

AGROECOSYSTEMS

Agroecosystems provide the overwhelming majority of crops, livestock feed, and livestock on which human nutrition depends. In 1997, global agriculture provided 95 percent of all animal and plant protein and 99 percent of the calories humans consumed (FAO 2000). Agroecosystems also contribute a large percentage of the fiber we use—cotton, flax, hemp, jute, and other fiber crops.

Globally, agroecosystems have been remarkably successful, when judged by their ability to keep pace with food, feed, and fiber demands (Box 2.4 Taking Stock of Agroecosystems). Per capita food production is higher today than 30 years ago, even though the global population doubled since then. However, agriculture faces an enormous challenge to meet the food needs of an additional 1.7 billion people—the projected population increase—over the next 20 years.

Historically, agricultural output has increased mainly by bringing more land into production. But the amount of land remaining that is both well suited for crop production (especially for annual grain crops) and not already being farmed is limited. A further limitation is the growing competition from other forms of land use such as industrial, commercial, or residential development. Indeed, in densely populated parts of India, China, Indonesia, Egypt, and Western Europe, limits to expansion were reached many years ago. Approximately 2.8 billion people live in or near agroecosystems (not including adjacent urban areas) (Wood et al. [PAGE] 2000).

Intensifying production—obtaining more output from a given area of agricultural land—has thus become essential. In some regions, particularly in Asia, farmers have successfully intensified production by raising multiple crops each year,

irrigating fields, and using new crop varieties with shorter growth cycles. On high-quality, nonirrigated lands, farmers have intensified production mainly by abandoning or shortening fallow periods and moving to continuous cultivation, with the help of modern technologies. Agricultural intensification is widespread even on lower-quality lands, particularly in developing nations. Intensification has also been significant around major cities (and to an unexpected extent, within cities), principally to produce high-value perishables such as dairy products and vegetables for urban markets, but also to meet subsistence needs.

The unprecedented scale of agricultural expansion and intensification has raised concerns about the state of agroecosystems. First, there is growing concern about their productive capacity—can agroecosystems withstand the stresses imposed by intensification? These stresses include increased erosion, soil nutrient depletion, salinization and waterlogging of soils, and reduction of genetic diversity among major crops. There is also concern about the negative impacts of agriculture on other ecosystems—impacts that are often accentuated by intensification. Examples include the harmful effects of increased soil erosion on downstream fisheries

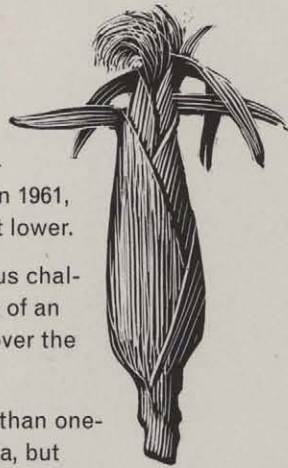
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Conditions and Changing Capacity

Box 2.4 Taking Stock of Agroecosystems

Highlights

- Food production has more than kept pace with global population growth. On average, food supplies are 24 percent higher per person than in 1961, and real prices are 40 percent lower.
- Agriculture faces an enormous challenge to meet the food needs of an additional 1.7 billion people over the next 20 years.
- Agroecosystems cover more than one-quarter of the global land area, but almost three-quarters of the land has poor soil fertility and about one-half has steep terrain, constraining production.
- While the global expansion of agricultural area has been modest in recent decades, intensification has been rapid, as irrigated area increased, fallow time has decreased, and the use of purchased inputs and new technologies has grown and is producing more output per hectare.
- About two-thirds of agricultural land has been degraded in the past 50 years by erosion, salinization, compaction, nutrient depletion, biological degradation, or pollution. About 40 percent of agricultural land has been strongly or very strongly degraded.



Key

Condition assesses the current output and quality of the ecosystem good or service compared with output and quality of 20–30 years ago.



Changing Capacity assesses the underlying biological ability of the ecosystem to continue to provide the good or service.



Scores are expert judgments about each ecosystem good or service over time, without regard to changes in other ecosystems. Scores estimate the predominant global condition or capacity by balancing the relative strength and reliability of the various indicators. When regional findings diverge, in the absence of global data weight is given to better-quality data, larger geographic coverage, and longer time series. Pronounced differences in global trends are scored as "mixed" if a net value cannot be determined. Serious inadequacy of current data is scored as "unknown."

FOOD PRODUCTION

Since 1970, livestock products have tripled and crop outputs have doubled, a sign of rising incomes and living standards. Food production, which was worth US\$1.3 trillion in 1997, is likely to continue to increase significantly as demand increases. Nonetheless, soil degradation is widespread and severe enough to reduce productivity on about 16 percent of agricultural land, especially cropland in Africa and Central America and pastures in Africa. Although global inputs and new technologies may offset this decline in the foreseeable future, regional differences are likely to increase.

WATER QUALITY

Production intensification has limited the capacity of agroecosystems to provide clean freshwater, often significantly. Both irrigated and rainfed agriculture can threaten downstream water quality by leaching fertilizers, pesticides, and manure into groundwater or surface water. Irrigated agriculture also risks both soil and water degradation through waterlogging and salinization, which decreases productivity. Salinization is estimated to reduce farm income worldwide by US\$11 billion each year.

WATER QUANTITY

Irrigation accounts for fully 70 percent of the water withdrawn from freshwater systems for human use. Only 30–60 percent is returned for downstream use, making irrigation the largest net user of freshwater globally. Although only 17 percent of agroecosystems now depend on irrigation, that share has grown; irrigated area increased 72 percent from 1966 to 1996. Competition with other kinds of water use, especially for drinking water and industrial use, will be stiffest in developing countries, where populations and industries are growing fastest.

BIODIVERSITY

Agricultural land, which supports far less biodiversity than natural forests, has expanded primarily at the expense of forest areas. As much as 30 percent of the potential area of temperate, subtropical, and tropical forests has been lost to agriculture through conversion. Intensification also diminishes biodiversity in agricultural areas by reducing the space allotted to hedgerows, copses, or wildlife corridors and by displacing traditional varieties of seeds with modern high-yield but uniform crops. Nonetheless, certain practices, including fallow periods and shade cropping, can encourage diversity as well as productivity.

CARBON STORAGE

In agricultural areas the amount of carbon stored in soils is nearly double that stored in the crops and pastures that the soils support. Still, the share of carbon stored in agroecosystems (about 26–28 percent of all carbon stored in terrestrial systems) is about equal to the share of land devoted to agroecosystems (28 percent of all land). Agricultural emissions of both carbon dioxide and methane are increasing because of conversion to agricultural uses from forests or woody savannas, deliberate burning of crop stubble and pastures to control pests or promote fertility, and paddy rice cultivation.

Data Quality

FOOD PRODUCTION

Value, yield, input, and production data are from the Food and Agriculture Organization (FAO) national tables, 1965-97. Consistency and reliability vary across countries and years. Ecosystem analysis requires more spatially disaggregated information. Fertility constraints are spatially modeled from the soil mapping units of FAO's Soil Map of the World. Global and regional assessments of human-induced soil degradation are based primarily on expert opinion. Developing reliable, cost-effective methods for monitoring soil degradation would help to both mitigate further losses and target restoration efforts.

WATER QUALITY

There are no globally consistent indicators of water quality that relate specifically to agriculture. In agricultural watersheds, the quantity of pesticides and nutrients—nitrogen and phosphorus—are good indicators of pollution from leaching and surface runoff. In mixed-use catchments it is much more difficult to separate from other sources such as human effluents and pesticides applied in gardens and public recreation areas. Pesticide data are more expensive to monitor. Data on suspended solids from soil erosion are also scarce and difficult to interpret.

WATER QUANTITY

Irrigated area is assessed using the Kassel University global spatial data, which indicate the percentage and area of land equipped for irrigation but has some inconsistencies in scale, age, and reliability of source. Irrigation water use data are derived from country-specific tabular data sets on irrigated area, water availability and use, and water abstraction. Little crop-specific information is available on irrigated area and production. Global estimates of rainfall from the University of East Anglia are based on spatial extrapolations of monthly data from climate stations over a 30-year period. Even though the resolution of these data is coarse, it allows assessment of both spatial and temporal variability.

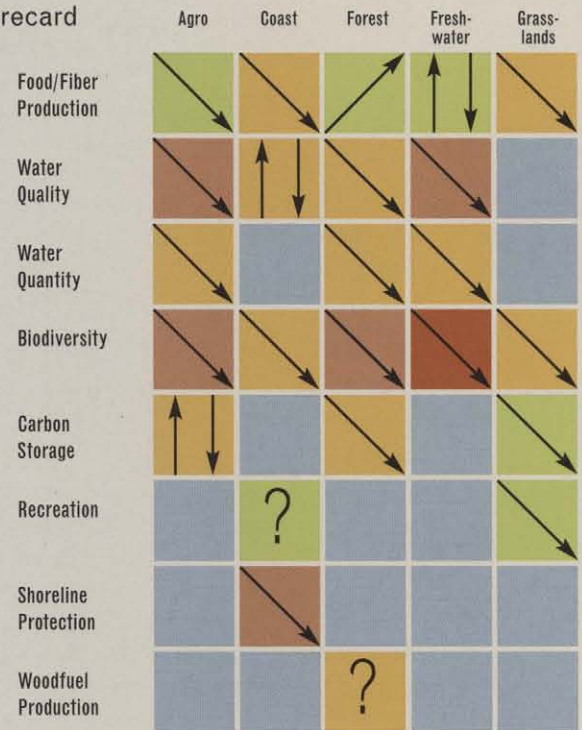
BIODIVERSITY

World Wildlife Fund for Nature (WWF) global spatial data describe potential natural habitats and ecoregions. These were developed from expert opinion and input maps of varying resolution and data, but the data do provide a general understanding of the spatial patterns of natural habitats. Genetic diversity data are compiled from major germplasm-holding institutions. Area adoption data for modern varieties of cereals are compiled from survey and agricultural census.

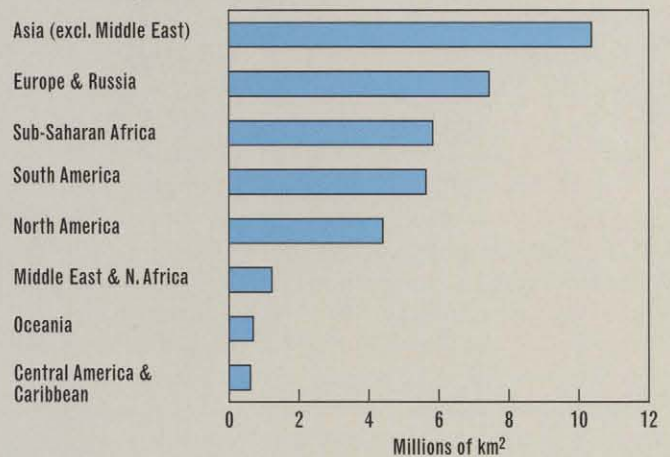
CARBON STORAGE

Storage capacity is modeled for vegetation and soils based on carbon storage capacity by land cover type at a resolution of half a degree for a single point in time. Data would be improved by better characterization of agricultural land-cover types and their vegetation content. Soil carbon data were derived for Latin America using FAO and the International Soil Reference and Information Centre's Soil and Terrain database.

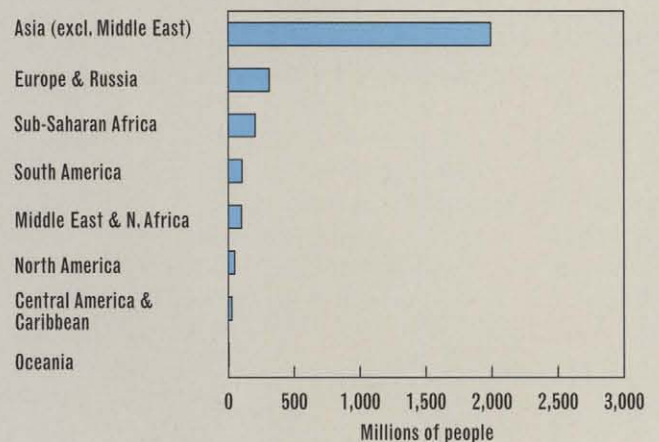
Scorecard



Area of Agroecosystems



Population of Agroecosystems



and reservoirs and the damage to both aquatic ecosystems and human health from fertilizer and pesticide residues in water sources, in the air, and on crops. Agricultural practices also have even broader consequences for biodiversity and for alteration of the global carbon, nitrogen, and hydrological cycles (Thrupp 1998; Conway 1997).

Characterizing Agroecosystems

EXTENT AND GROWTH

Agriculture is one of the most common land uses on the planet and agroecosystems are quite extensive. Determining their exact extent depends on how they are defined.¹ The PAGE study, making use of satellite imagery, defined agricultural areas as those where at least 30 percent of the land is used for cropland or highly managed pasture (Box 2.5 The Global Extent of Agriculture). Using this definition, agroecosystems cover approximately 28 percent of total land area (excluding Greenland and Antarctica). This includes some overlap with forest and grassland ecosystems because land-use is often quite fragmented spatially, with agricultural plots forming part of a mosaic of uses—agriculture alongside forest or grassland areas. The Food and Agriculture Organization of the United Nations (FAO) reports an even greater percentage of land in agriculture—37 percent (FAO 2000). FAO's figures are derived from national production statistics rather than from satellite data and include all permanent pasture.

The actual area of agroecosystems probably falls somewhere between these estimates. Since the satellite data are based on only 1 year of data, areas that were not cultivated that year but are still used for agricultural purposes (for example, an area under fallow or regions that alternate year to year between cropland and pasture) may be underestimated in the satellite images. It is also more difficult to detect extensive pastures and some perennial crops using satellite data because of their similarity to natural grasslands and forests.

According to FAO, 69 percent of agroecosystems consist of permanent pasture, with the remainder of the area under crops. However, this global average masks very large differences among regions in the balance between crops and pastureland. In some regions, pastureland predominates: pastures make up 89 percent of the agroecosystem area in Oceania, 83 percent in Sub-Saharan Africa, 82 percent in South America, and 80 percent in East Asia. In other regions, croplands occupy much larger areas: 92 percent of agroecosystem area in South Asia and 84 percent in Southeast Asia. In India, crops cover 94 percent of the agroecosystem area. On croplands, annual crops such as wheat, rice, maize, and soybeans occupy 91 percent of the area, with the remainder in permanent crops, such as tea, coffee, sugarcane, and most fruits (FAO 2000).

Most agricultural production, with the exception of dairy and perishable vegetable production, is derived from intensively managed croplands located away from major concentrations of population. However, since the 1980s, the growth of urban and periurban agriculture has accelerated, especially in developing countries. By the early 1990s, approximately 800 million people globally were actively engaged in urban agriculture, using a variety of urban spaces including home-sites, parks, rights-of-way, rooftops, containers, and unbuilt land around factories, ports, airports, and hospitals (FAO 1999a). Urban residents, who would otherwise spend a high proportion of income on food, engage in agriculture to increase their own food security and nutrition or as an income source. An estimated 200 million urban dwellers produce food for sale (Cheema et al. 1996).

FAO statistics show that the total area in agriculture expanded slowly between 1966 and 1996, from 4.55 Bha to 4.92 Bha—about an 8 percent increase (FAO 2000). This low growth rate masks a more dynamic pattern of land-use changes, with land conversion to and from agriculture taking place at much higher rates. It is these aggregate changes, for which data are scarce, that are most relevant from an ecosystem perspective.

Despite global growth, agricultural area has actually decreased in many industrialized countries. Both the United States and Western Europe have progressively been taking land out of agriculture for the last 30 years, and Oceania for the last 20. During this period, these three regions have removed a total of 49 Mha from agricultural production. Agricultural land has also decreased significantly in Eastern Europe, largely because of liberalization of production and marketing and poor economic conditions. South Asia's total agricultural area has remained constant for more than 20 years at approximately 223 Mha. However, expansion of agricultural area is still significant in some regions. Agricultural land increased by almost 0.8 percent/year during 1986–96 in China and Brazil and by 1.38 percent/year in West Asia (FAO 2000).

INTENSIFICATION

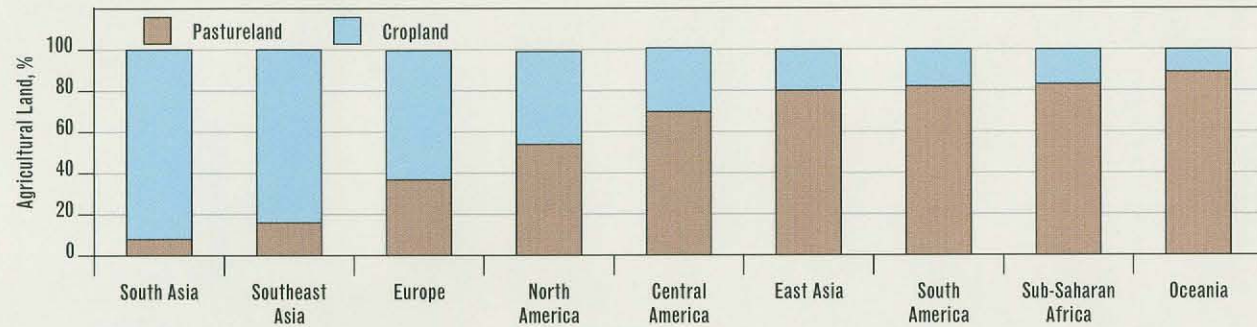
Although the net global expansion of agricultural area has been modest in recent decades, intensification has been rapid. Irrigated area grew significantly over the past 3 decades, from 153 Mha in 1966 to 271 Mha in 1998. Globally, irrigated land accounts for only 5.5 percent of all agricultural land—17.5 percent of cropland—but in some regions irrigation is much more extensive. For example, China and India together contain 41 percent of the global irrigated area and Western Europe and the United States contain another 12.5 percent. In contrast, the arid and semiarid regions of Sub-Saharan Africa and Oceania (primarily Australia), contain only 3 percent of the world's irrigated land (FAO 2000) (Box 2.6 Intensification of Agriculture).

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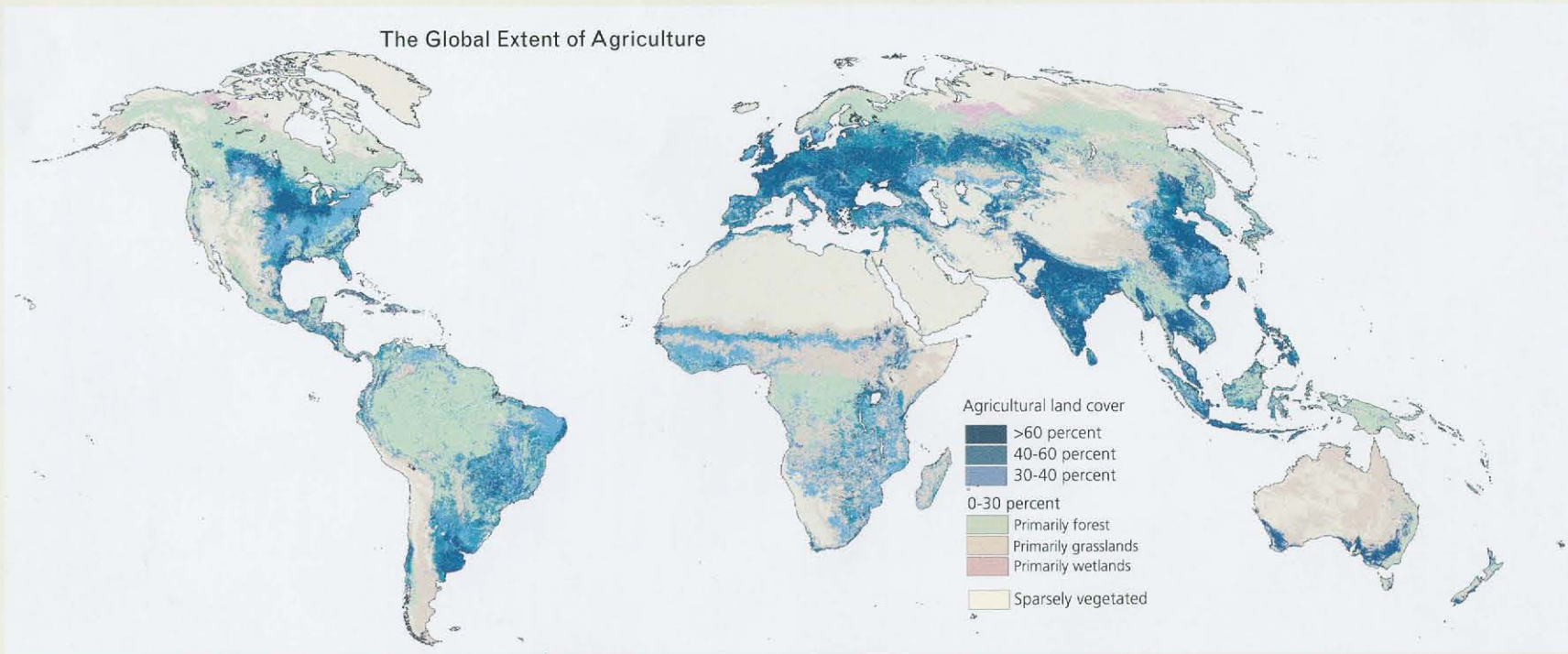
Box 2.5 The Global Extent of Agriculture

Agricultural lands cover about 36 Mha, 28 percent, of Earth's land area (excluding Greenland and Antarctica). Although agricultural area has increased worldwide in the past 30 years, it has decreased in many industrialized countries. Globally, about 31 percent of agroecosystems are croplands and 69 percent are pasture, but actual proportions of each vary widely among regions.

Composition of Agricultural Land



The Global Extent of Agriculture



Sources: Wood et al. [PAGE] 2000. The map is based on Global Land Cover Characteristics Database Version 1.2 (Loveland et al. [2000]) and USGS/EDC (1999a). The figure is based on FAOSTAT (1999).

Box 2.6 The Intensification of Agriculture

As population has grown and good agricultural land has become scarcer, inputs such as water, fertilizer, pesticides, and labor have been applied more intensively to increase output. In Asia, where population pressures

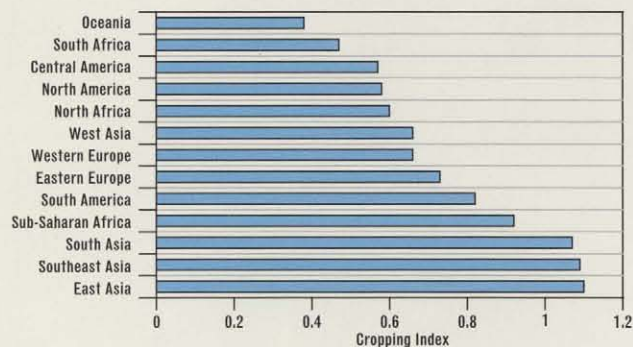
are greatest, virtually all of the cropland is harvested each year, sometimes two to three times a season, as the use of irrigation, new varieties of quick-growing seeds, and fertilizers has replaced traditional practices of leaving land fallow to restore

Wheat Yields, 1866–1997

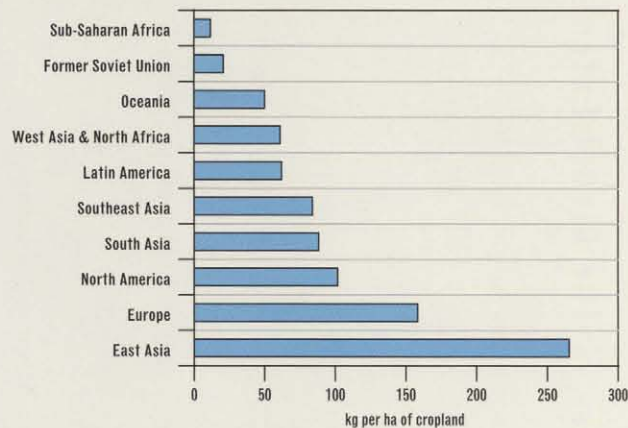


Intensification of Cropping, 1995–97

The cropping index is the harvested area of land planted in annual crops divided by the total area of such land. A value of more than 1 indicates more than one crop harvested per year per hectare.

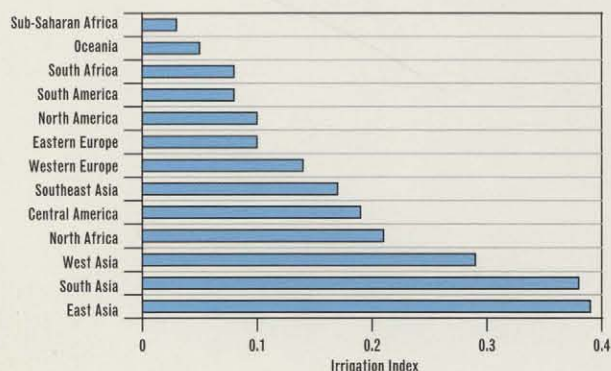


Use of Commercial Fertilizer, 1995–97

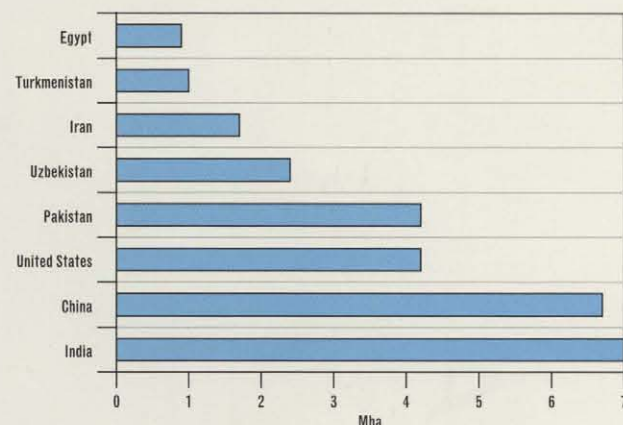


Intensification of Irrigation, 1995–97

The irrigation index is the irrigated area of cropland divided by the total area of cropland.



Irrigated Land Damaged by Salt, 1987

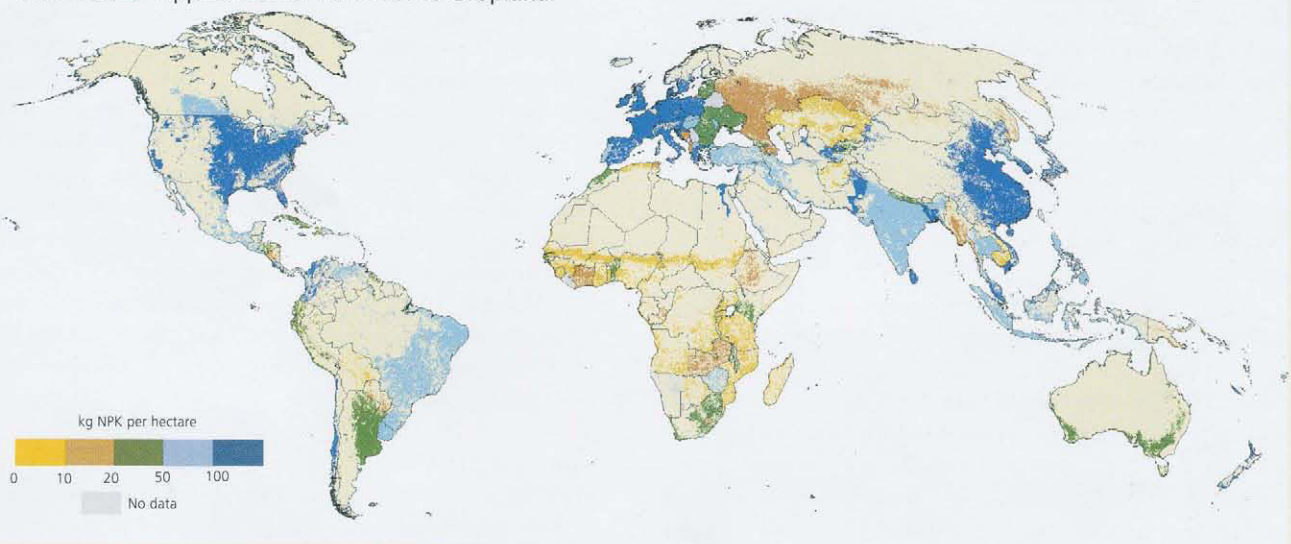


fertility. Even marginal lands in Africa are in continuous use to meet demands for food, although water and fertilizer inputs are much lower there.

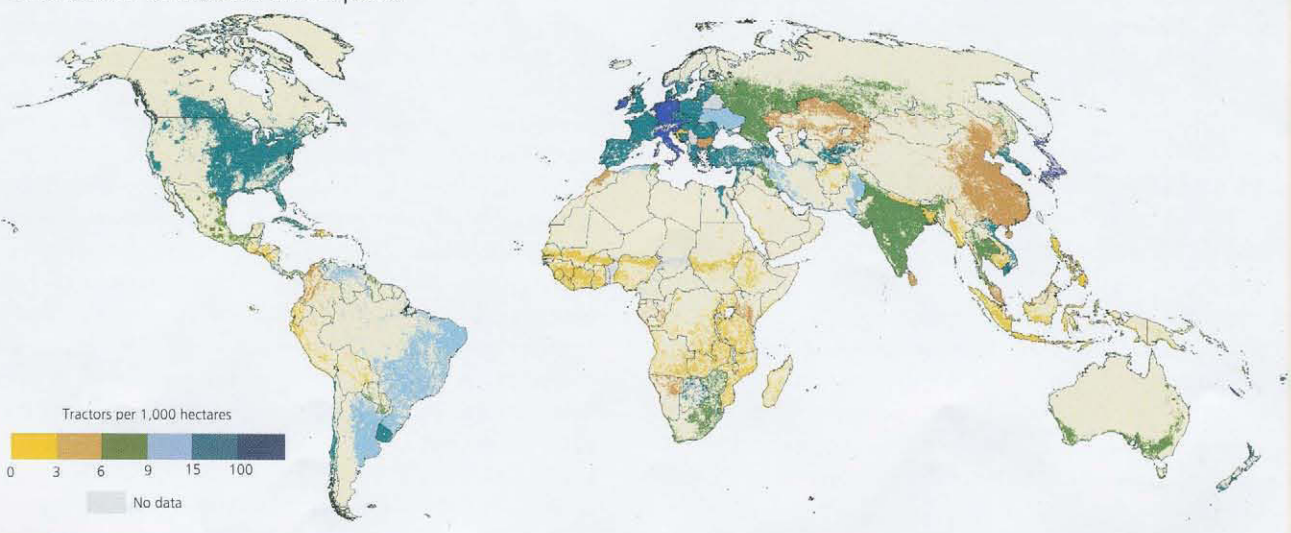
Many agroecosystems are vulnerable to the stresses imposed on them by intensification. There is much local evidence of soil salinization caused by poorly managed irrigation systems, loss in soil fertility through overcultivation, compaction by tractors or livestock, and lowering of water tables through overpumping for irrigation.

Continued agricultural intensification need not lead inexorably to environmental degradation, however. Farming communities in all parts of the world have responded to degradation, particularly when it affects their livelihoods, with measures such as planting trees to control erosion, regulating cultivation around local water sources, restricting pesticides and other pollutants, rehabilitating degraded soils, and adopting new technologies. (See Chapter 3, *Regaining the High Ground: Reviving the Hillsides of Machakos, Kenya.*)

Commercial Application of Fertilizer to Cropland



Distribution of Tractors on Cropland



Sources: Wood et al. [PAGE] 2000. The maps are based on FAOSTAT 1999. They show national values within the global extent of agriculture, augmented by additional irrigated areas (Döll and Siebert 1999). Wheat yields are from USDA-NASS (1999). Irrigated land damaged by salt is based on Postel (1999:93). All other figures are based on FAOSTAT (1999).

Production intensity is also reflected in the use of inputs such as tractors and fertilizers. The current global consumption of fertilizer totals about 137 million tons/year (1997), representing a dramatic increase in consumption during the last 50 years (FAO 2000).

In recent years, irrigation growth rates have slowed considerably and growth in fertilizer consumption has moderated. Following a decline from the late 1980s to the mid-1990s, total fertilizer consumption is again increasing and is currently around 6 percent below its 1988 peak (FAO 2000).

SOIL AND SLOPE CONSTRAINTS

Despite the high productivity of global agriculture and the rapid intensification of production on some lands, many of the world's agricultural lands offer less than optimal conditions. Steep slopes (more than 8 percent incline) or poor soil conditions limit production on a significant portion of agricultural land. Soil fertility constraints include high acidity, low potassium reserves, high sodium concentrations, low moisture-holding capacity, or limited depth. If more than 70 percent of agricultural land in a particular region has one or more of these constraints, it is said to have "significant" soil constraints.

Using these definitions, 81 percent of agricultural land has significant soil constraints and around 45 percent of agricultural land is steep. Approximately 36 percent of agricultural land is characterized by both significant soil constraints and slopes of 8 percent or more. Areas with both steep slopes and significant soil constraints make up 30 percent of temperate, 45 percent of subtropical, and 39 percent of tropical agricultural land. Average agricultural yields are generally lower and degradation risks are generally higher in these areas than in more ecologically favored environments. Nonetheless, these marginal lands represent a significant share of global agriculture and support roughly one-third of the world's population (Wood et al. [PAGE] 2000).

Assessing Goods and Services

FOOD, FEED, AND FIBER

Economic Importance

The food, fiber, and animal feed that the world's agroecosystems produce is worth approximately \$1.3 trillion per year² (Wood et al. [PAGE] 2000). Agriculture is most important to the economies of low-income countries, accounting for 31 percent of their GDP, and more than 50 percent of GDP in many parts of Sub-Saharan Africa. In middle-income countries, agriculture accounts for 12 percent of GDP. But in the high-income countries of Western Europe and North America, where other economic sectors dominate, the contribution of agriculture to GDP is just 1-3 percent, even though the

value of the agricultural output in these countries represents 79 percent of the total market value of world agricultural products (Box 2.7 The Economic Value of Agricultural Production).

Conventional measures of agriculture's share of GDP actually understate agriculture's contribution to economies. For example, agricultural GDPs in the Philippines, Argentina, and the United States comprise 21 percent, 11 percent, and 1 percent of those countries' total GDPs, respectively; yet the total value of agriculture, including manufacturing and services further along the marketing chain, comprises 71 percent, 39 percent, and 14 percent of their respective total GDPs (Bathrick 1998:10).

Beyond the economic value of the food produced, agroecosystems also provide employment for millions. Agricultural labor represents the livelihood, employment, income, and cultural heritage of a significant part of the world's population. In 1996, of the 3.1 billion people living in rural areas, 2.5 billion—44 percent of the world population—were estimated to be living in households dependent on agriculture. The labor force directly engaged in agriculture is an estimated 1.3 billion people—about 46 percent of the total labor force. In North America, only 2.4 percent of the labor force is directly engaged in agriculture, while in East, South, and Southeast Asia as well as in Sub-Saharan Africa, agricultural labor accounts for 56-65 percent of the labor force (FAO 2000).

Human Nutrition

Agriculture was developed for a simple but fundamental purpose—to provide adequate human nutrition. Globally, agroecosystems produce enough food to provide every person on the planet with 2,757 kcal each day, which is sufficient to meet the minimum human requirement for nutrition (FAO 2000). However, many people do not have adequate access to that food, and an estimated 790 million people are chronically undernourished. In Sub-Saharan Africa, 33 percent of the population is undernourished; in the Caribbean 31 percent; and in South Asia 23 percent (FAO 1999b:29).

Global demand for food is still increasing significantly, driven by population growth, urbanization, and growth in per capita income. One of the most notable changes in demand is the dramatic increase in meat consumption, particularly in the developing world. This has been dubbed the "livestock revolution." Between 1982 and 1994, global meat consumption grew by 2.9 percent per year, but it grew five times faster in developing countries than in developed countries, where meat consumption is already high (Delgado et al. 1999:9-10).

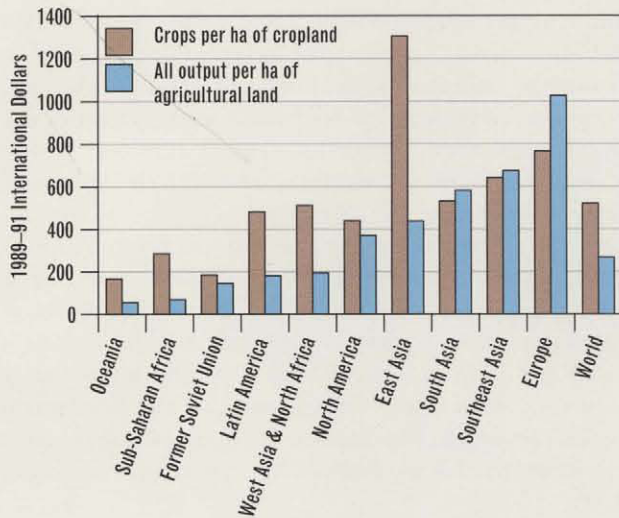
Between 1995 and 2020, global population is expected to increase by one-third, totaling 7.5 billion people. Global demand for cereals is projected to increase by 40 percent, with 85 percent of the increase in demand coming from developing countries. Meat demand is projected to increase

Box 2.7 The Economic Value of Agricultural Production

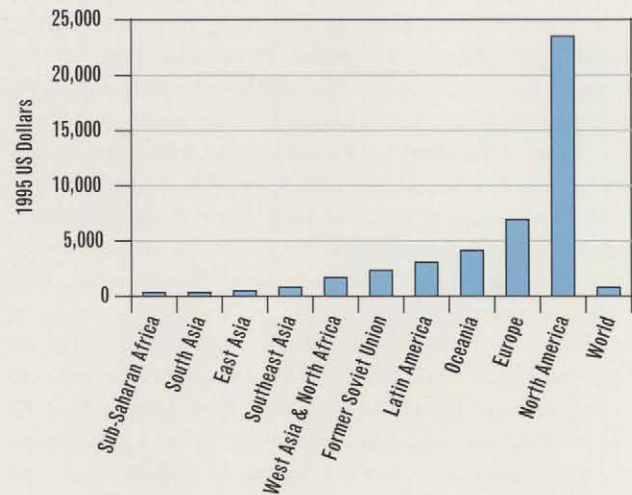
The total value of output from agroecosystems is US\$1.3 trillion per year. Worldwide, 46 percent of the total labor force works in agriculture, and almost half the total population lives in rural communities that depend on agriculture. Cropland generally has more valuable outputs per

hectare than pasture, except in Europe, South Asia, and Southeast Asia, where pastures support intensive livestock production. Output per worker varies dramatically from region to region, reflecting difference in level of commercialization of agriculture and opportunities for off-farm employment.

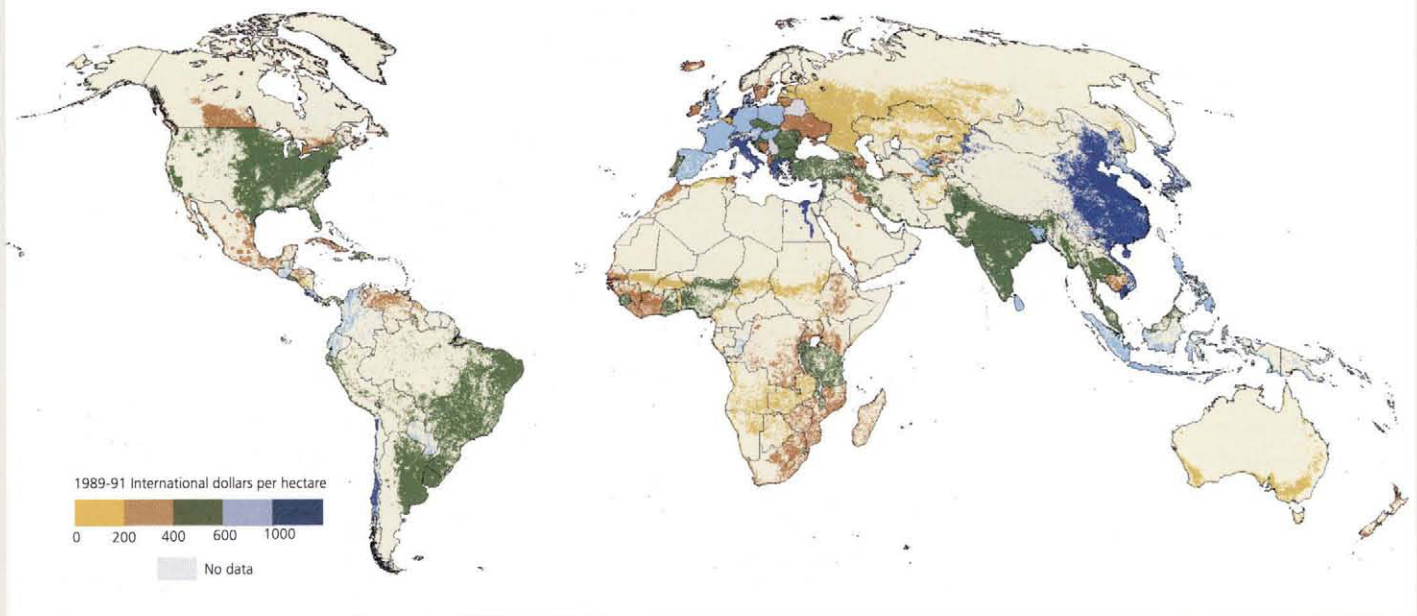
Value of Production per Hectare, 1995–97



Value of Agricultural GDP per Agricultural Worker, 1995–97



The Value of Crops per Hectare of Cropland, 1995–97



Sources: Wood et al. [PAGE] 2000. The map shows national values within the global extent of agriculture, augmented by additional irrigated areas (Döll and Siebert 1999). Value of production table and map are based on FAO (1997) and FAOSTAT (1999). Value of agricultural production weights the output of 134 primary crop and 23 primary livestock commodity quantities by their respective international agricultural prices for 1989–91. Value of crop production is based on the 134 primary crops only. Value of agricultural GDP per agricultural worker is based on World Bank (2000) and FAOSTAT (1999).

by 58 percent, with approximately 85 percent of the increase coming from developing countries. Demand for roots and tubers is expected to grow 37 percent, with 97 percent of this increase coming from the developing world (Pinstrup-Andersen et al. 1999:5–12). And, if significant progress is made in alleviating poverty during this period, there will be an additional increase in demand as the poor and malnourished use their increased income to buy food they previously could not afford.

Productive Capacity

Changes in Yield Growth. Rapid yield growth in most major crops has been instrumental in meeting the food needs of growing populations, particularly in the second half of this century. Recently, however, the growth of cereal crop yields has been slowing, raising concerns that future production may not be able to keep pace with demand. Moreover, there is evidence from some parts of the world that maintaining the growth in yields, or even holding yields at current levels, requires proportionately greater amounts of fertilizer input, implying that the quality of the underlying soil resource may be deteriorating.

These trends must be interpreted cautiously. Even if yields continue to grow rapidly, this does not necessarily indicate that agroecosystems are in good shape, since increased inputs like fertilizer and pesticides could mask underlying depletion of soil nutrients. Nor does a slowdown in the growth of crop yields prove agroecosystem conditions are worsening, since market factors such as falling commodity prices and high fertilizer prices may also account for slower production. Nonetheless, the declining rate of yield growth is worrisome in a world where the growth in food demand is not expected to slow.

Soil Degradation. One measure of the long-term productive capacity of an agroecosystem is the condition of its soil. Natural weathering processes and human management practices can both affect soil quality. Sustaining soil productivity requires that soil-degrading pressures be balanced with soil-conserving practices. The principal processes of soil degradation are erosion by water or wind, waterlogging and salinization (the buildup of salts in the soil), compaction and crusting, acidification, loss of soil organic matter and soil microorganisms, soil nutrient depletion, and accumulation of pollutants in the soil.

Different types of soil degradation are associated with different types of agricultural land use. For example, salinization is associated most often with intensification of irrigated land, and compaction with mechanized farming in high-quality rain-fed lands. Nutrient depletion is often associated with intensifying production on marginal lands but can occur on any soil if nutrients extracted by crops are not adequately replenished. Water erosion is also often associated with marginal lands that have been extensively cleared and tilled. Soil

pollution is a particular problem in periurban agriculture (Scherr 1999).

The 1990 Global Assessment of Soil Degradation (GLASOD), based on a structured survey of regional experts, provides the only continental and global-scale estimates of soil degradation (Oldeman et al. 1991). The GLASOD study suggested that 1.97 Bha had been degraded between the mid-1940s and 1990 (Scherr 1999:17; Wood et al. [PAGE] 2000). This represents 15 percent of terrestrial area (excluding ice-covered Greenland and Antarctica).

To assess the extent and severity of soil degradation on agricultural lands in particular, PAGE researchers overlaid the GLASOD data on the map of agricultural land (land with more than 30 percent agricultural use). This revealed that 65 percent of agricultural lands have some amount of soil degradation. About 24 percent were classified as “moderately degraded” which, according to GLASOD, signifies that their agricultural productivity has been greatly reduced. A further 40 percent of agricultural land fell into the GLASOD categories of “strongly degraded” (lands that require major financial investments and engineering work to rehabilitate) or “very strongly degraded” (lands that cannot be rehabilitated at all) (Wood et al. [PAGE] 2000). Among the most severely affected areas are South and Southeast Asia,³ where populations are among the densest and agriculture the most extensive (Box 2.8 Soil Degradation in South and Southeast Asia).

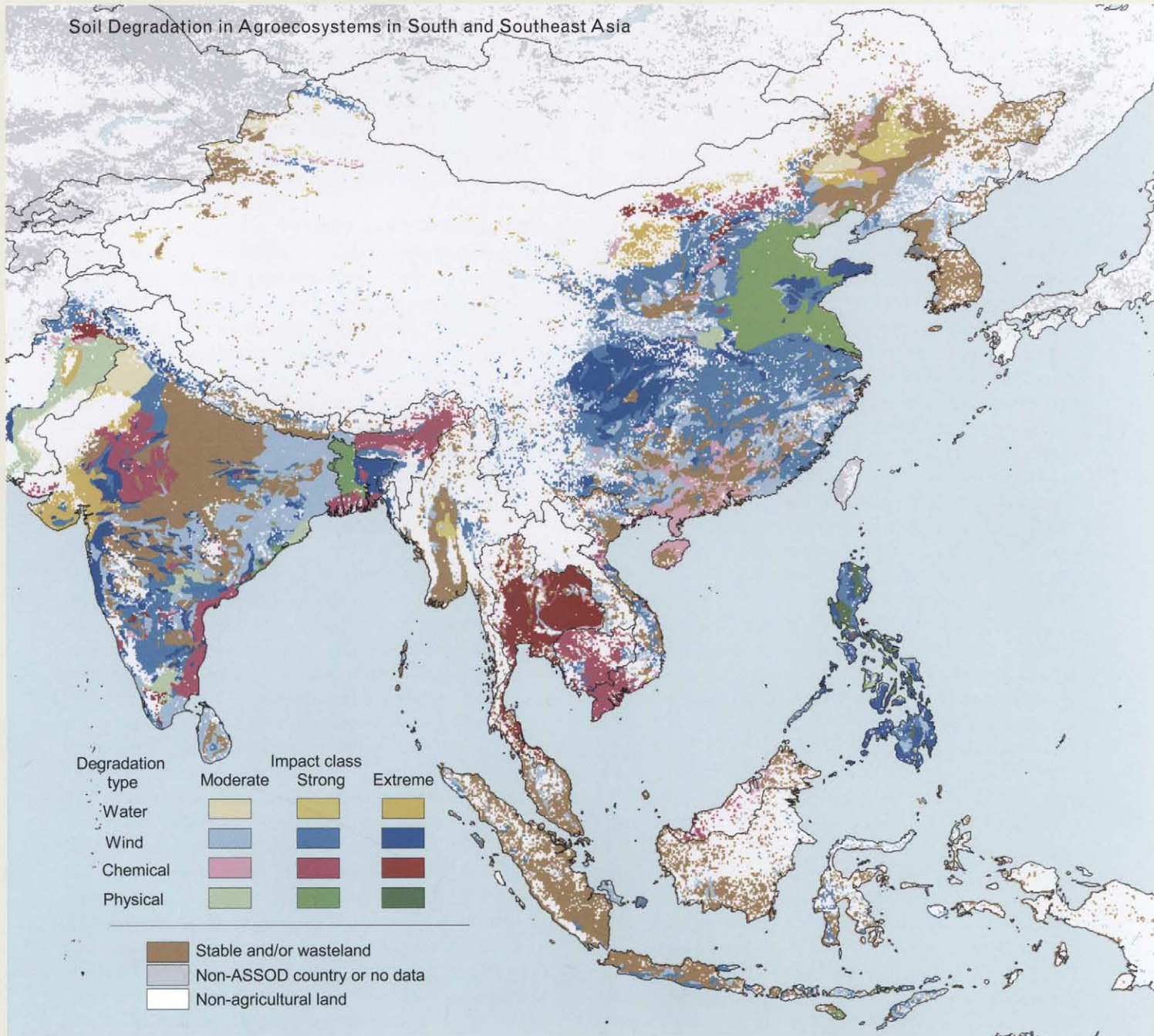
Soil Nutrient Balance. One indicator of soil condition—and productive capacity—is soil nutrient balance. One of the most common management techniques used to maintain the condition of agroecosystems, particularly intensively cultivated systems, is to replenish soil nutrients with organic manures or inorganic fertilizers containing nitrogen, phosphorus, and potassium. Too little replenishment can lead to soil nutrient mining—the progressive loss of nutrients as crops draw on them for growth. Too much replenishment (overfertilization) can lead to leaching of excess nutrients and the consequent soil and water pollution problems as these unused nutrients find their way into surrounding soils and freshwater systems.

An estimate of the nutrient balance of an agroecosystem can be obtained by measuring the nutrient inputs (inorganic and organic fertilizers, nutrients from crop residues, and nitrogen fixation by soybeans and other legumes) and outputs (nutrient uptake in the main crop products and the crop residue). PAGE researchers calculated these nutrient balances at the national level for individual crops in Latin America and the Caribbean (Henaó 1999) and found that for most of the crops and cropping systems, the nutrient balance is significantly negative—in other words, soil fertility is declining (see Box 2.9 Hot Spots and Bright Spots).

The observed increases in production in recent decades must therefore be due to a combination of area expansion,

Box 2.8 Soil Degradation in South and Southeast Asia

South and Southeast Asia, where agricultural production systems are among the most intensive in the world, have soils that are among the most degraded. In these regions, soils are significantly steeper, more subject to erosion, and more likely to be salinized, acidic, depleted of potassium, and saturated with aluminum than the soils of most other regions.



Sources: Wood et al. [PAGE] 2000. The map is based on Van Lynden and Oldeman (1997), and Global Land Cover Characteristics Database Version 1.2 (Loveland et al. [2000]). It shows soil degradation within the extent of agriculture.

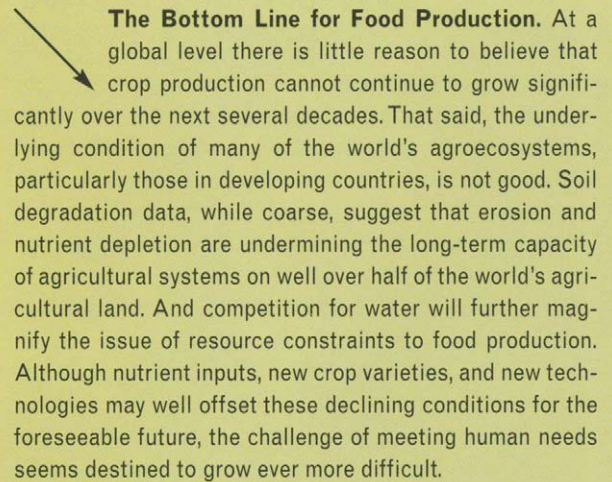
improved varieties, and other factors that mask or offset the effects of soil degradation. By overlaying nutrient balance with trends in yields, it is possible to identify potential degradation “hot spots” where yield growth is slowing and soil fertility is declining. Areas where the capacity of agroecosystems to produce food appears most threatened include northeast Brazil and sections of Argentina, Bolivia, Colombia, and Paraguay.

Soil nutrient balances are also available for most of Sub-Saharan Africa at continental, national, and district levels (Smaling et al. 1997:47–62). Findings there also suggest widespread nutrient depletion.

Productivity Losses. The cumulative productivity loss from soil degradation over the past 50 years has been roughly estimated, using GLASOD figures, to be about 13 percent for cropland and 4 percent for pasture lands (Oldeman 1998:4). The economic and social impacts of this degradation have been far greater in developing countries than in industrialized countries. In industrialized countries, soil quality plays a relatively less important role in overall agricultural productivity because of the high level of fertilizer and other inputs used. Furthermore, the most important grain-producing areas in industrialized countries typically have deep, geologically “new” soils that can withstand considerable degradation without having yields affected.

Soil degradation has more immediate impacts on the food supply in developing countries. Agricultural productivity is estimated to have declined significantly on approximately 16 percent of agricultural land, especially on cropland in Africa and Central America, pastures in Africa, and forests in Central America. The GLASOD study estimates that almost 74 percent of Central America’s agricultural land (defined by GLASOD as cropland and planted pastures) is degraded, as is 65 percent of Africa’s and 38 percent of Asia’s (Scherr 1999:18). Detailed studies based on predictive models for Argentina, Uruguay, and Kenya calculated yield reductions between 25 and 50 percent over the next 20 years (Mantel and van Engelen 1997:39–40).

Subregional studies have documented significant aggregate declines in crop yields due to degradation in many parts of Africa, China, South Asia, and Central America (Scherr 1999). Crop yield losses in Africa from 1970 to 1990 due to water erosion alone are estimated to be 8 percent (Lal 1995:666). Estimates of the economic losses associated with soil degradation in eight African countries range from 1 to 9 percent of agricultural GDP (Bøjör 1996:170). Total annual economic loss from degradation in South and Southeast Asia is estimated to be 7 percent of the region’s agricultural GDP (Young 1994:75). Given that more than half of all land in this region is not affected by degradation, the economic effects in the degraded areas appear to be quite significant. Economic losses from erosion in different regions of Mexico vary from approximately 3 to 13 percent of agricultural GDP (McIntire 1994:124).



The Bottom Line for Food Production. At a global level there is little reason to believe that crop production cannot continue to grow significantly over the next several decades. That said, the underlying condition of many of the world’s agroecosystems, particularly those in developing countries, is not good. Soil degradation data, while coarse, suggest that erosion and nutrient depletion are undermining the long-term capacity of agricultural systems on well over half of the world’s agricultural land. And competition for water will further magnify the issue of resource constraints to food production. Although nutrient inputs, new crop varieties, and new technologies may well offset these declining conditions for the foreseeable future, the challenge of meeting human needs seems destined to grow ever more difficult.

WATER QUANTITY AND QUALITY

Agriculture is perhaps the most significant human influence on the world’s water cycle, affecting quantity, timing, and quality of water available to freshwater systems. At a global scale, agriculture accounts for the greatest proportion of total freshwater withdrawals of any sector of human activity. Agriculture also has the highest consumptive use of water (use that results in returning water to the atmosphere, rather than back to streams or groundwater). Approximately 70 percent—2,800 km³—of the 4,000 km³ of water humans withdraw from freshwater systems each year (Shiklomanov 1997:69) is used for irrigation (WMO 1997:9).

This volume of water irrigates 271 Mha of croplands (FAO 2000). Although this number represents only 17 percent of total cropland, it produces 40 percent the world’s crops (WMO 1997:9). Of the water used for irrigation, 50–80 percent is returned to the atmosphere or otherwise lost to downstream users (Shiklomanov 1993:19). As a consequence, irrigation can significantly decrease river flows and aquifer levels and can shrink lakes and inland seas.

The Aral Sea represents an extreme case of the ecological damage agricultural water diversions can inflict. Withdrawals to irrigate cotton and other crops shrank the sea to one-third of its original volume by the early 1990s, thus increasing its salinity. Fish species and fishing livelihoods were lost before steps were taken to restore some of the flows (WRI 1990:171; Gleick 1998:189).

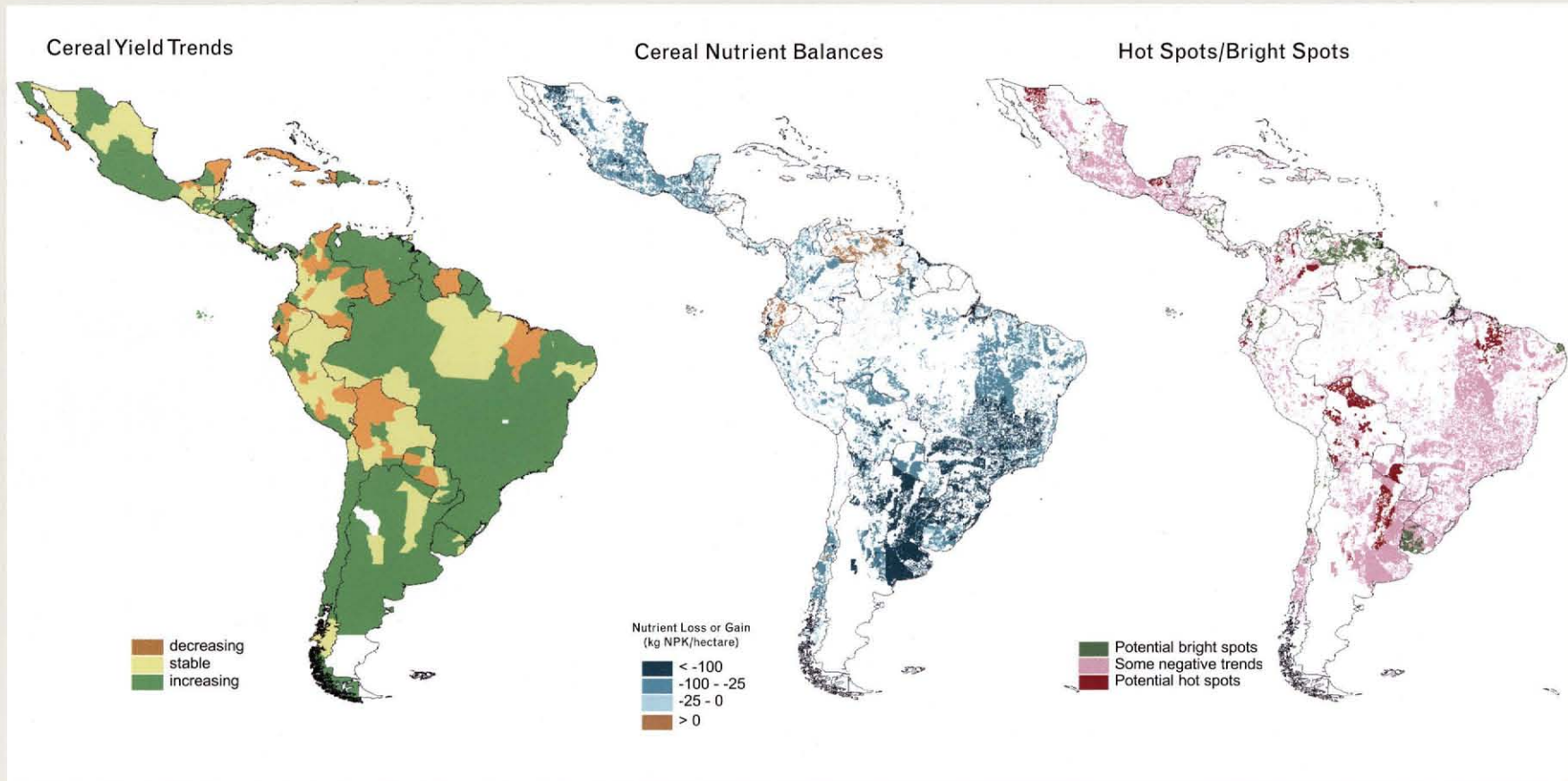
For 82 percent of the world’s agroecosystems, rainfall is the sole source of water for agricultural production. Although rain-fed agriculture has less sweeping impacts on freshwater flows than irrigated agriculture, it can still affect the quantity and timing of downstream flows. These impacts are highly site-specific, depending on the type of agriculture, the soil’s slope and condition, and the patterns and intensity of rainfall.

Both irrigated and rain-fed agriculture can pose threats to water quality from the leaching of fertilizer, pesticides, and ani-

Box 2.9 Hot Spots and Bright Spots in Latin American Agroecosystems

Cereal yields have generally been increasing in Latin America over the past 20 years (left map), but at the expense of stocks of nutrients in the soils in which cereals and other crops are grown. In fact, most Latin American agricultural soils show a negative “nutrient balance,” meaning that more nutrients are lost through plant growth and harvest than are replaced through additions of fertilizer, manure, or legume cover crops (center map). Com-

binning these maps yields a picture of agricultural “hot spots”—areas where yield growth is slowing and soil fertility is declining (right map). Hot spots where agricultural capacity appears to be most threatened are in northeast Brazil and parts of Argentina, Bolivia, Columbia, and Paraguay. Some “bright spots”—where yields are stable or increasing and nutrient balances are positive—also appear, but cover a much smaller area.




Sources: Wood et al. [PAGE] 2000. Cereal yield trends are based on subnational 1975-98 data for rice, wheat, maize, and sorghum. Nutrient balances are based on national balances of applied nutrients less extraction by cereal crops. They were allocated to specific geographic areas using subnational production statistics and information on climate, soil, and elevation. Map of hot spots and bright spots combines the map of cereal yield trends and the map of cereal nutrient balances.

mal manure into groundwater or surface water. Sediment from erosion can also greatly degrade surface water quality. Irrigated agriculture also creates problems associated with excess water in the soil profile: waterlogging and salinization. Both problems can decrease productivity and lead to abandonment of the affected land. In India, China, and the United States—countries that rely heavily on irrigation—an average of 20 percent of irrigated land suffers from salinization. According to one estimate, salinization costs the world's farmers \$11 billion/year in reduced income—almost 1 percent of the total value of agricultural production (Postel 1999:92; Wood et al. [PAGE] 2000).

One measure of the relative impact of various agroecosystems on freshwater systems is their efficiency of water use. Seckler et al. (1998) calculated average irrigation efficiency—the proportion of irrigation water that is actually consumed by crops for growth, compared with the proportion that evaporates or is otherwise wasted. More efficient irrigation systems require less water to meet crop needs, often by delivering water more directly to plant roots, and they are better timed to meet plant growth requirements.

Globally, irrigation efficiency averaged 43 percent in 1990 (Seckler et al. 1998:25). In general, agroecosystems in arid regions have more efficient irrigation systems. Irrigation efficiency in the driest regions runs as high as 58 percent, whereas regions with abundant water supplies have efficiency as low as 31 percent. Thirty-one percent efficiency means more than two-thirds of irrigation water in these areas is wasted, although some water lost to underground leakage may become available for downstream use (Seckler et al. 1998:25). Irrigation efficiencies in China and India are intermediate—39 percent and 40 percent, respectively.

The increasing competition for water from other sectors poses a challenge for agriculture, especially in developing countries where urban populations and the industrial sector are growing quickly. Both industrial and domestic water demands generally take precedence over agriculture. Indeed, irrigated agriculture may increasingly have to rely on recycled water from industrial facilities and wastewater treatment plants to meet its needs. Many believe that water scarcity and its impact on water services such as irrigation is one of the most immediate natural resource concerns from the perspective of human welfare (Rosegrant and Ringler 1999). Certainly, current trends emphasize the critical importance of developing agroecosystems that use water more efficiently, and that minimize the salinization and waterlogging of soils and the leaching of pesticides, fertilizer, and silt into surface and groundwater.

 **The Bottom Line for Water Services.** Overall, the capacity of agroecosystems to maintain the quantity and quality of incoming water resources, and deliver those to downstream users, is declining. Although the consumptive use of water to produce more

food represents an important and legitimate water service within agroecosystems, the deterioration in water quality that accompanies this is an often significant penalty for other ecosystems. Irrigation inefficiency increases water withdrawals and contributes to unsustainable rates of groundwater extraction, reduced river flows, and damage to aquatic ecosystems. Downstream water quality is particularly at risk in areas where farmers apply agrochemicals and animal manure abundantly. Poorly managed irrigation can also directly reduce the productivity of agroecosystems through waterlogging and salinization. Improvements in the efficiency of agricultural water use are increasingly important as both food needs and competing water demands continue to grow.

BIODIVERSITY

Agricultural lands support far less biodiversity than the natural forests, grasslands, and wetlands that they replaced. Even so, the biodiversity harbored in agricultural regions is important in its own right. From a purely agricultural perspective, the diversity of naturally occurring predators, bacteria, fungi, and plants in a region can contribute to agricultural production by helping to control pest and disease outbreaks, improving soil fertility and soil physical properties, and improving the resilience of agroecosystems to natural disasters such as floods and droughts. Moreover, the genetic diversity found in traditional crop varieties and in wild species provides a reservoir of genetic material that breeders can use to develop improved crop and animal varieties.

The expansion of agricultural land has, nonetheless, had major impacts on biodiversity. Using maps of the potential habitat that would naturally occur in a region, based on climate and soil characteristics, PAGE researchers estimated the percentage of different habitat types that had been converted to agriculture. Among the most heavily affected natural habitats, 46 percent of the potential area of temperate broadleaf and mixed forests is now agricultural land, accounting for 24 percent of total agricultural land. Close behind, 43 percent of the potential area of tropical deciduous forest (similar to rainforest, but with distinct dry seasons and more open canopy) has been converted to agriculture, accounting for 10 percent of total agricultural land. These types of forest are far more biodiverse than agroecosystems.

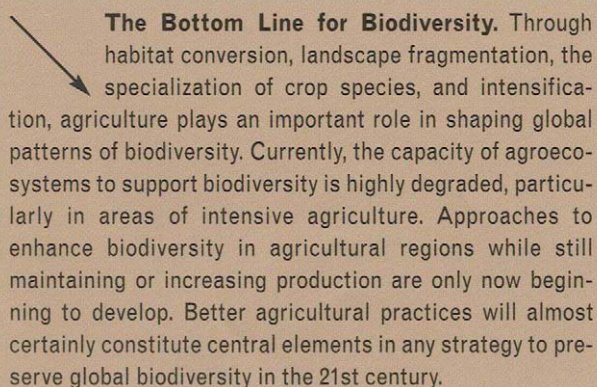
Within agroecosystems, different management practices can further alter biodiversity. Intensification tends to greatly diminish the capacity of agroecosystems to support biodiversity by fragmenting and reducing the area of hedgerows, copses, wildlife corridors, and other refuges and natural habitats within the agricultural landscape. Pesticides and other agrochemicals can also be toxic to wildlife and soil microorganisms, including many beneficial birds, pollinators, and carnivorous insects. On the positive side, the

increasing use of trees on agricultural lands can increase their biodiversity potential. In Latin America, Sub-Saharan Africa, and South and Southeast Asia, trees are a significant and often a growing part of the agricultural landscape (Wood et al. [PAGE] 2000).

In addition to on-farm tree planting, positive trends include the increasing adoption of “no tillage cultivation,” where disturbance of the soil is greatly minimized, helping to preserve soil integrity and minimize erosion. The use of integrated pest management, where pesticides are used more sparingly and in combination with nonchemical pest controls to protect crops, is also expanding. Further, the growth of high-yielding, intensive production systems has a positive side, too, in that it has forestalled the conversion of at least 170 Mha of natural habitat in the tropics (Nelson and Mare-dia 1999) and perhaps as much as 970 Mha worldwide (Golkany 1999).

In terms of genetic diversity, global agriculture focuses on relatively few species and thus begins from a somewhat narrow base. More than 90 percent of the world’s caloric intake comes from just 30 crops, and only 120 crops are economically important at a national scale (FAO 1998:14). Nonetheless, there has traditionally been immense genetic diversity within these crop species, and this diversity has historically helped to maintain the productivity of agroecosystems and is a source of genetic material for modern plant breeding.

Today, however, crop genetic diversity is tending toward decline. Modern crop varieties are taking on more uniform characteristics, and these varieties are planted over large areas in monocultures. This tendency is not limited to high-income countries where the commercialization of agriculture is most prevalent. Modern crop varieties are displacing traditional varieties throughout the world, threatening the loss of an enormous genetic resource and increasing the vulnerability of large areas of homogeneous crops to pest and disease attack. Across all developing countries, modern rice varieties were being grown on 74 percent of the planted area in 1991, modern wheat on 74 percent in 1994, and modern maize on 60 percent in 1992 (Morris and Heisey 1998:220).



The Bottom Line for Biodiversity. Through habitat conversion, landscape fragmentation, the specialization of crop species, and intensification, agriculture plays an important role in shaping global patterns of biodiversity. Currently, the capacity of agroecosystems to support biodiversity is highly degraded, particularly in areas of intensive agriculture. Approaches to enhance biodiversity in agricultural regions while still maintaining or increasing production are only now beginning to develop. Better agricultural practices will almost certainly constitute central elements in any strategy to preserve global biodiversity in the 21st century.

CARBON STORAGE

Carbon is of fundamental importance to the fertility of agroecosystems. The organic matter content of soil, and its stability over time, are key indicators of long-term soil quality and fertility. The level of soil organic matter affects the water retention and tilth of soils, as well as the richness of the soil biota.

Typically, when natural ecosystems such as forest or savanna are converted to agriculture, their soils quickly lose a significant percentage of their soil organic matter. Successful agriculture can arrest this decline and rebuild soil organic matter to its original levels through appropriate crop rotations and the application of nutrients (particularly from organic sources), or through such practices as zero or minimum tillage. On the other hand, excessive tilling, removing crop residues from fields, and practices that promote soil erosion will accelerate loss of organic matter.

Carbon in agroecosystems—in both soils and vegetation—also plays an important role in the global carbon cycle. Except for some production systems in the tropics, agricultural soils generally store more carbon than do the crops or pastures they support. Agricultural vegetation stores an average of 5–6 kg of carbon per square meter (kgC/m^2), while agricultural soils store an average of 7–11 kgC/m^2 (Wood et al. [PAGE] 2000). Together, the vegetation and soils in agroecosystems contain approximately 26–28 percent of all the carbon stored in terrestrial ecosystems.

Land-use change and land management practices, of which agricultural activities are an important part, emit an estimated 1.6 GtC to the atmosphere annually, about 20 percent of human-related greenhouse gas emissions (IPCC 2000:5). There are many distinct agricultural sources of carbon emissions. Prime sources of carbon dioxide include conversion of forests and woody savannas to agricultural land, and deliberate burning of crop stubble and pastures to control pests and diseases and promote soil fertility. Other activities produce methane—another carbon-based molecule that is a more powerful greenhouse gas than CO_2 . Livestock rearing and paddy rice cultivation are both major methane sources.

Some researchers believe that the net release of carbon dioxide from agriculture could decrease between 1990 and 2020 (Sombroek and Gommers 1996), while emissions of methane will continue to climb, pushed by the continuing growth in the number of livestock. Emissions of nitrous oxide (N_2O), an even more potent greenhouse gas derived from nitrogen fertilizers, is also rising rapidly.

There is a growing belief that agriculture can play a much greater role in reducing global carbon emissions and in increasing carbon storage. For example, control of agricultural burning, improved diets for cattle and other livestock, and soil conservation can reduce emissions. Meanwhile, better cultivation practices, mixing trees into agricultural systems, and planting improved pasture grasses can help store more carbon. Recent studies show that conservation pro-

grams and the adoption of no tillage cultivation in the United States increased carbon storage in U.S. croplands by around 138 MtC/year during the 1980s (Houghton et al. 1999:577).



The Bottom Line for Carbon Storage. Agroecosystems store about 26–28 percent of total terrestrial carbon—mostly in the soil. Improved nutrient management, reduced soil erosion, and the widely

adopted use of minimum tillage cultivation tend to increase soil organic matter and, hence, can play some role in increasing carbon storage capacity in agricultural soils. On the other hand, livestock rearing and rice cultivation are significant and growing sources of carbon emissions tied to agriculture, and agricultural burning and land conversion remain prime sources as well.