X ENVIRONMENTAL AND RESOURCE CHALLENGES TO FUTURE GROWTH

INTRODUCTION

Finite quantities of land and water worldwide that are suitable for agriculture limit the scope for bringing new natural resources on line for food production. In addition, some contraction in resources for agriculture due to rising pressure to divert resources already in agriculture to nonagricultural uses may partially offset any expansion. This puts the pressure for future food supplies primarily on land already in agriculture. Yet environmental degradation in areas already in production can dampen projected growth in food supplies by eroding the productive capacity of the natural-resource base; any new areas brought under production may be even more susceptible to degradation than are current areas.

Advances in crop productivity may help mitigate degradation-induced slowdowns in the growth of the food supply as agriculture approaches the limits to its expansion. If environmental degradation should exceed expectations or efforts to improve productivity fall short, however, the impact on food supplies could be major. Asia, whose high population densities put more pressure on natural resources than is the case elsewhere, presents a compelling example of degradation trends and efforts to counterbalance productivity losses. More than this, because of Asia's growing importance to the world economy and food supplies, what happens can have worldwide impact.

This chapter examines possible environmental and resource constraints on agricultural production growth and future food supplies. What is the potential for bringing more land resources into agriculture, compared to the likely losses due to urbanization? To what extent will water scarcity limit crop production growth, especially when the trend is for water used in agriculture to be siphoned off to meet growing demands from other sectors? What is the probability that agriculture will bump up against limits by placing too heavy demands on the world's energy resources? Evidence for land degradation, including degradation due to misuse of water resources, is reviewed and estimates of the magnitude of the ensuing crop productivity losses presented. Strategies aimed at raising crop productivity are evaluated, including closing the gap separating yields in farmers' fields from current biophysical limits and raising farmers' yields by setting new, higher biophysical limits: fertilizer use; management of plant genetic resources; and biotechnology. Finally the evidence on potential agricultural effects of global warming is reviewed.

CROPLAND – WILL THE BASE FOR FOOD SUPPLY SHRINK OR EXPAND?

Scarcity of data and difficulties in interpretation pose a challenge for anyone hoping to account fully or accurately for the amount of land being added to, and taken out of, cultivation. While some country-level data or estimates on net changes in cropland are available, a look at broader estimates about the potential for bringing new land under production, as well as for losing arable land to nonagricultural uses, is needed to give an idea of the scope of the problem over the next couple of decades.

Potential for Cropland Expansion

In 1993, worldwide crop area was approximately 1,070 million hectares, 70 percent of it harvested for cereal and root crops. The food-crop portion alone of total crop area may go up an additional 50 million ha by 2010, virtually all in the developing world (see projections in the Appendix and Chapter XII). The crop area harvested in 1993 is about one third of the projected theoretical maximum area potentially suitable for crop production of 3,300 million ha out of a total of 12,400 million ha in land resources (consisting of arable land, permanent pasture, forest and woodland, and other land) (Buringh and Dudal 1987). Most of this potential cropland (2,600 million ha), is classified as having low or medium capability for crop production, with only 700 million ha in high-potential areas. The remaining 10,100 million ha are classified as having zero potential for growing crops

But is the theoretical maximum a practical one? Most current cultivation takes place on relatively good agricultural land; additional land converted to cropland would be expected to have lower productivity levels than does the existing land stock. Conversion to the maximum would also mean taking land out of uses—such as forest and rangeland—where they are fulfilling essential functions. According to Kendall and Pimentel (1994), the world's arable land might be expanded by at most 500 million ha, at productivity below present levels. Nearly 90 percent of this potential cropland is located in developing countries, but it falls mainly outside Asia, in Sub-Saharan Africa and Latin America. Asia has less room for expanding cropland, since farmers there already cultivate nearly 80 percent of the potentially arable land (Plucknett 1995). So the scope for greater food production coming from more agricultural land is limited, particularly for Asia. The land gained by expansion will probably produce less food than in existing crop areas, since it is likely to be of low potential, possibly better suited for uses other than growing crops.

Loss of Cropland to Urbanization

Juxtaposed against these limits to the expansion of cropland in Asia is the specter of inroads made on cropland by nonagricultural uses. While historically more potential cropland has been converted to agricultural activities and grazing than urbanization has taken away, it has been suggested that current, unprecedented increases in urban populations may constitute a potential threat to agricultural production, through the loss of prime agricultural land (Brown and Kane 1994).

In 1975, 38 percent of the world's population, or 1.5 billion people, lived in cities. By 1995, that number had grown to 2.6 billion, or 45 percent of the population. The developing and developed worlds, however, faced quite different levels of urbanization: for example, urban population accounted for 70 percent of the total in both North America and Europe, but only 34 and 35 percent in Africa and Asia, respectively. From 1995 levels, overall urban populations are projected to grow at 2.3 percent per annum until 2025, when they will number over 5 billion, and constitute a majority (61 percent) of the population. Nearly all urban population growth, about 90 percent, will occur in developing countries, where roughly 150,000 people are added to the urban population every day.

In Asia, a threshold of sorts will be met in 2020. In that year, one of every two Asians is projected to be an urban resident, almost double the 1980 figure (27 percent). Among East and Southeast Asian countries, only Thailand, Myanmar and the PRC are expected to still have large rural populations (at 33 percent, 40 percent, and a projected 49 percent, respectively). In South Asia, by contrast, only the most urbanized countries, such as Pakistan, will hit this 50 percent urban threshold by 2020; in Nepal, only 21 out of every 100 residents will live in cities (WRI 1998).

Does urbanization mean that cities will sprawl to take over vast amounts of agricultural land? For all developing countries, estimates put the annual loss of arable land transformed to urban uses due to expanding urban populations at 476,000 ha (USAID 1988). Between 1990 and 2020, this would mean a loss of nearly 10 million ha of land to urban uses. While for Asia (as elsewhere), data on urban absorption of land previously under cultivation are scarce, present-day urban densities for selected cities provide a clue as to how much land cities hosting populations the size of these 2020 projections might need.

In the PRC, for example, in order to support projected urban populations in 2020 at the existing urban density of about 150 people per hectare, urban area must expand beyond 1993 levels by approximately 2.4 million ha, or an average of 87,000 ha per year. In Southeast Asia, projections from 1993 to 2020 using population densities found in major cities of each country show Indonesian cities taking over 416,000 ha, Philippine cities occupying an additional 232,000 ha, and Thai urban areas increasing by roughly 74,000 ha. In South Asia, nearly 1.5 million ha in India and Pakistan combined (623,000 ha in India and 802,000 ha in Pakistan) will be converted to urban uses. While in order to chart actual cropland loss to urbanization, other factors would have to be considered, including the type of land converted into urban uses and the final urban per capita land area, this exercise does give some idea of the scale of possible land loss.

Net Expansion/Loss of Cropland

To determine actual changes in cropland requires balancing out many factors beyond expansion and contraction of crop area, for many of which data are scarce, easily misinterpreted, or both. The case of the PRC illustrates the challenges of finding and interpreting information. It also shows that despite the challenges, estimates have been possible, at least in this case and for some historical or short-term projections.

In the PRC, as elsewhere, figures of land leaving agriculture may be overestimated, in that they indicate gross rather than net conversion of land to nonagricultural use. In other words, while land converted from agricultural to nonagricultural use is reported, land reclaimed for agricultural use is not. In addition, the categories used to describe how land use is shifting may be misinterpreted as meaning an unequivocal loss to the food supply. Widely reported reductions in cereal area in the PRC between 1990 and 1994, for example, stem in significant part from conversion of cereal land to inland aquaculture and from shifts of land to other crops, like vegetables or fruits, and from temporary fallowing of land due to the declining profitability of cereals during this period (Alexandratos 1996; Lindert 1996). Moreover, for land- and water-scarce countries such as the PRC, conversion of cropland to higher-value uses often constitutes a win-win situation for both economic development and environmental sustainability (Paarlberg 1997). After 1994, as the profitability of cereals once again improved, harvested cereal area also increased, from 86 million ha in 1994 to 91 million ha in 1996.

Despite the difficulties in making precise projections, given the amount of cropland still available for cultivation, likely land conversion to urban and other uses does not present a serious threat to food supplies on an Asia-wide basis. In several Asian countries, however, withdrawal of land from agriculture due to urbanization will probably contribute to reductions in production growth, with only limited potential to compensate for this loss by expanding into new arable areas. Moreover, even where there is an ample margin to expand agricultural area, overall crop area is expected to grow only slowly (see also Chapter XI).

WATER RESOURCES – DOES SCARCITY ENDANGER FUTURE FOOD SUPPLY?

Despite legitimate concern about whether cropland will be sufficient to meet agricultural demand, the resource base that may pose the most serious threat to future global food supplies is water. In many regions of the developed and developing worlds, groundwater is being depleted as pumping rates exceed the rate of natural recharge. While mining of both renewable and nonrenewable water resources can be an optimal economic strategy, it is clear that groundwater overdrafting is excessive in many instances. In parts of the North China Plain, for example, groundwater levels are falling by as much as one meter per year; in portions of the southern Indian state of Tamil Nadu heavy pumping is estimated to have reduced water levels by as much as 25–30 meters in a decade (Postel 1993).

The potential for increasing food production by expanding irrigated area or tapping into new sources of water supply is limited by rising costs. Both South and Southeast Asia have felt the trend of rising costs in irrigation development over the last few decades. In India, for example, the real costs of new irrigation have doubled since the late 1960s and early 1970s; in Sri Lanka, they have tripled. Indonesia has seen irrigation development costs go up 200 percent, while in the Philippines costs have increased by more than 50 percent and in Thailand by 40 percent (Rosegrant and Svendsen 1993). The result of these increases in costs (combined with declining cereal prices) is low rates of return for new irrigation construction.

Coupled with rising environmental concerns about irrigation (see the section on land degradation below), reduced rates of return to new irrigation have greatly slowed the rate of expansion of irrigated areas. This is a worrisome trend for global food supplies: irrigated area accounts for nearly two thirds of world rice and wheat production and thus plays a much larger role than rainfed land in global (and Asian) food production, so that growth in irrigated output per unit of land and water is essential if growing populations are to be fed.

Turning to nontraditional sources of water may provide some relief under particular conditions, but this path does not hold the answer to Asia's need for new water supplies. Desalination offers an infinite supply of fresh water, but at a high price, and will not be a significant factor in most of Asia. The reuse of wastewater will similarly make an important contribution only in the most arid regions, where the cost of new water supplies is very high. Water harvesting (the capture and diversion of rainfall or floodwater to fields to irrigate crops) will be important in some local and regional ecosystems. Like methods tapping other nontraditional sources, results may be important locally and in certain low-potential areas, but will not have a significant impact on global food production and water scarcity; reliance on irrigated area remains (Rosegrant 1995; Rosegrant and Meinzen-Dick 1996).

To make matters worse, rapidly growing household and industrial demand for water will increasingly be seeking to draw on the same water as irrigated agriculture. In much of developing Asia, new urban water supplies cost three to four times more than already developed existing water sources (World Bank 1993b). Since irrigated agriculture generally accounts for around 80 percent of water diversion in Asia, transfer of some of this water to meet growing urban demands is often seen as a relatively low-cost alternative to developing new water supplies. This raises a particularly difficult challenge: to save enough water from agriculture without sacrificing crop yields and output growth, while at the same time allowing reallocation of water from agriculture to rapidly growing urban and industrial uses.

Meeting the challenge involves improving the efficiency of agricultural water use so as to generate physical savings of water as well as economic savings. In agriculture, more can be done to make sure water is used by crops before it can either escape into the air (increasing crop output per unit of evaporative water loss), or into the ground (improve water use before its loss to water sinks). Further gains could come from lessening degradation such as salinization and other water pollution that diminishes crop yield per unit of water (see below). It is unclear how large each of these potential water savings might be, but estimates of water use efficiency in irrigation give some idea. For the developing world, this falls typically in the range of 25 to 40 percent. Making urban supply systems more efficient may also help: for the developing world's major metropolitan areas, "unaccounted-for water," much of which is direct water loss to the oceans, is often 50 percent or more (Rosegrant and Shetty 1994; Rosegrant 1995).

These inefficiencies seem to imply that there is a potential for huge savings from existing uses of water and that the challenge can easily be met. The potential savings of water in many river basins, however, are neither as dramatic nor as easy to achieve as implied by these efficiency figures. Because much of the water "lost" from irrigation systems is reused elsewhere (Seckler 1996), improvements in irrigation-system efficiency do not necessarily mean overall efficiency gains. In fact, even though individual water users in these basins are inefficient, whole-basin water-use efficiencies are quite high due to reuse and recycling of drainage water. In sum, efficiency gains from existing systems may prove to be limited. This significantly narrows the scope for overcoming the threat of water scarcity to the food supply by reducing wastage in water use from existing sources.

The directions for water-policy reform to address these serious challenges were introduced in Chapter V. Dealing with water scarcity and quality will require both substantial new investments in urban water systems and irrigation systems and reform of water management. The reform of water-demand management for both groundwater and surface water will be essential in meeting new water demands by saving water in existing uses and in improving the quality of water and soils. The necessary reforms will involve changing the institutional and legal environment in which water is supplied and used to one that empowers water users to make their own decisions regarding use of the resource, while providing correct signals regarding the real scarcity value of water, including environmental externalities. Reforms will need to be tailored to the specific institutional context in any given region, but important elements include establishment of secure water rights for users; decentralization and privatization of water-management functions (to private sector or community-based organizations); and the use of incentives, including markets in tradable property rights, pricing reform and reduction in subsidies, and effluent or pollution charges.

ENERGY – PLENTIFUL ENOUGH TO SUPPORT A GROWING FOOD SUPPLY?

Direct forms of energy (farm machinery, animal and human labor) and indirect (manufacture of agricultural chemicals, farm machinery and irrigation) have been essential factors in bringing about increases in agricultural productivity. The green revolution raised the energy intensity of agricultural production a hundred-fold or more in some cases (but from a near-zero base), with plant breeding aimed at designing plants that could cope with high levels of fertilizer use (Kendall and Pimentel 1994). In developed countries, the manufacture and operation of farm machinery account for the largest, albeit declining, share of commercial energy uses in agricultural production (52 percent in 1982), followed by chemical fertilizers with an increasing share (44 percent in 1982). In developing countries, however, fertilizers take first place, accounting for 69 percent of energy share in 1982 (Bhatia and Malik 1995).

Despite increases in energy intensity in agriculture, agricultural uses of energy account for only a small fraction of total energy consumption. In 1990, production of fertilizer, the most energy-intensive agricultural input, required only about 2 percent of global energy consumption; this level is expected to decline to about 1.6 percent by 2020. Considerable energy efficiency improvements in fertilizer plants after the energy crisis of the 1970s help explain this low figure. Possibilities for further increasing energy efficiency lie on the horizon, in the globalization and privatization of fertilizer markets as well as the removal of energy subsidies and inefficient organizational structures (Bumb and Baanante 1996).

Furthermore, overall energy use in agriculture constitutes only a small part of agricultural production costs. During the last 20 years, direct farm expenses in the United States for fuels, oils, and electricity have varied between 3.5 and 7.4 percent of total farm production expenses. Together with expenditures for pesticides and fertilizers, the cost share was between 11.2 percent and 17.2 percent of total farm production expenses. A study of the effects of large energy price changes on the agricultural sectors of different regions concluded that even extremely large and sustained increases in energy prices lead only to small declines in agricultural output and land prices, even in the very energy-intensive United States (McDonald et al. 1991). The threat to Asian agriculture—which uses far less energy—from higher energy prices would be minimal.

Although overall energy use has been increasing during the last decades, there is some evidence that energy intensity has been decreasing in developed countries. Bonny (1993) showed a downward trend of direct energy use in French agriculture since the 1970s, citing a 30 percent drop in direct and indirect energy intensity in the production of one ton of wheat in a region in France between 1955–60 and 1990. Finally, energy prices are projected to decrease for the next decade: according to the World Bank (1996b), crude oil prices are expected to fall from US $51.22 per barrel in 1980 (constant 1990 dollars) to US $13.23 per barrel by 2005.

Energy use clearly was an essential factor in bringing about the green revolution in the 1960s and will remain essential for achieving food security in the coming decades. However, with the prospects of increasing energy efficiency, with lower energy prices, and with only a small proportion of overall energy devoted to agriculture, energy availability may not be a serious resource constraint to long-term agricultural growth.

LAND DEGRADATION – WHAT EXTENT AND PRODUCTIVITY EFFECTS?

Land degradation can lead to lower crop yields, through several avenues. It may require farmers to increase input levels just to maintain yields, reducing total factor productivity; it may lead them to convert the land to lower-valued uses; or it may cause them to temporarily or permanently abandon their plots. Within the last decade, efforts to examine the extent of degradation and its productivity impact, worldwide and regional, have been stepped up, allowing the beginnings of an empirical look at the threat environmental degradation poses to future food production.

Extent of Land Degradation

Oldeman, Hakkeling, and Sombroek (1990) provide the most comprehensive assessment of global land degradation to date; further work on regional degradation and productivity effects build on it. It classifies the main types of land degradation as soil erosion from wind and water, chemical degradation (loss of nutrients, soil salinization, urban-industrial pollution, and acidification), and physical degradation (compaction, waterlogging, and subsidence of organic soils). Out of the total land resource base, Oldeman, Hakkeling, and Sombroek estimated that 1,964 million ha, roughly 16 percent, suffered from some degree of degradation. By far the greatest cause of this degradation, roughly 84 percent, is erosion, with water erosion accounting for a majority, 56 percent, and wind erosion responsible for a further 28 percent). Water, then, plays an important role in land degradation: in addition to water erosion's large impact, water-related effects (for example, from salinization and waterlogging) are incorporated within overall figures for chemical degradation (12 percent of degraded land), and physical degradation (4 percent of degraded land).

In South and Southeast Asia, degradation levels are proportionally even higher: the Assessment of Human-Induced Soil Degradation in South and Southeast Asia (ASSOD) found that agricultural activity had led to the degradation of 27 percent of all land and to the deforestation of 11 percent (Scherr 1999). Out of the 1,843 million hectares surveyed under ASSOD, loss of topsoil from erosion by water affected 19 percent, while erosion by wind affected 5 percent.

Productivity Effects of Land Degradation

Not all this degradation affects crop productivity. Of all degraded land worldwide, an estimated 562 million ha, or just under 30 percent, is degraded agricultural land. Here, chemical degradation plays a much larger role than it does in degradation overall, accounting for 40 percent of degraded land. Similarly, in Asia, the degradation figures given above refer to all land, not just arable land, which constituted only part, roughly 21 percent, of the ASSOD survey area. Of the arable area surveyed, the ASSOD study found 30 percent suffered from a decline in soil fertility, and a further 17 percent was degraded because of water-related problems—10 percent from salinization and 7 percent from waterlogging (Van Lynden and Oldeman 1997 as cited in Scherr 1999).

Are these trends alarming for future food supplies? As prevalent as degradation seems from these figures, ultimately the threat to food production must be gauged in relation to degradation's effects on productivity. Building on work that measures degradation's extent, more studies that measure the productivity effects of degradation have emerged, for Asia as elsewhere.

For Asia, all human-induced soil degradation in the period since World War II has resulted in an average cumulative productivity loss of 12.8 percent for cropland, according to estimates by Oldeman (1998) as cited in Scherr (1999). Over roughly the same period (1945 to 1990), South Asia has suffered a slightly higher accumulated loss of yield of approximately 16.5 percent, according to Crosson (1998), using productivity loss figures for the region from the FAO (1994). Both figures from Asia fall well above a global estimate of 5 percent for the same period (as cited in Crosson 1998).

In terms of percentage of productivity lost, Asian rainfed areas have been hit only slightly harder than those under irrigation, but only because the extent of the area hit is somewhat larger and not because the productivity effects of degradation were substantially greater. Dregne and Chou (1992) estimate that 10 percent of rainfed areas in Asia, as opposed to a slightly smaller 8 percent of irrigated land, have experienced a loss in productive potential of at least 25 percent. Furthermore, over half of all rainfed lands in area, and more than one third of irrigated land in Asia, experienced a loss of 10 percent of productive potential. Some information is also available on productivity loss due to specific types of degradation: soil erosion, soil fertility decline, and the water-related land degradation problems of salinization and waterlogging.

Soil losses have led to yield declines in crops in rainfed upland areas, as well as in perennial crops in plantation systems, according to separate case studies undertaken in different parts of Asia. In the upland rainfed areas of Java, Indonesia, erosion has caused annual yields for several crops (corn, soybeans, and groundnuts considered jointly, and cassava considered separately) to decline an estimated 4 to 7 percent (Magrath and Arens 1989 as cited in Crosson 1998). Mingsarn and Benjavan (1999) cite two studies on yield decline for perennial tree crops due to loss of soils in Sri Lanka. In one, loss of topsoil on a Sri Lankan tea plantation resulted in yield declines of only 0.7 kg per hectare from an average yield of 1,634 kg per hectare. In the other (Samarappuli et al. 1997), rubber yields fell by 175 kg per hectare per year for every 1-cm loss of topsoil. That productivity effects of soil loss have been shown to vary under different conditions is in keeping with expectation: soil depth, structure, and slope in a given area, combined with known crop needs, would all help shape the point at which soil loss would be expected to hurt productivity substantially. To the extent that knowledge of the resource base in Asia and elsewhere improves, therefore, hypotheses about the extent of the productivity effects of soil losses in Asia can be refined and tested.

Losses in soil fertility can also mean yield declines. In the Asian environment, this effect is commonly observed in intensive rice monoculture systems as well as of rice-wheat systems, through a decline in the partial factor productivity of nitrogen fertilizer (Hobbs and Morris 1996; Pingali, Hossain, and Gerpacio 1997). When fertilizer levels are held constant, intensive rice culture can, over time, reduce the soils' ability to meet the plants' nitrogen requirements, especially in the later period of crop growth, thereby affecting crop yields and resulting in a declining partial factor productivity of nitrogen (Cassman et al. 1994). Declining soil nitrogen supply is caused not by the prolonged use of chemical fertilizers, but rather by intensive rice monoculture systems themselves (Cassman et al. 1994, Pingali and Rosegrant 1998). Cassman and Pingali (1993) estimate the magnitude of yields foregone due to declining soil nitrogen supply to be around 30 percent over a 20-year period, at all nitrogen levels, based on long-term experiment data from the IRRI farm. Farmers have been increasing the amount of chemical fertilizers applied in order to maintain their yield levels. Because of a lack of nutrient balance in fertilizers applied, increased application has not stemmed an observed trend of increased incidence of phosphorus, potassium and micronutrient deficiency (De Datta, Gomez, and Descalsota 1988). Because of increased cropping intensities and the predominance of year-round irrigated production systems, which have depleted naturally occurring soil nutrients, phosphorus and potassium deficiencies in particular are becoming widespread across Asia in areas not previously considered to be deficient (Pingali and Rosegrant 1998).

Still, at least for the PRC and according to one study, the impact of soil fertility declines on crop yields has not as yet been too severe. Lindert (1996) shows mixed trends in soil quality between the 1930s and the 1980s and concludes that soil degradation is neither nationwide nor concentrated in the more erosion-prone areas. In order to evaluate these conflicting trends in economic terms, Lindert estimates agricultural production functions for the period of 1981–86 with agricultural outputs and inputs in 1985. His results indicate that acidity, alkalinity, and potassium, which have not deteriorated since the 1930s, are also the most significant soil-chemistry parameters for agricultural yields in the PRC. In addition, shifts away from the main staple crops (grains, oils, and cotton) towards vegetables and animal products show positive effects on soil quality. Other trends may also brighten prospects: improved security of property rights, for one, by encouraging on-farm conservation investments, might actually advance soil conservation efforts in the future. Not all accounts for the PRC are as encouraging, however. Other experts find strong signs of degradation other than soil fertility losses hitting the agriculturally most favorable areas of the PRC. The degradation stems from deforestation, overgrazing, and salinization (see, for example, Huang and Rozelle 1995).

That the water-related degradation problems of salinization and waterlogging are particularly serious in the PRC and elsewhere in Asia should come as no surprise, given the importance of water management and the extent of irrigated agriculture in the region. Intensive use of irrigation water in areas with uneven toposequence and poor drainage can lead to a rise in the water table due to the continual recharge of groundwater. In semiarid and arid zones this leads to salinity buildup, while in humid zones it leads to waterlogging.

Salinization can occur when evapotranspiration exceeds rainfall, causing a net upward movement of water through capillary action, causing a concentration of salts on the soil surface. High water tables prevent the flushing of salts from the surface soil. The overall effect can be serious even when the groundwater itself is not saline; over the long term, salt can build up with evaporation of continuously recharged water of even low salt content (Moorman and van Breemen 1978). In the short term, salinity buildup leads to reduced yields; in the long term, it can lead to abandonment of cropland (Samad et al. 1992; Postel 1989; Mustafa 1991). Excessive irrigation and poor drainage (especially seepage from unlined canals) can induce salinity problems, with poor irrigation system design and management often driving factors. Postel (1989) estimated that 24 percent of irrigated land worldwide suffers from salinity problems, with several of the most affected countries—the PRC, India, and Pakistan, in a group that also included the United States and the then-Soviet Union—located in Asia.

The PRC's salinity problems date back centuries. By 1992, 7.7 million ha (more than 15 percent of total irrigated area), mostly in the North China Plain, was said to suffer from the combined effects of salinity and alkalinity (Huang, Rosegrant, and Rozelle 1996). The North China Plain and far-west regions, where large-scale irrigation has expanded rapidly in the past several decades, bear the brunt of the country's salinization problems; more recently, though, these areas have started to face serious water shortages (Huang and Rozelle 1995).

In Pakistan, salinity affected large areas in Sind Province after the introduction of extensive irrigation, which led to a rise in the water table from a depth of 20–30 m to 1–2 m within 20 years (Moorman and Van Breeman 1978). In India, Dogra (1986) estimates that salinity problems afflict nearly 4.5 million ha. Other examples from South Asia can be found in Chambers (1988), Abrol (1987), Dogra (1986) and Harrington et al. (1992).

In higher-rainfall areas, such as East India, rain flushes out accumulated salts, relieving salinity buildup. Still, in these zones similar causes—excessive water use and poor drainage—lead to another type of degradation that also lowers productivity, waterlogging. Waterlogged fields have lower productivity levels because of lower decomposition rates of organic matter, lower nitrogen availability, and accumulation of soil toxins. In the case of wheat, low plant populations in some areas can be attributed to waterlogging, especially when it occurs early in the growing season, during the germination and emergence stages. Hobbs et al. (1996) report for the Nepal Tarai that waterlogging reduced yields by half a ton per hectare. Throughout India, Dogra (1986) estimates area affected by waterlogging at 6 million ha (slightly exceeding area affected by salinization).

In some geographic regions, then, land degradation may be of overriding importance, leading to yield declines (or greater use of inputs to counteract degradation's effects), lower-value uses of the area, or even abandonment of plots. Still, the aggregate effect on productivity has not yet reached the stage where it poses a serious threat to aggregate food supply in Asia. If rates of degradation accelerate dramatically, particularly in high-potential areas (due to continued intensive use—see Chapter VI) but also in low-potential areas (because of pressure to expand agriculture there), the story could change dramatically, placing future food supply at risk.

IMPROVED CROP PRODUCTIVITY – THE KEY TO A SECURE FOOD SUPPLY?

Asian food production can rise through expansion of cropping area and increases in cropping intensity or through improvements in agricultural productivity. Given the projected slow growth in crop area in the future (see Chapter XII), higher agricultural productivity will have to bear most of the burden for achieving the necessary production rates to meet global food demand. Yet crop-yield growth has already slowed significantly in Asia (see Chapter V) and land degradation has also started to take a toll on yields (see above). In addition, new sources of water to meet agricultural needs are increasingly expensive to tap, while room for efficiency gains from existing sources may not be sufficient (see above). Will agricultural productivity, as the main engine of agricultural production growth, be able to keep up with global food needs, or are the biophysical yield limits already in sight?

Along with a theoretical maximum of arable area across the globe comes a biophysical limit of food production for the earth. It is reached when all land suitable for agriculture is cropped and irrigated, the potential yield on each field attained, and the remaining suitable grazing land grazed. The potential crop yield on any given piece of land has its own specific upper limit, determined by soil type, climate, crop properties, and available irrigation water. It is reached when the farmer selects the optimal combination of crop species and management practices (Penning de Vries et al. 1995).

Maximum theoretical yields, the highest limit of biological potential for specific crops at given locations, are generated on the basis of photosynthetic potential, land quality, length of the growing season, and water availability. They have been calculated in grain equivalents (with rice in milled form) by Linneman et al. (1979). Biophysical limits vary from one region to another due to different underlying conditions in the agricultural sectors.

Asia has a comparatively low biophysical limit, with an estimated maximum production of 13 tons per hectare per year. In South America, on the other hand, the potential is 18 tons per hectare; in Africa, 14 tons per hectare; in North and Central America, 11 tons per hectare, and in Europe and Australia, 10 tons per hectare. As measured in 1990–92, a wide margin separates actual yields, which vary from 0.7 to 3.8 tons worldwide per ha per season, on average, from these theoretical maximum figures. Thus, despite the slowdown in yield growth over the past 15 years, overall yield trends by country and region indicate ample room for yield improvement for most crops and regions against the theoretical maximum (Plucknett 1995).

That ample room exists for realizing gains in crop yields, however, is no cause for complacency, as the data on slowdown in yield growth underlines. Agricultural research at several levels will be essential. Some of it must be aimed at sustaining existing crop yields—productivity maintenance research to counter threats, for example, of evolving pest populations. Another portion must target ways of closing the gap between farm and research-station yields (which stand reasonably close to the theoretical ceilings), by reviewing the role fertilizer can play in future crop productivity and by investigating new techniques, including improved and extended resistance to biotic and abiotic plant stresses using existing plant genetic resources. Finally, strategic research aimed at raising the theoretical maximum yield ceilings, primarily through advances in genetic manipulation and biotechnology, is also needed (Plucknett 1995). Such gains are expected to translate into some yield improvements on farmers' fields (and not merely to widen the gap between realized and theoretical yields). Still, most strategies to improve crop productivity do contain some downside risk—some deleterious effects to the environment and/or future crop productivity—that must be kept in mind.

Fertilizer—Raising Yields or Damaging the Environment?

The role of fertilizer in raising yields is well documented, but excessive use may pose risks to the environment. Can continued expansion of fertilizer use support the yield gains necessary to meet effective food demand in the next decades without damaging the environment? Global fertilizer use increased from 64 million tons in 1966 to 158 million tons in 1988, then declined to 134 million tons by 1993 before increasing again to 158 million tons by 1996 (FAO 1998). The dip in global fertilizer use at the beginning of the 1990s resulted primarily from steep declines in fertilizer application in the reforming economies of Eastern Europe and the former Soviet Union (Bumb and Baanante 1996).

In Asian developing countries, fertilizer consumption increased rapidly during the last three decades, from 6 million tons in 1966 to 75 million tons in 1996. Thus the share of developing Asian countries in total fertilizer consumption rose dramatically from 9 percent in 1966 to 48 percent by 1996. As could be seen in Chapter V, fertilizer application rates are extremely high in some Asian developing countries, in particular the PRC, the Republic of Korea, and Viet Nam, and relatively high in most other countries of the region. At the same time, there is substantial potential for increased application in Myanmar, in most of South Asia other than high-intensity agricultural regions such as the Indian Punjab, and to a more moderate extent, in the Southeast Asian countries of Indonesia (particularly outside of Java), the Philippines, and Thailand.

With high long-term growth rates in fertilizer use, declining growth rates in yield, and very high fertilizer levels in relatively favorable areas of Asia, increasing amounts of fertilizer are being used to maintain current yield levels (although the yield declines are due not to fertilizer per se, but to the intensive systems themselves; see above). In areas like West Java in Indonesia, the Indian Punjab, and parts of the PRC, fertilizers are used at or above economically optimum levels at the border prices that would prevail in the absence of subsidies. In much of East Asia, further increases in fertilizer application will be small, but there is considerable room for improvement in fertilizer-use efficiency, nutrient uptake rates, and nutrient balance (Rosegrant and Pingali 1994).

Bumb and Baanante (1996) estimated effective demand growth for fertilizer, taking into account foreign-exchange availability, exchange rate, crop and fertilizer prices, the development of irrigation and other infrastructure, and the impact of policy reforms on fertilizer demand. During the 1990-2020 period, global fertilizer demand is projected to increase

1.2 percent per year and by a rapid 2.1 percent per year in Asia. In absolute terms, this means the world would use about 208 million tons in 2020, up from 144 million tons in 1990. Asia would virtually double its fertilizer consumption, from 53 million tons in 1990 to 101 million tons in 2020.

Can the production of fertilizer keep up with its projected effective demand? The projections of supply potential developed by the World Bank/FAO/UNIDO Industry Fertilizer Working Group (1994) and the International Fertilizer Development Center (Bumb 1995) suggest that the world will have the capacity to produce between 147 and 163 million tons of fertilizer nutrients in the year 2000. In order to meet the projected effective demand in 2020, an additional 55 to 71 million tons of nutrients will have to be produced. Assuming the lower capacity figure for 2000, fertilizer production should be increased at an annual rate of 1.4 percent during the 2000–2020 period to satisfy the projected effective fertilizer demand. Given the 5.7 percent annual growth in fertilizer production during the 1960–90 period and continued low energy prices, reaching this required growth should not be difficult. Bumb and Baanante (1996) also show that raw materials are not likely to be a constraint in meeting future global fertilizer demand.

The one constraint that could slow the expansion of fertilizer capacity is continued low fertilizer prices. In 1993 the real price of urea dropped to only one third of its 1980 price before beginning to recover and in 1995 was still only 60 percent of the 1980 value. The 1995 prices of diammonium phosphate, phosphate rock, potassium chloride, and TSP were also in the range of 50 to 60 percent of their 1980 values. World Bank (1996b) projections indicate that fertilizer prices will be stable or slightly lower through 2005. If these price levels constrain future investment in fertilizer production capacity, fertilizer prices could increase in later years. Although this would improve efficiency of fertilizer use, it would also induce a reduction in the growth of its use; the net result might be negative effects on crop yield growth.

Are the levels of fertilizer used in Asia a threat to the environment? The two major direct environmental effects of high levels of fertilizer use are nitrate leaching or runoff and eutrophication. Nitrates can leach from the soil or run off in drainage water when the supply of nitrogen from fertilizer and other sources exceeds nitrogen uptake by plants. Nitrates that leach into drinking water supplies can cause severe health problems. Eutrophication occurs when fertilizer is carried by soil erosion and water runoff into lakes, rivers, or other water bodies, potentially causing excess growth of algae, oxygen depletion, and fish mortality. These side effects are of considerable concern in Western Europe and parts of North America and policies are being put in place to selectively reduce fertilizer use there (Leuck et al. 1995). There is little evidence to date of nitrate leaching and eutrophication from fertilizer use in Asia, however. With the possible exception of intensively cultivated areas of East and Southeast Asia and pockets of high fertilizer use elsewhere, fertilizer use in Asia is low enough so that nitrate leaching and eutrophication do not pose a significant problem.

In developing Asia, as elsewhere, then, some danger from fertilizer to the environment and human health could develop. With fertilizer use in Asian developing countries likely to increase greatly over the next decades, emphasis must be placed on improving fertilizer use efficiency to limit additional surface and groundwater pollution. Much of the danger can be mitigated through more appropriate use of fertilizer, particularly removal of policies, such as fertilizer price subsidies, that encourage its overuse. In this way, the important yield gains from proper fertilizer use need not be negated in order to preserve the environment.

Plant Genetic Resources—A Narrowed Base?

Concerns about long-term effective use of fertilizer have combined with fears about lost genetic diversity through agricultural modernization to focus attention on the need to define how best to use the plant genetic base to help boost crop productivity and meet future food supply. Can plant genetic resources sustain further growth in food-crop yields, so that farmers' results approach the promise held by physical limits to crop productivity? Deriving the answer involves maintaining the resources in a way that heighten their chance of contributing to future yield gains.

Genetic resources can be conserved *ex situ* (not in the original or natural environment), or *in situ* (where naturally recurring). *Ex situ* strategies preserve plant seeds and propagating parts in gene banks, preventing the loss of species and subspecies. *In situ* conservation allows observation of the evolution of species as they interact with pests and pathogens (Smale and McBride 1996). *In situ* conservation of genetic resources may be an important complement to *ex situ* conservation because it allows adaptive and evolutionary processes to continue and may provide as yet unknown genetic characteristics for future breeding (Wright 1996; Smale and McBride 1996). Since these processes are longer-term in nature, though, for the foreseeable future crop-yield increases will rely on germplasm drawn from breeding lines stored *ex situ* (Wright 1996; Evenson and Gollin 1994).

Global *ex situ* storage of germplasm is substantial for the major food crops. Approximately 75 to 90 percent of the estimated genetic variation in the major crops and about 50 percent for minor crops is found in gene banks (Wilkes 1992). Concerns have been expressed, however, about the availability of information on sources, propagation techniques, basic characteristics, and the quality of some of the germplasm held in gene banks (McNeely et al. 1990). Even to maintain adequately, evaluate thoroughly, and document properly the system of germplasm banks already in place—without trying to expand its coverage of genetic diversity—will require sustained funding.

Although the available germplasm is characterized by wide genetic variation, the number of varieties actually tapped and utilized to develop new varieties is relatively small at any given time. This practice has led to the criticism that the development of modern rice and wheat varieties has narrowed the genetic base in farmers' fields, thereby increasing the threat of disastrous yield declines if, for example, genetic resistance to an insect or disease breaks down.

This criticism is based on a narrow understanding of genetic diversity in terms of just a couple of its many dimensions. Criticism usually focuses on spatial diversity and ignores trends even in that measure, at least for some crops. For rice, a decline in spatial diversity may well have followed the introduction of modern varieties in the 1960s. For wheat, on the other hand, spatial diversity (measured as the concentration of leading varieties in farmers' fields at a given time) is on the rise and is greater now than in the early 20th century (Smale 1996; Smale and McBride 1996). And for both rice and wheat, components of genetic diversity other than spatial diversity have improved over time. They include temporal diversity (average age and rate of replacement of cultivars); polygenic diversity (the pyramiding of multiple genes for resistance to provide longer-lasting protection from pathogens); and pedigree complexity (the number of landraces, pureline selections, and mutants that are ancestors of a released variety) (Evenson and Gollin 1994; Smale 1996).

In short, genetic diversity is multi-dimensional and extraordinarily complex, as well as difficult and expensive to measure. Trends in genetic diversity of cereal crops are mainly positive. This diversity, moreover, can do more than just protect against large downside risk for yields: it has in fact been generated primarily as a byproduct to breeding for yield and quality improvement and provides a pool of genetic resources for future yield growth. The threat of unforeseen, widespread, and catastrophic yield declines striking as the result of a narrower genetic base must be gauged against this reality.

Biotechnology—Higher Yield Ceilings?

The key to tapping the potential represented by the available genetic resources (and to increasing genetic diversity) will increasingly be the application of biotechnology techniques in tandem with conventional plant breeding. Biotechnology for agriculture includes

- agricultural microbiology;
- cell and tissue culture to propagate plant species more rapidly and facilitate “wide crosses” (crosses between different species);
- new diagnostic methods using monoclonal antibodies or nucleic acid probes to identify diseases and viruses;
- genetic mapping techniques for faster identification of useful genetic material to make conventional plant breeding more efficient; and
- genetic engineering to incorporate “alien” or novel genes into plant species (Persley 1994; Leisinger 1995).

The benefits from biotechnology include the introduction of higher plant resistance to pests and diseases; the development of tolerance to adverse weather conditions; the improvement in nutritional value of some foods; and ultimately the increase in the genetic yield potential of plants. While conventional breeding can have similar aims, genetic engineering can create “transgenic” crops that include genetic material that would otherwise never or only in extremely rare cases belong to a certain species (Kathen 1996), with a potential for greater gains made in each category.

The main successes of biotechnology thus far have been in improved pest and disease resistance, increasing yields through reduction in yield losses and extension of potential areas for production of high-yielding crops, rather than direct increases in crop-yield potential. A recent survey of releases of transgenic plants in developing countries identified 159 releases, nearly one half of which conveyed herbicide resistance, one third provided insect resistance, and the remainder virus-resistance, product-quality and other improvements (Kathen 1996).

Biotechnology research is currently dominated by the private sector in developed countries: it is estimated that some US $900 million was spent on agricultural biotechnology research and development in 1985, of which US $800 million was spent in developed countries and US $550 million by the private sector (Livernash 1996). The International Agricultural

Research Centers (IARCs), after a relatively slow start, have been increasing their research in crop-related modern biotechnology. Over the 1985–95 period, about US $260 million have been provided for international agricultural biotechnology programs, including US $206 million for 25 international agricultural research programs and about US $7 million for four international biotechnology networks (Cohen 1994).

The small share of developing countries in biotechnology research is partly due to time lags caused by the development of a complex and expensive technology that originated in the developed world. But it is also a function of what appears to have been a conscious decision on the part of developing-country research centers and the IARCs to "go slow" on biotechnology. This approach stemmed from the perception that (a) biotechnology research had not yet reached the state of "tool development" where large expenditures would be justified; (b) biotechnology research in the modern era of intellectual property rights is inherently a private-sector activity; and (c) the support system for the IARCs and National Agricultural Research Institutes (NARs) is oriented towards the development of technology, not upstream science (Evenson and Rosegrant 1993). Although all three justifications have some validity, since most current agricultural biotechnology research undertaken in developed countries is aimed at plants suitable for temperate climates, it will be crucial to increase biotechnology research aimed at the situations prevalent in developing countries in order to give these countries access to the next-generation yield potentials (Livernash 1996). In addition, more active biotechnology research in developing countries may be needed to help compensate for deleterious effects should new biotechnology products from the developed world replace exports from the developing world, as well as to guarantee proper compensation of biotechnology development based on developing-world genetic resources (Leisinger 1995). It will also be important for IARCs to react quickly to new developments in this area, given the fast pace of research and, in particular, decisions on property rights.

Fortunately, new institutional arrangements between developed and developing countries have been put in place recently and some developing countries, like the PRC and India, have increased their annual budgets for their research institutes. The IARCs could play an essential role in developing local biotechnology capacity, sharing information across countries, and collaborating with private-sector partners (Livernash 1996). This process would be greatly facilitated by the removal of unnecessary barriers to the free movement of plant materials, clarification of biosafety regulations, and provision of improved property rights protection for new products (Yudelman 1996). If funding and collaboration efforts between international centers continue to grow, biotechnology will provide a significant boost to crop production in the next century, proving particularly beneficial to developing countries with strong technological potential (Commandeur and von Roozendaal 1993 as cited in Leisinger 1995).

At the same time, given the reliance of biotechnology on new combinations of genetic elements, there are some uncertainties about potential negative effects, as underscored by the reluctance among some consumers to accept products generated by biotechnology. Will new creations crowd out native species, to the ultimate detriment of the gene pool? What are the hazards of a dangerous substance being created, then unleashed (or evolving into something dangerous after release)? Significant research into the extent of the danger is needed; policies that ensure caution as regards release are already a step in this direction.

CLIMATE CHANGE—DIFFERENT CROP PRODUCTIVITY EFFECTS FOR DEVELOPING VS. DEVELOPED WORLD

According to many studies, in the coming decades, global agriculture faces the prospect of a changing climate, which might adversely affect the goal of meeting global food needs. The prospective climate change consists of global warming and associated changes in hydrological regimes and other climatic variables, such as higher temperatures, shorter growing seasons, changing moisture regimes, and extreme weather patterns. It also includes secondary effects on social and economic systems induced by increasing concentrations of greenhouse gases from human activities, especially carbon dioxide (CO_2), which is projected to double by the year 2100, producing an expected temperature rise in the range of 1.5°–4.5°C (Wolfe 1996; Downing 1993; Kendall and Pimentel 1994).

Global warming could have both negative and positive effects on agriculture. A 1°C increase in mean annual temperature may advance the thermal limits of cereal cropping in the mid-latitude Northern Hemisphere by 150–200 km (Schimmelpfennig et al. 1996). At higher latitudes, increased temperatures can lengthen the growing season and ameliorate cold-temperature effects on growth. In warmer mid-latitude environments, adverse effects of climate change include increased pests and disease on crops and livestock, soil erosion, and desertification due to more intense rainfall and prolonged dry periods, as well as reduced water resources for irrigation (Downing 1993). Despite the many studies on global warming since the 1980s, however, there is no consensus on the impact of three major variables on agriculture: the magnitude of regional changes in temperature and precipitation, the magnitude of the beneficial effects of higher CO_2 on crop yields, and the ability of farmers to adapt to climate changes (Wolfe 1996).

Sensitivity studies of world agriculture to potential climate changes have indicated that global warming may have only a small overall impact on world food production, because reduced production and yields in some areas are offset by increases in others. Tropical regions, however, including many Asian regions, may suffer negative impacts from droughts, due to the nonlinear relationship between temperature and evapotranspiration, even though climate changes in these regions are expected to be less. These regions will also face greater difficulties in shifting planting dates, as they are limited more by rainfall than by temperature (Reilly 1995). Although results vary by climate-change scenario and by study, regions critically vulnerable in terms of resources to support their populations and projected decreases in water available to plants include parts of the semi-arid tropics and sub-tropics, such as western Arabia, southern Africa, or eastern Brazil, and some humid tropical and equatorial regions, such as Southeast Asia and Central America (Downing 1993). Most studies also conclude that changes will benefit Japan and the PRC.

Moderate global warming can have positive impacts on crop yields. Most plants growing in experimental environments with enhanced CO_2 levels exhibit a "CO_2 fertilization" effect that increases crop yields. Under experimental conditions, for rice, wheat, and more than 90 percent of the world's plant species, the estimated effect from a doubling of CO_2 is a 30-percent yield increase. For maize, millet, sorghum, and sugar cane, the effect is a much lower 7-percent yield increase (Schimmelpfennig et al. 1996). Under field conditions, with CO_2-stimulated weeds, potential lack of water and other nutrients, yield increases are estimated to be only one quarter to one third of the effect under experimental conditions (Kendall and Pimentel 1994).

In order to assess the potential impact of climate change on agriculture and food supply, complex climate, crop growth, and economic/food trade models have been linked. Between 1989 and 1992, a comprehensive study of alternative scenarios for the direct effects of greenhouse gas-induced climate changes on crop yields (wheat, rice, maize, and soybean) was conducted at 112 sites in 18 countries with the help of crop-growth models. The study concluded that with a continuation of current trends in economic growth rates, partial trade liberalization, and medium population growth rates; with assumed modest farm-level adaptations to climate change; and without the CO_2 fertilization effect; the estimated net impact of climate change would be a reduction in global cereal production of up to five percent by 2060. This global reduction could be largely overcome by major forms of adaptation such as installation of irrigation. The climate change would increase the disparities between developing and developed countries: production in the developed world could benefit from climate change and production in developing nations could decline. In scenarios that simulate more aggressive economic and farm-level adaptations to changing climate and that include the CO_2 fertilization effect, negative global cereal-yield impacts are nearly eliminated (with estimated yield changes in the range of +1.0 percent to –2.5 percent) and persist only in developing countries (Rosenzweig et al. 1993).

Similar scenarios focusing on results in Asia showed large ranges of crop-yield swings with doubling of CO_2. Matthews et al. (1995, as cited in Rosenzweig and Hillel 1998) largely bear out the result of lower yields in more tropical areas (up to a 30-percent drop), and higher yields at higher latitudes (up to a 38-percent rise), at least for rice and given current varietal vulnerabilities. One study for the southern PRC suggested higher temperatures would extend northward by as much as 10 degrees of latitude the area suitable for double- or triple-cropping rice (Jin et al. [1995] as cited in Rosenzweig and Hillel [1998]). Rising sea levels could also encroach on agricultural lands, a particular threat for Bangladesh and also for Malaysia (Karim et al. [1994] and Parry et al. [1992] for the two countries, respectively, both as cited in Rosenzweig and Hillel [1998]).

More recent studies concur that the negative effects of climate change on agriculture are likely to have been overestimated by studies that do not take into account broader economic and environmental implications or account for economic adjustments. Utilizing a modeling approach that captures some of these adjustment processes, Darwin et al. (1995) conclude that

- global changes in temperature and precipitation patterns are not likely to endanger food production for the world as a whole;
- farmer adaptations are the main mechanisms for keeping up world food production under global climate change;
- costs and benefits of global climate change will not be equally distributed around the world; and

- although water supplies are likely to increase as a whole under climate change, regional and local water shortages could occur.

The impact on crop yields is generally more positive: world cereal production increases by between 0.9 percent and 1.2 percent, even without the CO_2 fertilization effect (Darwin et al. 1995).

Prospective global temperature increases will occur gradually and not until far into the next century; crop yield reductions and economic losses due to global warming appear manageable (perhaps even positive over the next few decades). Thus, global warming will have little or no impact on global food production through the year 2010, but could increasingly disrupt Asian agriculture in the more distant future.

CONCLUSIONS

Asia is fast approaching its limits in terms of area available for cropland, and Asian agriculture may literally lose ground to urbanization. Likewise, development of new irrigation is likely to be slow for Asia, principally due to its high costs. Nontraditional water-development options are not realistic alternatives in enough areas to solve the problem or are also too expensive. Here too, the nonagricultural sector’s growing demands threaten to siphon water from agriculture and reduce productivity. While some gains in efficiency of water use may mitigate this effect, complex tradeoffs are involved. Environmental degradation is widespread and its productivity effects are beginning to be felt. While these are not yet at a level that threatens the food supply, impacts are being felt primarily in high-potential areas and are direct byproducts of precisely the technologies used to date to boost yields, for example, overuse of fertilizer and improper management of irrigation systems. If not countered, this trend could spell danger in the future, especially given the aforementioned limits to expansion.

Other avenues for yield growth being built into research strategies are undertaken to close the gap between the yields farmers achieve and theoretical maxima and to push up those maxima. At the same time, buffers to catastrophic yield declines now or in the future are starting to be more explicitly factored into strategies for preserving genetic diversity on site and in germplasm banks.

The broad conclusion is that environmental and resource constraints are not intrinsically limiting to the necessary growth in crop production to meet Asian food demand in the coming decades. But continued weakness in environmental policies could lead to significantly increased resource degradation; any negative changes of unexpected magnitude or in a shorter period of time than expected could mean a slowdown in projected agricultural production growth significant enough to pose a real danger to food security.

For land, policies to counteract degradation should be targeted toward high-risk zones. In these zones, significant public investments in research, technology development, extension services, and rural infrastructure may be necessary to stabilize or reverse degradation. In addition, high risk should be defined not just by the extent of degradation, but also by crop-productivity effect, taking into account the area's importance to overall food supply. More broadly, land degradation can also be mitigated through policy reforms, such as the establishment of property rights to land, market and price reforms, and the elimination of subsidies to agricultural inputs.

For water, many questions remain unanswered. Can significant real water savings be achieved through improved water-management policies? What will be the impact on food production and food security of transfers of saved water out of agriculture? Understanding the contributions of water-management and -investment policies to future food security would provide important guidance to national and international policymakers and could generate large benefits for food producers and consumers in developing countries. But it is clear that both significant new investments in water-supply and sanitation systems and irrigation systems and reform of water-demand management will be necessary. Water management will need to move to market-oriented allocation methods as well as community-based management.

In any scenario, improvements in crop yields must occur for future food security to be guaranteed. The threat of land and water degradation and scarcity only up the ante in this regard. And awareness has been raised through experience with the environmental consequences of techniques that aimed to, and did, substantially improve crop yields, staving off a danger to world food supplies in the past: more care must be taken in the design and implementation of continued efforts to further boost yields, lest they inadvertently have the opposite effect. That said, raised awareness should not prevent careful evaluation of risks and benefits. While efforts to preserve and improve genetic diversity need to be stepped up and made more sophisticated, explicitly taking into account evolutionary pressures on plants and pathogens, a strong foundation for this exists. And, while the unknowns in biotechnology or the potential risk from a misstep may be great, there are also potentially great rewards from steps already known to carry less risk; these must be pursued.

While it may seem unrealistic to expect simultaneous improvement in all these areas, especially given the complexity and amount in each area that is still unknown, the fact that the set of policies necessary to encourage food-production growth while protecting the environment is quite consistent across the resource issues reviewed here should heighten chances that they can be conveyed and implemented. In the broadest sense, these are the same policies that have been discussed in several other chapters and several other contexts above, to improve the flexibility of resource allocation in agriculture: removal of subsidies and taxes that distort incentives; establishment of secure property rights; investments in research, education and training, and public infrastructure; better integration of international commodity markets; and a greater inclusion of populations in Asian economies into these markets.