Land Quality, Agricultural Productivity, and Food Security at Local, Regional, and Global Scales

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Increased resource use and improvements in technology and efficiency have increased global food production more rapidly than population in recent decades, but 800 million people remain food insecure (figure 1). Meanwhile growth in global agricultural productivity appears to be slowing, and land degradation has been blamed as a contributing factor (see box: definitions).

The interactions between biophysical processes and economic choices are complex, and data necessary to measure these processes are scarce, so estimates of land degradation's impact on productivity vary widely—as high as 8 percent per year due to soil erosion alone in the United States and as low as 0.1 percent per year due to all forms of soil degradation on a global scale. These differences make it difficult to assess potential impacts on food security or the environment, and thus the appropriate nature and magnitude of policy response.

Recent improvements in economic analysis of geographic data offer new insights. ERS recently conducted an integrated set of studies that examine how agricultural productivity varies with differences and changes in land quality, and how degradation-induced changes in productivity affect food security. Results indicate that land degradation does not threaten productivity growth and food security at the global level. But problems do exist in some areas, especially where resources are fragile and markets function poorly.

Growth in population and income has increased demand for food

Global demand for food has increased rapidly since the mid-20th century as a result of growth in population, income, and other factors. The world's population nearly doubled over the past four decades, to 6 billion in 1999. World population growth has slowed in recent years, but is still projected to reach 9 billion by about 2050. Per capita income is projected to grow by an average of about 2 percent per year over the next decade, continuing recent trends. Based on these factors, the Food and Agriculture Organization (FAO) and the International Food Policy Research Institute (IFPRI) project that global demand for cereals will increase by 1.2-1.3 percent per year over the next several decades, while demand for meat will increase slightly faster. Most of the increased demand is projected to come from developing countries, especially from Asia.

World food supplies have increased faster than demand… so far

Between 1961 and 1999, the FAO's aggregate crop production index grew at an average annual rate of 2.3 percent. Crop production per capita has increased more slowly, but it has in fact increased for the world as a whole (at an average rate of 0.6 percent per year) and in all regions except Africa. Global cereals production per capita (figure 2) has fallen since 1984, with steady increases in Asia offset by long-term declines in sub-Saharan Africa and more recent declines in North America, Europe, Oceania, and the former Soviet Union. But these more recent declines were due not to binding resource and technology constraints but rather to the combined effects of weak grain prices, policy reforms and institutional change.

IFPRI projects that world cereal production will increase by about 1.3 percent per year through 2020, enough to raise per-capita cereal production by about 0.2 percent annually. Such increases have the potential to satisfy projected food demands (and nutritional requirements) for the foreseeable future, but actual patterns will depend on the availability and quality of productive resources and on the market incentives, policy measures, and research investments that influence how those resources are used.

Cropland expansion has slowed

FAO reports that the total area devoted to crops worldwide has increased by about 0.3 percent per year since 1961, to 3.7 billion acres in 1998 (figure 3). Growth has slowed markedly in the past decade, to about 0.1 percent per year, as a result of weak grain prices, deliberate policy reforms (in North America and Europe), and institutional change (in the former Soviet Union). FAO estimates that an additional 6.7 billion acres currently in other uses are suitable for crop production, but this land is unevenly distributed geographically, and includes land with relatively low yield potential and significant environmental value.

Given economic and environmental constraints on cropland expansion, the bulk of increased crop production in the future will need to come from increased yields on existing cropland. FAO data indicate that world cereal yields rose by about 2.5 percent per year from 1961 to 1990, but growth slowed to 1.1 percent per year in the 1990s (figure 4). As a result of reduced input use (reflecting low cereal prices), market and infrastructure constraints, and low levels of investment in agricultural research and technology, IFPRI and FAO project that yield growth will slow further to about 0.8 percent per year over the next several decades.

Trends in genetic improvements, fertilizer, water, and climate pose challenges

Genetic improvements have contributed greatly to gains in yields and production of major crops, beginning with wheat, rice, and maize in the 1960s. About half of all recent gains in crop yields are attributable to genetic improvements. By the 1990s, 90 percent of land in wheat in the developing countries was in scientifically bred varieties, as was 74 percent of land in rice and 62 percent of land in maize. In the developed countries, 100 percent of land in wheat, maize and rice was in scientifically bred varieties by the 1990s (and probably even earlier). Gains from genetic improvements will continue in future, but likely at slower rates and increasing costs, particularly because gains in input responsiveness have already been relatively fully exploited.

FAO data indicate that increased fertilizer consumption accounted for one-third of the growth in world cereal production in the 1970s and 1980s. Growth in fertilizer consumption per hectare of cropland has been slowing, however, from a global average annual increase of about 9 percent in the 1960s to an average annual decline of about 0.1 percent in the 1990s. Among developing regions, per-hectare fertilizer consumption increased most rapidly in land-scarce Asia and most slowly in Africa. Growth in fertilizer consumption also slowed (and even declined) in the developed regions, but remains at relatively high levels. Future changes in fertilizer use will need to balance its potential to mitigate on-site land degradation (in the form of soil fertility depletion) with the risk of increased off-site degradation (in the form of impacts on water quality, for example).

Water will be a critical factor limiting increased crop production in the 21st century. Agriculture accounts for more than 70 percent of water withdrawals worldwide, and over 90 percent of withdrawals in low-income developing countries. The total extent of irrigated cropland worldwide has grown at an average annual rate of 1.9 percent since 1961, although this rate has been declining (FAO 2000; figure 5). About 18 percent of total cropland area is now irrigated, most of it in Asia. Population growth and the increasing cost of developing new sources of water will place increasing pressure on world water supplies in the coming decades.

Even as demand for irrigation water increases, farmers face growing competition for water from urban and industrial users, and to protect ecological functions. In addition, waterlogging and salinization of irrigated land threaten future crop yields in some areas.

The Intergovernmental Panel on Climate Change (IPCC), representing a broad scientific consensus, projects that the earth's climate will change significantly over the course of the 21st century because of increasing concentrations of carbon dioxide and other "greenhouse" gases in the atmosphere (Reilly 1996, 2002). Changing patterns of precipitation, temperature, and length of growing season resulting from a doubling of atmospheric concentrations of carbon dioxide would tend to increase agricultural production in temperate latitudes and decrease it in the tropics (where most developing countries are located). In aggregate, global crop production would be little affected. This conclusion is strengthened when the productivity-enhancing effects of a more carbon-enriched atmosphere and farmers' responses to climate change are considered. But potential impacts and adjustment costs vary widely, and could be quite high in some areas.

Land quality varies widely

ERS recently examined regional differences in cropland quality using geographic data on land cover, soil, and climate (figure 6). Among the countries of sub-Saharan Africa, an average of 6 percent of cropland has soils and climate that are of high quality for agricultural production. The proportion of high-quality cropland was higher in other regions, ranging from an average of 20 percent among Asian countries, 29 percent among high-income countries (mainly countries in North America and Europe, plus Australia and Japan), and 30 percent among the countries of Latin America and the Caribbean.

Land quality changes over time as a result of natural and human-induced processes, but data on these changes are extremely limited. Only one global assessment has been done to date: the Global Assessment of Soil Degradation (GLASOD) in 1991 (Oldeman et al. 1991). Based on the judgment of over 250 experts around the world, GLASOD estimated that 38 percent of the world's cropland had been degraded to some extent as a result of human activity since World War II (including 65 percent of cropland in Africa, 51 percent in Latin America, 38 percent in Asia, and 25 percent in North America, Europe, and Oceania). GLASOD identified erosion as the main cause of degradation (affecting 4 billion acres, mostly in Asia and Africa), followed by loss of soil nutrients (336 million acres, mostly in South America and Africa) and salinization (190 million acres, mostly in Asia).

Land quality affects agricultural productivity

Previous studies have sought to measure land quality's role in explaining differences in agricultural productivity between countries, but have considered only factors such as climate and irrigation because of data constraints. ERS researchers incorporated the role of soil characteristics as well, and found that the quality of labor, institutions, and infrastructure also affect productivity. Holding other factors constant, they found that the productivity of agricultural labor is generally 20-30 percent higher in countries with good soils and climate than it is in countries with poor soils and climate. In countries with poor soils and climate, basic inputs like fertilizer, water, and institutional stability are more important than they are in countries that are better endowed. Factors such as labor quality, road density, and mechanization appear less constraining for poorly endowed countries than they are for those with better soils and climate. These results are particularly clear in sub-Saharan Africa, but hold true in other regions as well.

Land degradation reduces crop yields

Based on climate and inherent soil properties, NRCS scientists have estimated water-induced erosion rates that vary widely by crop production area, soil, and region, but range in most cases between 5 and 7 tons per acre per year. Den Biggelaar et al. (forthcoming) recently reviewed over 300 plot-level experiments on yield losses due to soil erosion from around the world and found that for most crops, soils, and regions, yields decline by 0.01-0.04 percent per ton of soil loss. Combining these erosion rates and yield impacts allows estimates of potential annual yield losses to erosion in the absence of changes in farming practices.

These estimates vary widely by crop and region. Corn yield losses to soil erosion range from an average of 0.2 percent per year in North America to 0.9 percent per year in Latin America. Yield losses are generally lower for sorghum and millet, ranging from 0.1 percent for sorghum in North America to 0.5 percent for millet in Asia. Annual wheat yield losses are below 0.3 percent in all regions except Australia, where they average 0.7 percent. Differences in crop coverage limit comparison of regional totals, but aggregating across regions and crops generates an estimated potential erosion-induced loss of 0.3 percent per year in the value of crop production.

Farmers have incentives to address land degradation

These estimates represent *potential* impacts of water-induced erosion for selected crops on soils and in regions for which plot-level data were available. Estimated impacts would likely be larger if other degradation processes and crops were considered. On the other hand, *actual* impacts may also be smaller for any given crop and degradation process to the extent that farmers take steps to avoid, reduce, or reverse land degradation and its impacts.

Farmers choose between alternative technologies based on biophysical characteristics such as soil quality and access to water, as well as social and economic characteristics that include land tenure, income and wealth, and access to credit and information. Careful understanding of farmers' incentives is thus critical. For example, practices generating high net returns today may not do so indefinitely if they result in land degradation over time. But practices that reduce land degradation and offer higher net returns over time may require initial investments that inhibit adoption in the short term. ERS researchers explored such tradeoffs in a dynamic analysis of soils and economic data from the north-central United States. Results suggest that actual yield losses under practices that are optimal over the long run will typically be lower than potential losses derived from agronomic studies, and are generally less than 0.1 percent per year in the north-central United States.

Farmers' incentives depend on land tenure and other factors

In order to benefit from a conservation practice that requires an initial investment, a farmer must have some expectation that he or she will continue farming a particular plot of land long enough to realize the benefit. A farmer with a lease that expires after one year, for example, receives only a fraction of the benefit that would be realized by a farmer with a lease that runs for five years, and both of them receive less benefit than would a farmer who owns his or her land. ERS research confirms that conservation choices by U.S. corn producers vary significantly with land tenure and the timing of costs and returns to different practices.

Even with secure tenure and the prospect of long-term gains, a farmer might still be prevented from adopting a particular conservation practice if he or she is unable to afford the initial investment. This might be the case because of poverty, for example, or because of constraints on access to credit. A farmer might also lack the information needed to compare long-run costs and benefits to alternative practices. In circumstances characterized by such market imperfections, optimal choices by farmers would be expected to result in yield losses greater than those estimated under well-functioning markets, but still less than those found in the absence of farmer response (figure 7).

Farmers' responses to economic incentives lend support to the lower range of previous estimates of yield losses to land degradation. This does not mean that such losses are unimportant – just that they have historically been masked by increases in input use and improvements in technology and efficiency. Problems do exist in some areas, especially where resources are fragile and markets function poorly. Given projections that yield growth is slowing, yield losses to land degradation are likely to become more of a concern in the future.

Reductions in land degradation would improve food security – to a point

Food security depends on secure and sustainable access to sufficient food for activity and health. Access depends in turn on the supply of food and people's ability to acquire it, both of which are influenced by agricultural productivity. Given that productivity is affected by differences and changes in land quality, how much do these factors contribute to food security at local, regional and global scales?

ERS analyzed the affects of erosion-induced yield losses on projected food gaps and numbers of people hungry in 67 low-income countries. The baseline food security model (Shapouri and

Rosen 2000) projects that 694 million people will be hungry in these 67 countries in 2010 (down from 774 million in 2000) (figure 8). We assume that the baseline reflects optimal farmer choices under imperfect markets, resulting in yield losses to soil erosion averaging 0.2 percent per year. Alternative scenarios suggest that the number of people projected to be hungry in 2010 would fall 5 percent to 657 million if yield losses to land degradation were reduced by 0.1 percent per year (reflecting optimal practices under well-functioning markets). Eliminating yield losses to soil erosion entirely would reduce the number of hungry people even further, to 627 million in 2010. But the practices necessary to eliminate yield losses entirely would cost more in terms of other inputs than they would save in terms of yields, so they would not be economically optimal. Put another way, there would be more efficient ways of reducing the number of hungry people than by eliminating the final 0.1 percent annual yield loss to soil erosion.

Policymakers play a critical role

When markets function well, it is reasonable to expect that private incentives to reduce land degradation will suffice to address on-farm productivity losses. When markets function poorly, private incentives to address productivity losses are diminished. Policymakers play a critical role in establishing and maintaining the physical and institutional infrastructure necessary to allow markets to function effectively. This includes transportation and communication networks that facilitate input and output markets, as well as stable and transparent legal and political institutions that encourage longer-term planning horizons. Clear and enforceable property rights are critical in providing incentives for landowners to conserve or enhance land quality.

In addition to efforts to improve market performance in general, it may also be necessary in some circumstances to offer direct payments to enhance farmers’ incentives to adopt conservation practices. Such payments are well-established in conservation programs in the United States and in many other countries, but require careful attention to the timing and magnitude of payments in order to sustain incentives over time. While such approaches pose daunting challenges in terms of implementation, they may also help achieve the broader agricultural, environmental, and food security objectives of the World Food Summit, the United Nations Convention to Combat Desertification, and other multilateral initiatives.

For further information

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Box: Definitions

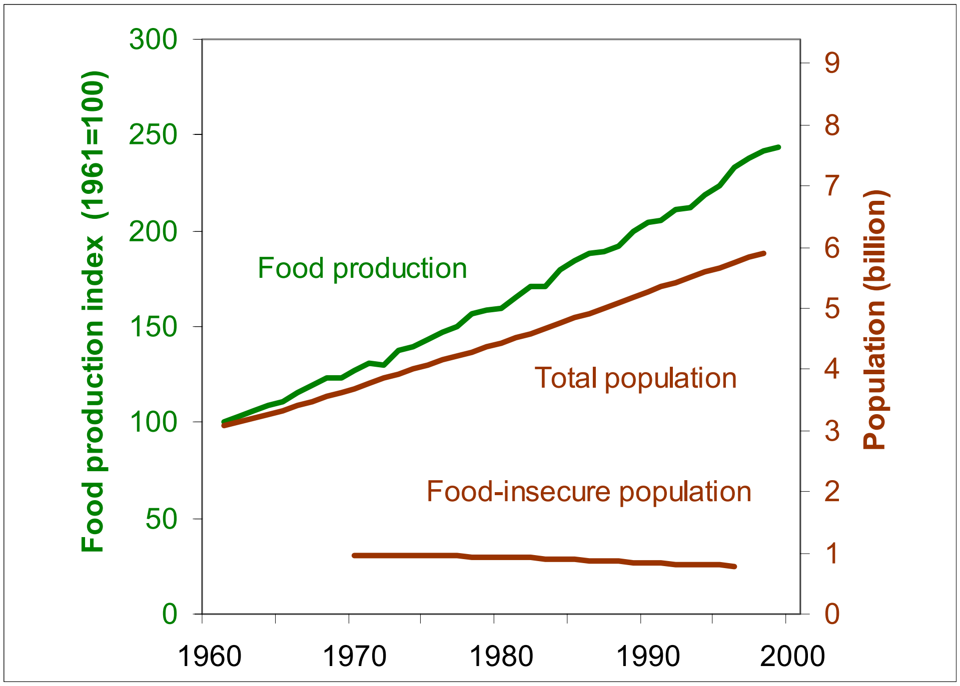
Land quality refers to the ability of land to produce goods and services that are valued by humans. This ability derives from inherent/natural attributes of soils (e.g. depth and fertility), water, climate, topography, vegetation, and hydrology as well as “produced” attributes such as infrastructure (e.g. irrigation) and proximity to population centers.

Land degradation refers to changes in the quality of soil, water and other characteristics that reduce the ability of land to produce goods and services that are valued by humans. Some forms of land degradation, such as nutrient depletion, can be halted or reversed relatively easily, for example by balancing nutrient application with that taken up in harvested crops. Other forms of land degradation, such as erosion or salinization, can be slowed or halted through appropriate management practices, but are generally very costly to reverse.

Agricultural productivity is a measure of the amount of agricultural output that can be produced with a given level of inputs. Agricultural productivity can be defined and measured in a variety of ways, including the amount of a single output per unit of a single input (e.g. tons of wheat per acre or per worker), or in terms of an index of multiple outputs relative to an index of multiple inputs (e.g. the value of all farm outputs divided by the value of all farm inputs).

Food security is generally defined in terms of access by all people at all times to sufficient food for active, healthy lives. As such, food security depends not only on how much food is available, but also on the access that people (e.g. individuals, households, and nations) have to food – whether by purchasing it or by producing it themselves. Access depends in turn on economic variables such as food prices and household incomes, as well as on agricultural productivity and the quality of natural resources.

Figure 1 World food production and population



Source: FAO

Figure 2 Cereal production per capita by region (and annual growth rate)

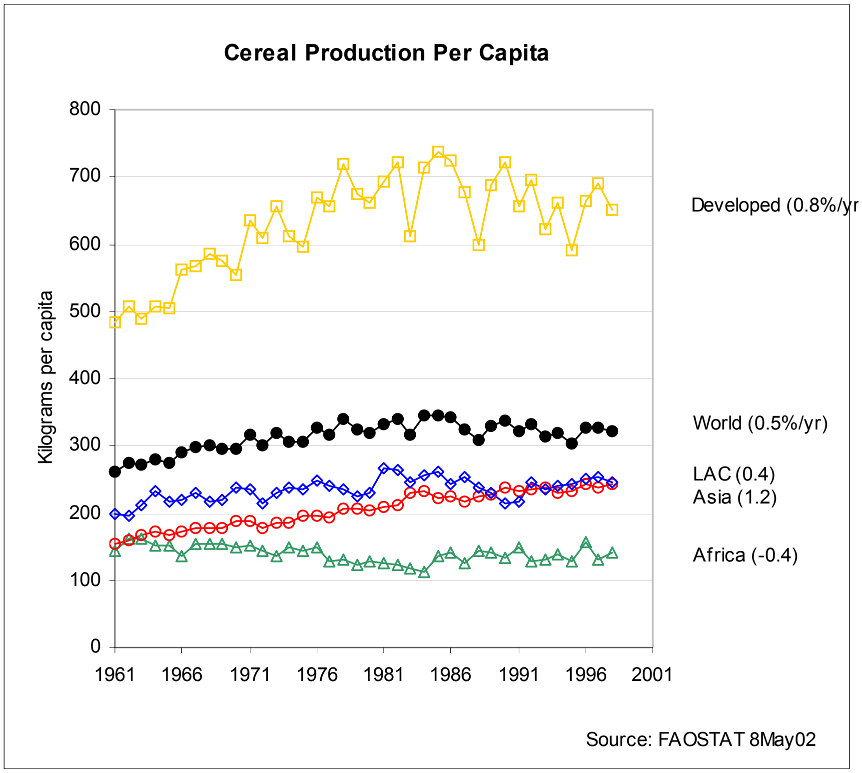
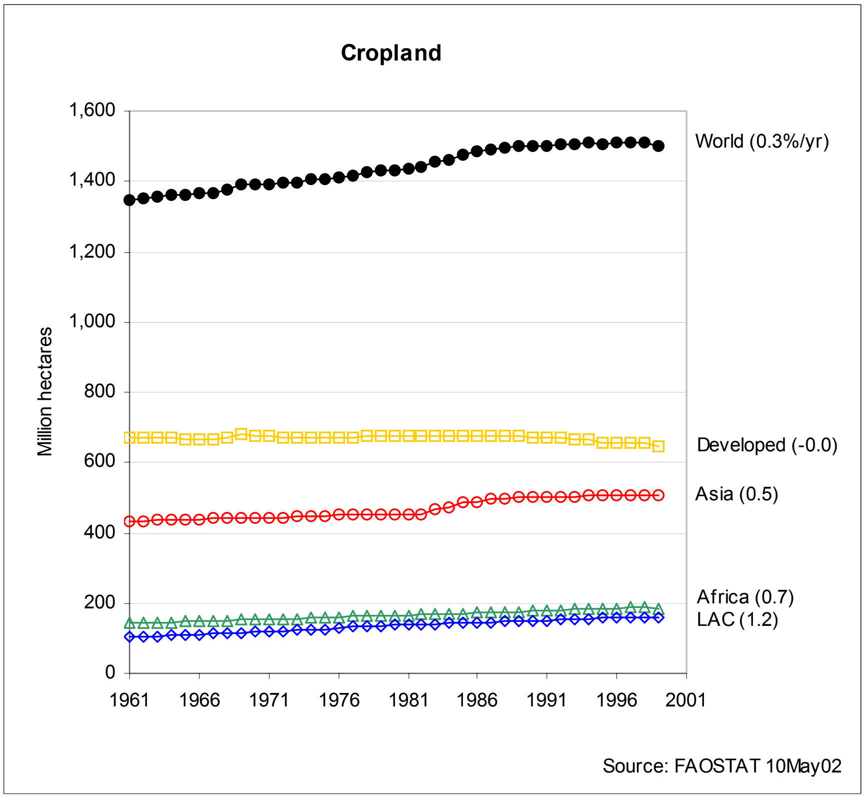


Figure 3 Cropland extent by region (and annual growth rate)



Source: FAOSTAT 10May02

Figure 4 Cereal yields by region (and annual growth rate)

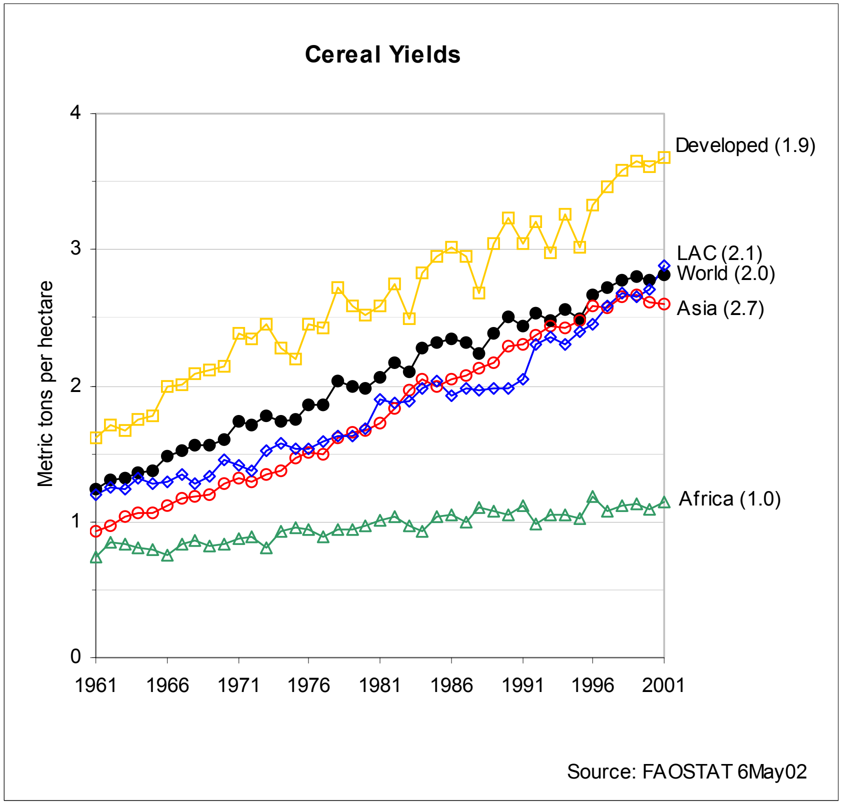
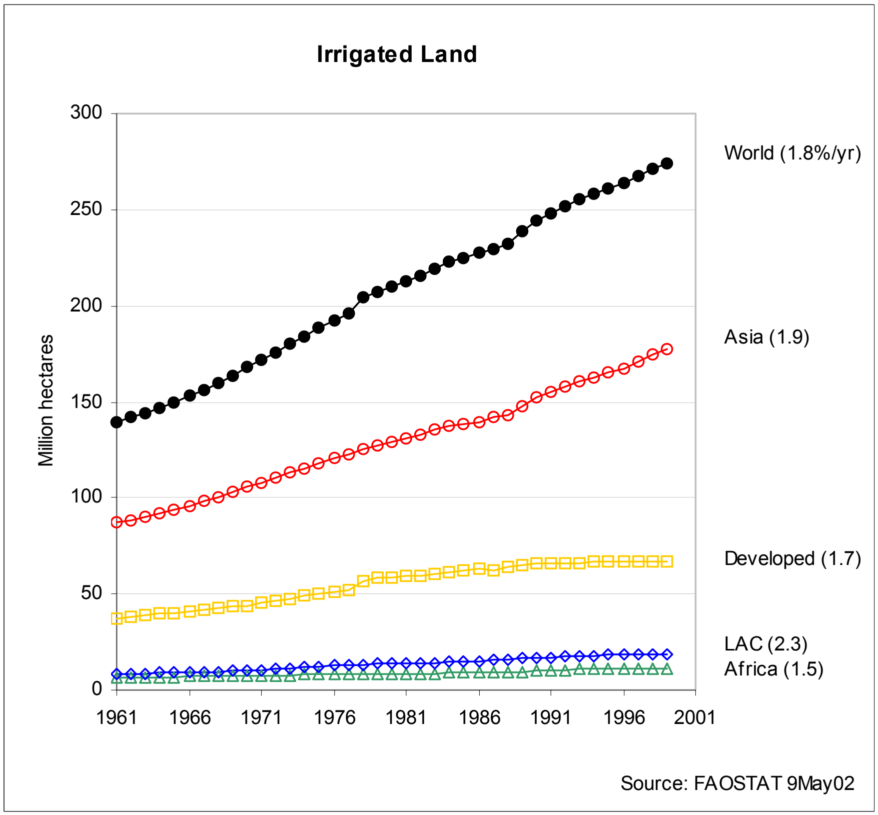
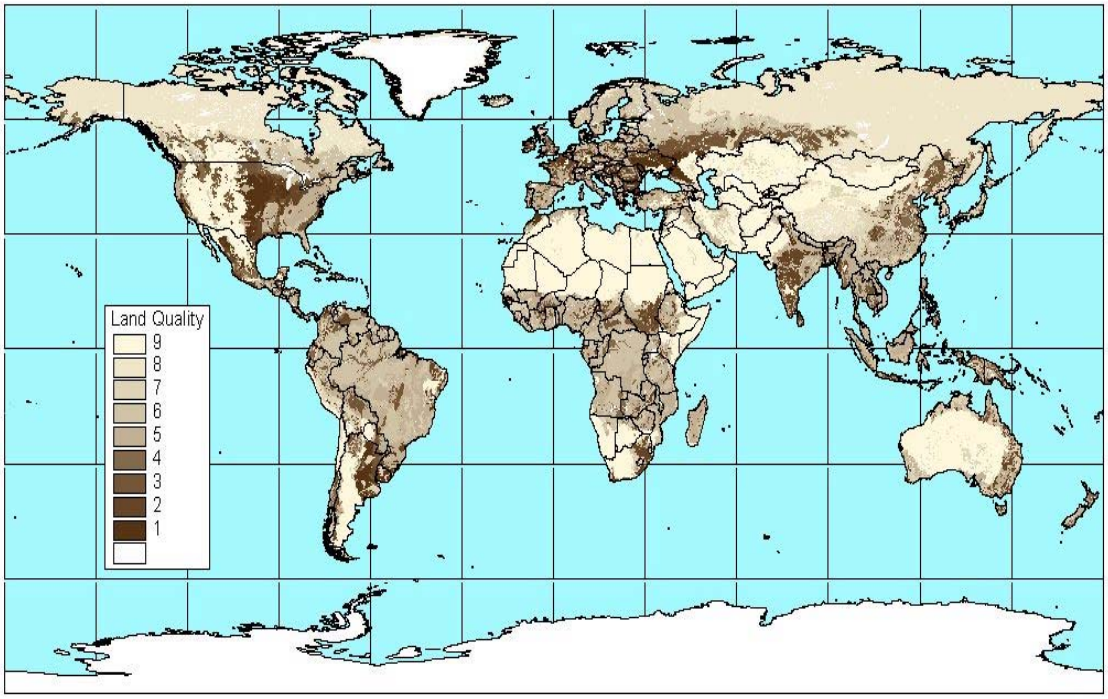


Figure 5 Irrigated land by region (and annual growth rate)



Source: FAOSTAT 9May02

Figure 6 Land quality classes



Source: USDA Natural Resources Conservation Service, World Soil Resources Office

Figure 7 Yields at different rates of land degradation

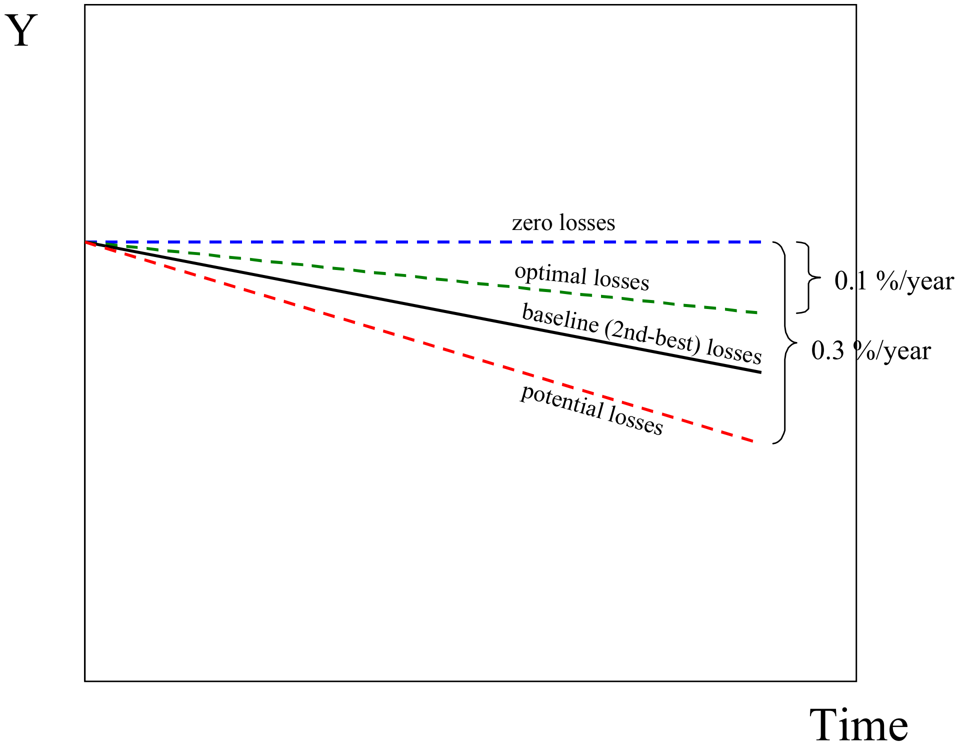


Figure 8 Food security in low-income developing countries under alternative yield-loss scenarios