At the same time, agriculture is often the main entry point for interventions aimed at environmental protection. It is the main user of land and water, a major source of greenhouse gas emissions, and the main cause of conversion of natural ecosystems and loss of biodiversity. The intricate links between the agriculture and environment agendas require an integrated policy approach.

The large environmental footprint of agriculture on natural resources remains pervasive, but there are many opportunities for reducing it. Getting the incentives right is the first step towards sustainability. Improving natural resource management in both intensive and extensive farming areas requires removing price and subsidy policies that send the wrong signals to farmers, strengthening property rights, providing long-term support to natural resource management, and developing instruments to help manage increased climate risks.

Better technologies and better ways of managing water and modern farm inputs are now available to make intensive farming more sustainable. But their widespread adoption is hindered by inappropriate pricing policies, insufficient training of farmers, and a failure to manage negative externalities. In less-favored regions, new and promising technologies are emerging, but their adoption is complicated by the length of time before payoffs are realized and the need for collective action. One of the more promising recent developments has been devolution of control to local organizations for community natural resource management.

On the positive side, many opportunities exist to harness agriculture's potential as a provider of environmental services. The emergence of new markets and programs for payments for environmental services is a promising approach that should be pursued by local and national governments as well as the international community. Agriculture's role is central to mitigation of climate change and protection of biodiversity, and carbon financing may become an important source of funding for these global public goods (chapter 11). But in many cases, development of markets for environmental services at the local level, with close proximity between service providers and consumers of these services, may be more promising than putting into place national payment schemes when governance and fiscal capacities are weak.