Securing and Sustaining Adequate World Food Production for the Third Millennium

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The doubling of grain production and tripling of livestock production since the early 1960s has resulted in a global food supply sufficient to provide adequate energy and protein for all. However, about 820 million people lack access to sufficient food to lead healthy and productive lives, and around 185 million children are seriously underweight for their age. At the close of the 20th century, astonishing advances in agricultural productivity and human ingenuity have not yet translated into a world free of hunger and malnutrition.

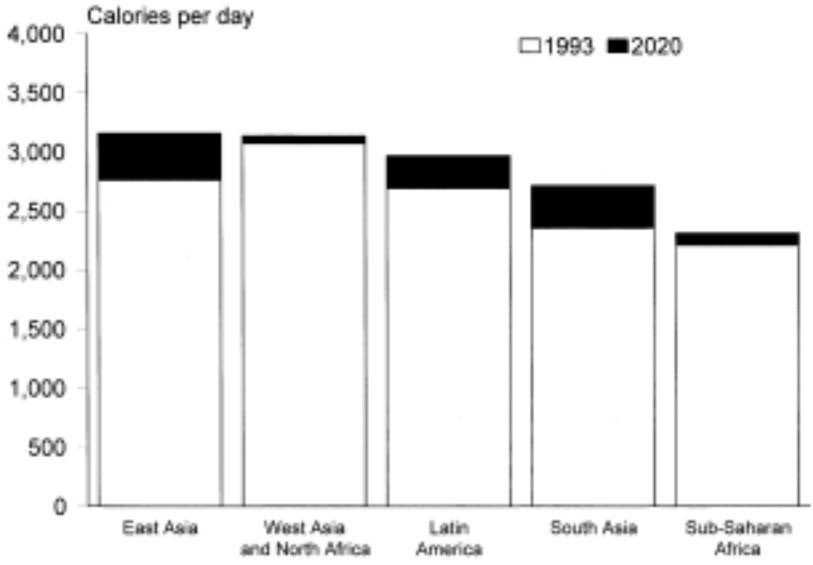
What are the prospects for global food security in the 21st century? Will there be enough food to meet the needs of current and future generations? Can, and will, global food security be attained or will food surpluses continue to co-exist with widespread hunger and malnutrition?

OUTLOOK FOR GLOBAL FOOD SECURITY

Projections of food production and consumption to the year 2020 offer some signs of progress. But prospects of a food-secure world — a world in which each and every person is assured continual access to the food required to lead a healthy and productive life — remain bleak if the global community continues with business as usual.

Worldwide, per capita availability of food is projected to increase around seven percent between 1993 and 2020, from about 2,700 calories per person per day in 1993 to about 2,900 calories. Increases in average per capita food availability are expected in all major regions. China and East Asia are projected to experience the largest increase, and West Asia and North Africa the smallest (Figure 1). The projected average availability of about 2,300 calories per person per day in Sub-Saharan Africa is just barely above the minimum required for a healthy and productive life. Since available food is not equally distributed to all,

Figure 1—Daily per capita calorie availability, 1993 and 2020



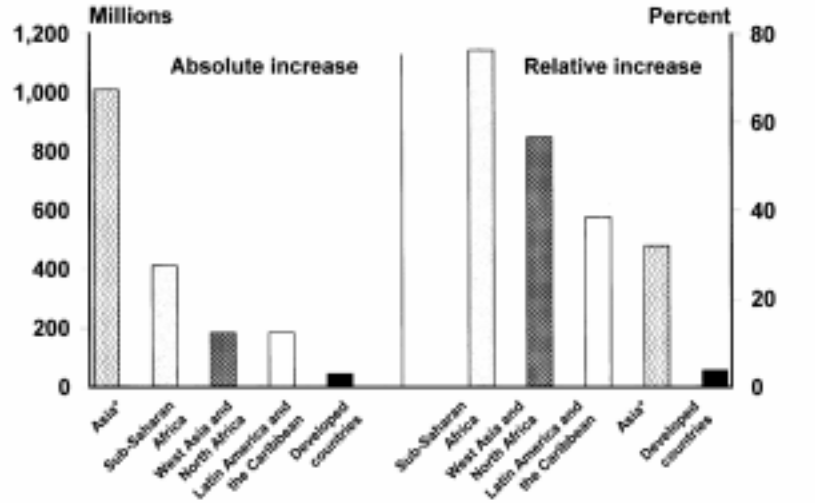
Source: IFPRI IMPACT simulations.

a large proportion of the region's population is likely to have access to less food than needed.

Demand for food is influenced by a number of forces, including population growth and movements, income levels and economic growth, human resource development, and lifestyles and preferences. Almost 80 million people are likely to be added to the world's population each year during the next quarter century, increasing world population by 35 percent from 5.69 billion in 1995 to 7.67 billion by 2020 (UN 1996). More than 95 percent of the population increase is expected in developing countries, whose share of global population is projected to increase by 79 percent in 1995 to 84 percent in 2020. Over this period, the absolute population increase will be highest in Asia, but the relative increase will be greatest in Sub-Saharan Africa, where the population is expected to almost double by 2020 (Figure 2).

At the same time, urbanization will contribute to changes in the types of food demanded. Much of the population increase in developing countries is expected in the cities; the developing world's urban population is projected to double

Figure 2—Absolute and relative population increases, 1995–2020

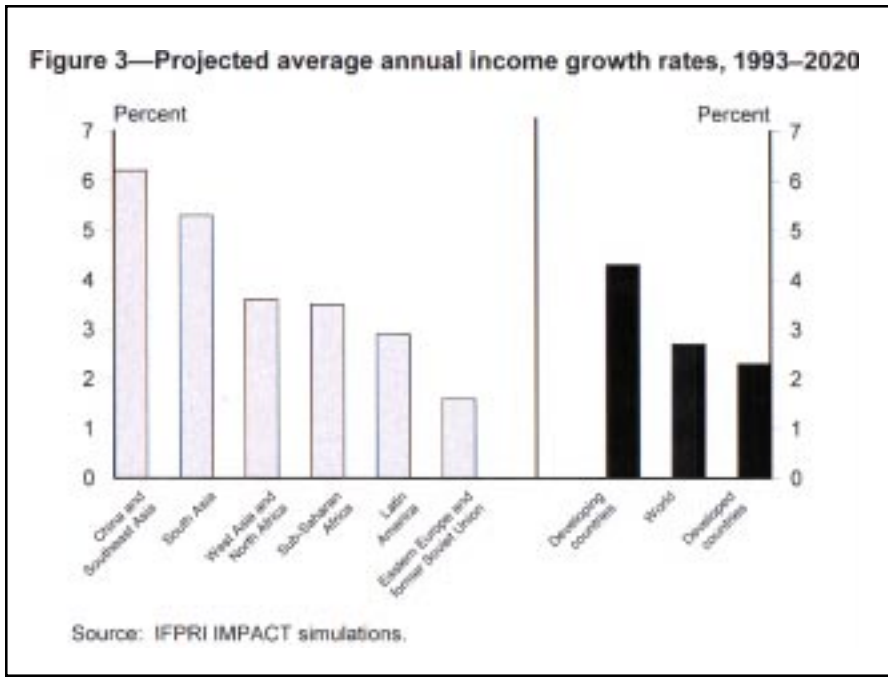


Source: United Nations Population Division, *World Population Prospects: The 1998 Revisions* (Electronic version, 1998).
Notes: Medium-variant projections. * Asia includes developing Oceana, Afghanistan, former Soviet Central Asia, and Iran; excludes Japan.

over the next quarter century to 3.6 billion (UN 1995). Urbanization profoundly affects dietary and food demand patterns: The increasing opportunity cost of women's time, changes in food preferences caused by changing lifestyles, and changes in relative prices associated with rural-urban migration lead to more diversified diets with shifts from basic staples such as sorghum, millet, and maize to other cereals such as rice and wheat that require less preparation and to milk and livestock products, fruits and vegetables, and processed foods.

People's access to food depends on income. Currently, more than 1.3 billion people are absolutely poor, with incomes of a dollar a day or less per person, while another two billion people are only marginally better off (World Bank 1997a). Income growth rates have varied considerably between regions in recent years, with Sub-Saharan Africa and West Asia and North Africa struggling with negative growth rates, while East Asia was experiencing annual growth rates exceeding seven percent (World Bank 1997b). Prospects for economic growth during the next quarter century appear favorable, with global income growth projected to average 2.7 percent per year between 1993 and

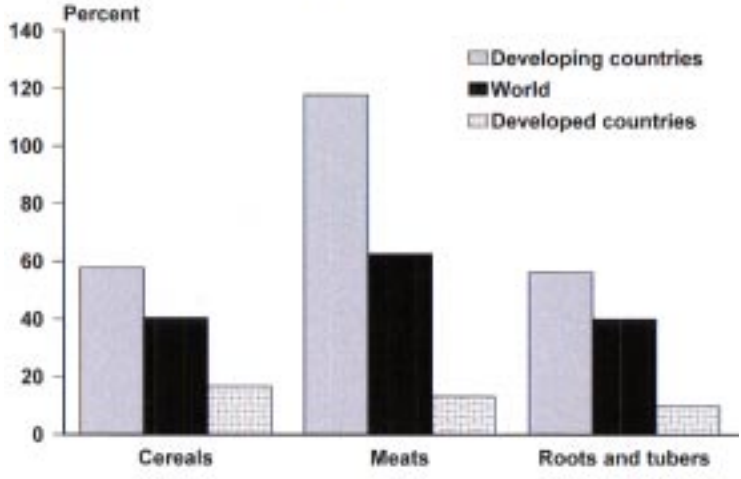
2020 (Figure 3). The projected income growth rates for developing countries as a group is almost double those for developed countries. Growth rates are projected to be lowest in Eastern Europe and the former Soviet Union. Even Sub-Saharan Africa is expected to experience positive per capita income growth between 1993 and 2020, although it will be quite low. However, unless significant and fundamental changes occur in many developing countries, disparities in income levels and growth rates both between and within countries are likely to persist, and poverty is likely to remain entrenched in South Asia and Latin America and to increase considerably in Sub-Saharan Africa.



Under the baseline scenario, IFPRI IMPACT projects global demand for cereals to increase by 41 percent between 1993 and 2020 to reach 2,490 million metric tons, for meat demand to increase by 63 percent to 306 million tons, and for roots and tubers demand to increase by 40 percent to 855 million tons (Figure 4).

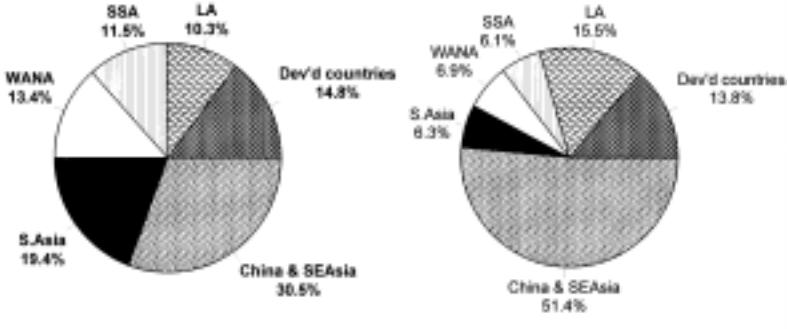
Developing countries will drive increases in world food demand. With an expected 40 percent population increase and an average annual income growth rate of 4.3 percent, developing countries are projected to account for most of the increase in global demand for cereals and meat products between 1993 and 2020 (Figure 5).

Figure 4—Increase in total demand for cereals, meats, and roots and tubers, 1993–2020



Source: IFPRI IMPACT simulations.

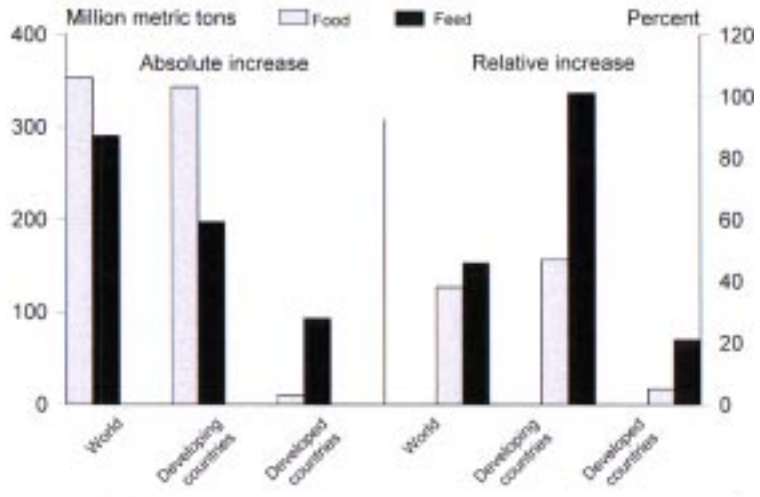
Figure 5—Increase in global demand for cereals and meat products, 1993-2020



Source: IFPRI IMPACT simulations.

Demand for cereals for feeding livestock will increase considerably in importance in coming decades, especially in developing countries, in response to strong demand for livestock products. Between 1993 and 2020, developing countries' demand for cereals for animal feed is projected to double while demand for cereals for food for direct human consumption is projected to increase by 47 percent (Figure 6). By 2020, 24 percent of the cereal demand in developing countries will be for feed, compared with 19 percent in 1993. However, in absolute terms, the increase in cereal demand for food will be higher than for feed. In developed countries, the increase in cereal demand for feed will outstrip the increase in cereal demand for food in both absolute and relative terms.

Figure 6—Absolute and relative increase in food and feed demand for cereals, 1993–2020

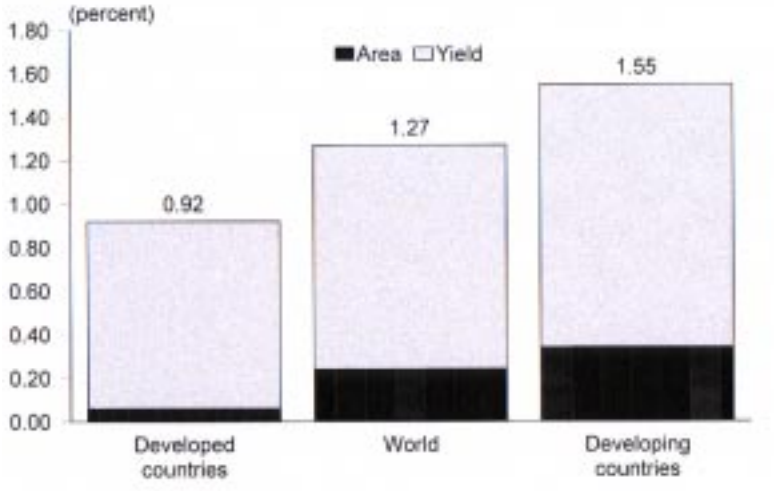


Source: IFPRI IMPACT simulations.

How will the expected increases in cereal demand be met? Primarily by productivity increases; increases in cultivated area will contribute less than 20 percent of the increase in global cereal production between 1993 and 2020 (Figure 7). Most of the growth in cereal area will be concentrated in the relatively low productivity cereals in Sub-Saharan Africa. There will be some expansion in Latin America, but cereal area will remain virtually stagnant in Asia.

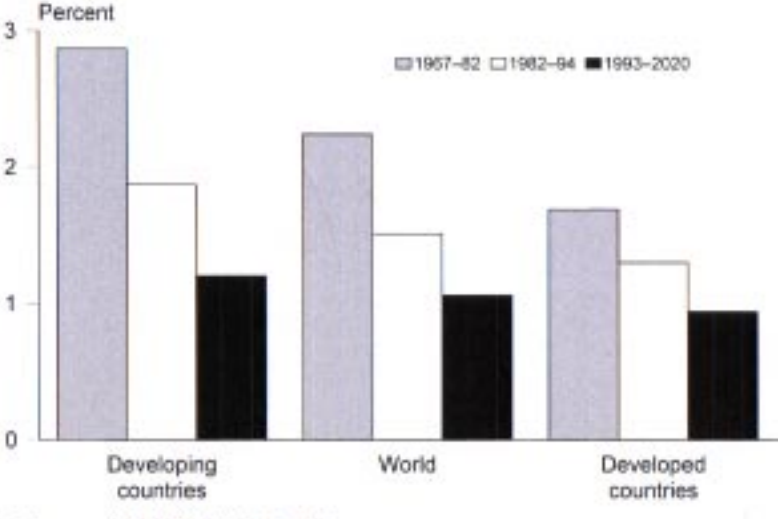
Since growth in cultivated areas is unlikely to contribute much to future production growth, the burden of meeting increased demand for cereal rests on improvements in crop yields. However, the annual increase in yields of the major cereals is projected to slow down during 1993–2020 in both developed and developing countries (Figure 8). This is worrisome given that yield growth

Figure 7—Growth in cereal production, 1993-2020



Source: IFPRI IMPACT simulations.

Figure 8—Annual growth in cereal yields, 1967–82, 1982–94, and 1993–2020



Source: IFPRI IMPACT simulations.

rates were already on the decline. The two key reasons for slow cereal yield growth rates are as follows:

(1) In regions where input use is high, such as Asia, farmers are approaching economically optimum yield levels, making it more difficult to sustain the same rates of yield gains; and

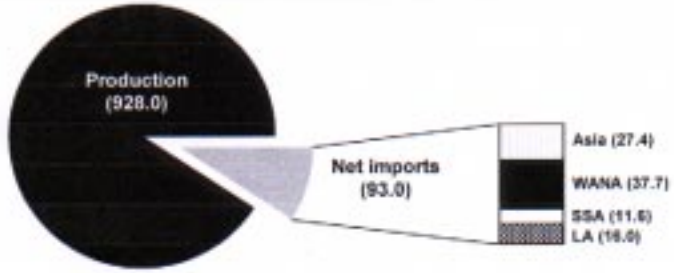
(2) declining world cereal prices are causing farmers to switch from cereals to other, more profitable crops and are causing governments to slow their investment in agricultural research and irrigation and other infrastructure.

With the projected slowdowns in area expansion and yield growth, cereal production in developing countries as a group is also forecast to slow to an annual rate of 1.5 percent during 1993–2020, compared with 2.3 percent during 1982–94. This figure is still higher, however, than the one percent annual rate of growth projected for developed countries during 1993–2020.

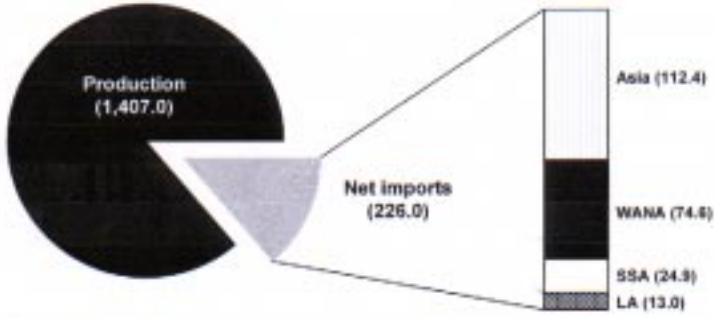
Food production will not keep pace with demand in developing countries, and an increasing portion of the developing world's food consumption will have to be met by imports from the developed world. The proportion of cereal demand that is met through net imports is projected to rise from nine percent in 1993 to 14 percent in 2020 (Figure 9). As a group, developing countries are projected to more than double their net imports of cereals (the difference between demand and production) between 1993 and 2020 (Figure 10). With the exception of Latin America, all major developing regions are projected to increase their net cereal imports. The quadrupling of Asia's net imports will be driven primarily by rapid income growth, while the 150 percent increase forecast for Sub-Saharan Africa will be driven primarily by its continued poor performance in food production. The United States is forecast to provide almost 60 percent of the cereal net imports of developing countries in 2020, the European Union about 16 percent, and Australia about 10 percent. The IFPRI projections indicate that long-term trends in real food prices will be falling slightly (Figure 11).

With continued population growth, rapid income growth, and changes in lifestyles, demand for meat is projected to increase by 2.8 percent per year during 1993–2020 in developing countries and by 0.5 percent per year in developed countries. While per capita demand for cereals is projected to increase by only eight percent, demand for meat will increase by 43 percent. The increase in per capita meat demand will be largest in China and smallest in South Asia; by 2020, Chinese per capita consumption of meat will be eight times that of South Asia (Figure 12). Meat production is expected to grow by 2.7 percent per year in developing countries during 1993–2020 (compared with 5.9 percent during 1982–94) and by 0.8 percent in developed countries (compared with 0.9 percent during 1982–94). Despite high rates of production growth, developing countries as a group are projected to increase their net meat imports 20-fold, reaching 11.5 million tons in 2020 (Figure 13). Latin America

Figure 9—Growing importance of net imports to meet developing-country cereal demand, 1993 and 2020
(millions metric tons)



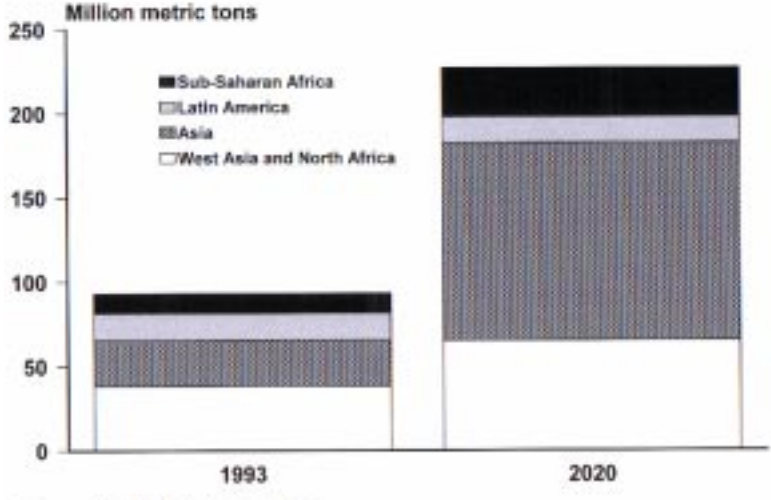
1993



2020

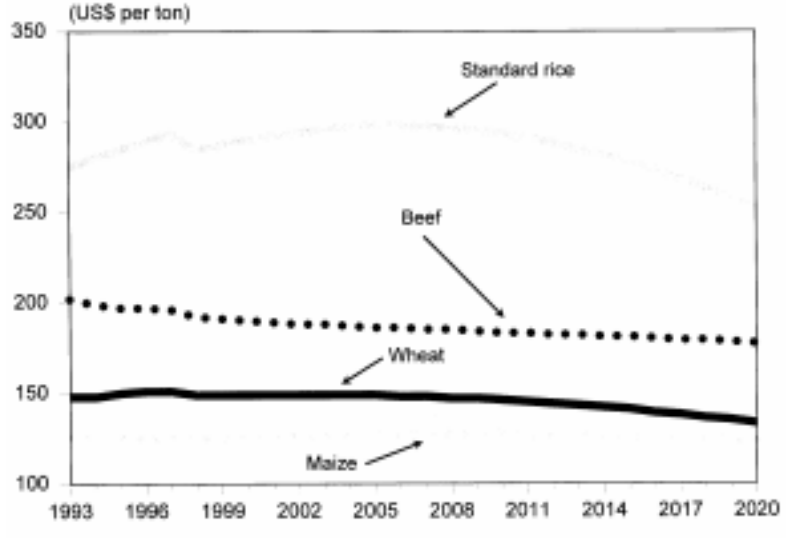
Source: IFPRI IMPACT simulations.

Figure 10—Net cereal imports of major developing regions, 1993 and 2020



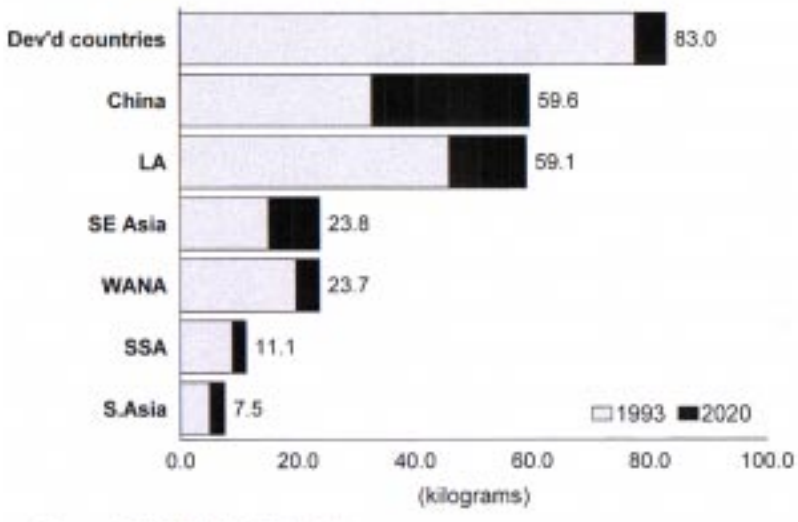
Source: IFPRI IMPACT simulations.

Figure 11—World food prices, 1993–2020



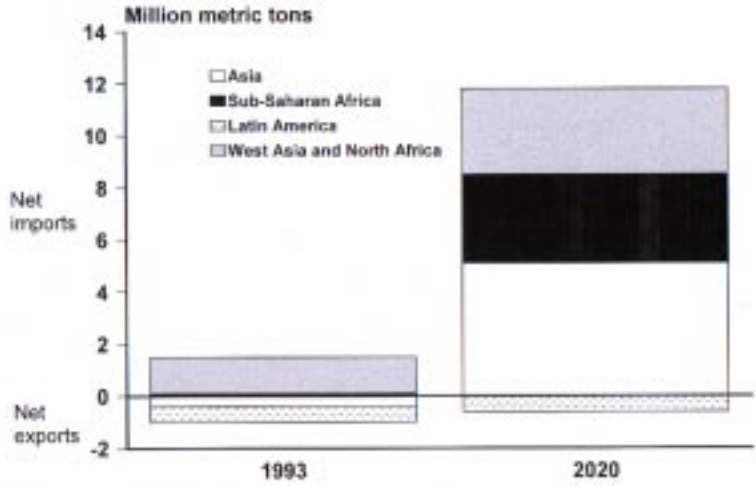
Source: IFPRI IMPACT simulations.
Note: Beef prices are per 100 kilograms.

Figure 12—Per capita demand for meat products, 1993-2020



Source: IFPRI IMPACT simulations.

Figure 13—Net trade in meat by major developing regions, 1993 and 2020



Source: IFPRI IMPACT simulations.

will continue to be a net exporter of meat, but Asia will switch from being a small net exporter to a large net importer.

Net imports are a reflection of the gap between production and market demand. For many of the poor, the gap between food production and nutritional needs is likely to be even wider than that between production and demand, because many of these people are priced out of the market, even at low food prices, and are unable to exercise their demand for needed food. The higher-income developing countries, notably those of East Asia, will be able to fill the gap between production and demand through commercial imports, but the poorer countries may be forced to allocate foreign exchange to other uses and thus might not be able to import food in needed quantities. It is the latter group of countries, including most of those in Sub-Saharan Africa and some in Asia, that will remain a challenge and require special assistance to avert widespread hunger and malnutrition.

Emerging Issues in Global Food Security

Volatile Cereal Prices

Concerns are growing that cereal prices may be more volatile than in the past (FAO 1996b). Reduced stocks and uncertainties associated with developments in China and the former Soviet Union, and increasing weather fluctuations among other factors, could increase price instability. On the other hand, market liberalization in developing countries, policy reform in developed countries, and more consistent and transparent stock-holding and trade policies will make producers more responsive to price changes and could reduce price instability. How these factors play out will determine whether cereal prices will be more volatile in coming years. In addition to price fluctuations in the international market, many low-income food-insecure developing countries suffer from large domestic price fluctuations owing to inadequate markets, poor roads and other infrastructure, and inappropriate policies and institutions. Even small changes in production resulting from better or poorer growing conditions may cause large fluctuations in food prices.

Feeding China

With one-fifth of the world's population and one of the fastest-growing and most rapidly transforming economies in the world, China has the potential to significantly affect global food markets depending on the extent of its future demand for cereals, its capacity to meet these demands through production, and the degree to which it enters world markets to satisfy its unmet needs (Rozelle and Rosegrant 1997). Views on the size and dominance of China's food economy in the 21st century vary widely, with some forecasting that China will be a major cereal exporter (Chen and Buckwell 1991; Mei 1995) and others cautioning that China might become a major cereal importer, if not the world's

largest importer (Garnaut and Ma 1992; Carter and Funing 1991; Brown 1995). IMPACT projections indicate that, in the baseline scenario, total cereal demand in China will increase by 42 percent, to 490 million tons, between 1993 and 2020, and cereal production by 31 percent, to 449 million tons. At 41 million tons, China's net cereal imports in 2020 would represent 18 percent of the developing world's projected net cereal imports. While sizable, China's projected imports are unlikely to pose an intolerable burden on the global food situation. For meat, China's production is projected to almost keep up with increases in demand. A predicted increase in demand of 132 percent between 1993 and 2020 would result in net imports of only 0.3 million tons — three percent of the developing world's projected net imports in 2020.

Alternative simulations suggest that only with extraordinarily rapid income growth, severe resource degradation, and failure to invest in agriculture would China's net cereal imports increase substantially and have a significant effect on world cereal prices (Rozelle and Rosegrant 1997). China is already a significant player in world food markets and is likely to become increasingly important. However, it does not represent a major threat to world food markets.

Feeding India

With a population of 930 million in 1995, India is the second most populous country in the world after China (UN 1996). Furthermore, population growth in India continues to be high and India's population is likely to exceed China's by 2020. Like China more than a decade ago, India is in the midst of major economic reform. If it succeeds, incomes in India will rise much faster than they have in recent decades, with profound effects on food demand and food security. In the IMPACT baseline scenario, India is projected to have an average annual economic growth rate of 5.5 percent during 1993–2020.

As incomes increase, will Indians greatly increase their consumption of livestock products, or will they remain more or less vegetarian, as India's history and cultural traditions would suggest? Views are mixed. In the baseline scenario, demand for livestock products is projected to increase by 4.6 million tons between 1993 and 2020 to 8.5 million tons (the corresponding increase in meat demand in China is 51 million tons to 89 million tons in 2020). Given the extremely low initial levels of livestock consumption in India, rapid growth in absolute demand for livestock would require a dramatic change in eating patterns. In a scenario modeling the effects of such a change in Indian diets, India's demand for meat products is forecast to increase almost 10-fold from 3.8 million tons in 1993 to 36.4 million tons in 2020. This increase in demand would have to be met through trade, as meat production is not projected to increase beyond the 8.5 million tons shown in the baseline scenario for 2020. India's projected net meat imports of 28 million tons under this scenario are a far cry from the less than 0.5 million tons forecast in the baseline scenario. This increase in Indian net imports would increase world meat prices by 21 percent

in 2020 relative to the baseline scenario and by 13 percent relative to 1993. If India attempts to meet potentially large increases in livestock demand through domestic livestock production rather than imports, thereby raising demand for feed grain, implications for global livestock and cereal trade and prices would be dramatically different from those predicted by the scenario that relies primarily on livestock imports to meet demand.

The Transition in Eastern Europe and the Former Soviet Union

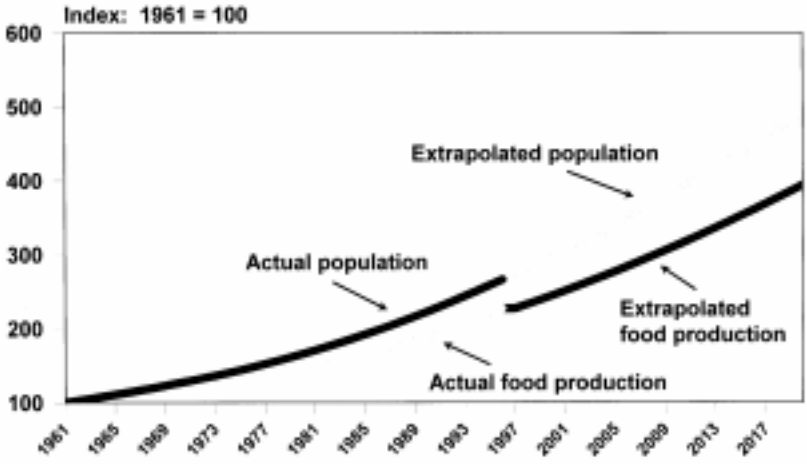
The fall of the Berlin Wall and the associated political changes in Eastern Europe and the former Soviet Union brought great promise for rapid economic growth in that part of the world. Many projected that food production in a number of countries affected, including Ukraine and the Russian Federation, would expand rapidly and significantly, causing Eastern Europe and the former Soviet Union to switch quickly from being net importers of grain to being significant net exporters (Tyers 1994). Although net grain imports by the former Soviet Union have fallen dramatically, this optimistic scenario has not materialized (FAO various years). There is still a great deal of uncertainty regarding future food production and demand in those countries.

IMPACT's baseline scenario projects that Eastern Europe and the former Soviet Union will become major net exporters of cereal by 2020, on the order of about 33 million tons. Cereal production is projected to increase by almost 40 percent between 1993 and 2020 to 341 million tons, while demand is projected to increase by 12 percent to 308 million tons. However, if incomes in Eastern Europe and the former Soviet Union grow faster than the baseline projection and crop productivity increases at a slower pace than forecast, these regions would remain net importers. For example, with an increase in income growth of 30 percent and a drop in production growth of two-thirds, crop production would increase by only 12 percent between 1993 and 2020 to 278 million tons while demand would increase to 304 million tons, resulting in net cereal imports of 26 million tons in 2020 — a very different outcome. Slow increases in crop production in Eastern Europe and the former Soviet Union could cause world cereal prices to be higher in 2020 relative to the baseline scenario. Changes in cereal production and demand in Eastern Europe and the former Soviet Union can have significant effects on the world food situation, but it would take very large declines in productivity growth in this region to dramatically drive up cereal prices.

Fragile Recovery in Sub-Saharan Africa

In Sub-Saharan Africa, the population growth rate has exceeded the rate of growth in food production since the early 1970s and the gap is widening, resulting in declining per capita food production (Figure 14). Simple extrapolations of the trends in population and food production growth since

Figure 14—Actual and extrapolated population and food production indexes for Sub-Saharan Africa, 1961–2020



Source: Data for 1961–96: Food and Agriculture Organization of the United Nations, FAOSTAT database, <http://faostat.fao.org> (accessed August and September 1997); extrapolations for 1997–2020: authors' estimates.

1961 show a further increase in the gap between population and food production. This is exactly the gap predicted by Malthus.[1] However, several recent developments suggest that Malthus' shadow over Sub-Saharan Africa could finally be waning.

First, Malthus' predictions grossly underestimated the potential of productivity-increasing technology. Where such technology has been effectively developed and utilized, such as in Asia, food production has expanded much faster than population. In Sub-Saharan Africa, the potential of appropriate productivity-increasing technology has yet to be realized. Maize yields for Africa and Asia were virtually the same in 1961, but since then they have tripled in Asia and quintupled in China while they have remained stagnant at around one ton per hectare in Africa (FAO 1997a; Byerlee and Eicher 1997). However, there are encouraging signs that productivity-increasing technology is beginning to accelerate yield growth of African food crops (CGIAR 1997).

Second, after a number of years of low or negative growth, Sub-Saharan Africa is experiencing economic recovery. However, this economic recovery is

fragile. Some of the factors that contributed to the recovery are short term in nature and cannot be expected to persist; these include higher commodity prices and favorable weather conditions. Other factors, such as policy reforms, an improved macroeconomic environment, and social and political stability, can have a more lasting effect on economic growth, if properly nurtured. Moreover, economic growth rates will have to be substantially higher if they are to make a dent in Sub-Saharan Africa's poverty. Per capita incomes have fallen so much that even if economic growth were to continue at the current pace (about five percent per year), it would still take at least a decade to recover to the levels prevailing in 1980 (CGIAR 1997).

If Malthus is to be proven wrong in Sub-Saharan Africa, a much greater effort must be made to ensure that farmers have access to appropriate production technology and that policies are conducive to expanded productivity in staple food crops. Besides new initiatives and expanded support for agricultural development, more must also be done to reduce population growth. Sub-Saharan Africa's annual population growth is projected to decline between 1993 and 2020. Yet the number of people added to the region's population every year is projected to increase until at least 2020, a consequence of the past high rates of population increases. Moreover, Sub-Sahara's projected annual population growth rate of 2.33 percent during 2015–2020 will be more than double the growth rates in other regions (UN 1996). Population growths of this magnitude will severely constrain efforts to increase income and improve welfare, while at the same time it will greatly increase the need for food.

Weather Fluctuations and Climate Change

With the recent resurgence of El Niño, followed by the relatively weaker La Niña, major weather fluctuations are under way or imminent in many parts of the world. These weather fluctuations could lead to sizable food production shortfalls and deterioration in food security in many parts of the world. The 1982–83 El Niño caused severe flooding in Latin America, droughts in parts of Asia, declines in fish stocks, and other weather-related damage estimated at over $10 billion (FAO 1997a, 1997b). The 1991–92 El Niño resulted in severe drought in Southern Africa that caused cereal production to drop by 60 percent or more in several countries, and imports and food aid had to increase to meet more than half of the cereal consumption in at least five countries (Pinstrup-Andersen, Pandya-Lorch, and Babu 1997). The 1997–98 El Niño far surpassed the last two major El Niños in severity, causing severe drought in Southeast Asia, flooding in the Andean countries of South America, and drought in a wide swath across Eastern Africa, and in general diminishing agricultural production around the globe. El Niño adds a major element of uncertainty to agricultural production and livelihoods around the world. And concerns are growing that El Niños may become more frequent and more severe in the fuure as a result of climate changes.

Although the trend of global warming is becoming increasingly clear, its effects on food production are still uncertain. Some research suggests that growing conditions will deteriorate in current tropical areas (where many of the developing countries are located) and improve in current temperate areas (where many of the developed countries are located) (Rosenzweig and Parry 1994; Fischer et al. 1996). However, effects on productivity and production will occur over a long period of time and will be very small in any given year. Therefore, it is reasonable to believe that policies and technologies can be developed to effectively prevent or counter the negative productivity effects of global warming. Failure by the public sector to act, and failure by the market and the private sector to respond, could result in significant long-term effects on food supply. Such a scenario might include reduced food production in tropical and subtropical countries and increased production in temperate countries. Whether these opposing effects will cancel each other out through expanded international trade, with little or no effect on total world food supply, is yet to be determined.

Growing Water Scarcity

Unless properly managed, fresh water may well emerge as the key constraint to global food production. While supplies of water are adequate in the aggregate to meet demand for the foreseeable future, water is poorly distributed across countries, within countries, and between seasons. And, with a fixed amount of renewable water resources to meet the needs of a continually increasing population, per capita water availability is declining steadily. Today, 28 countries with a total population exceeding 300 million people face water stress;[2] by 2025, their number could increase to about 50 countries with a total population of about three billion people (Rosegrant, Ringler, and Gerpacio 1997; Population Action International 1995).

Demand for water will continue to grow rapidly. Since 1970, global demand for water has grown by 2.4 percent per year (Rosegrant, Ringler, and Gerpacio 1997). Projections of water demand[3] to 2020 indicate that global water withdrawals will increase by 35 percent between 1995 and 2020 to reach 5,060 billion cubic meters. Developed countries are projected to increase their water withdrawals by 22 percent, more than 80 percent of the increase being for industrial uses. Developing countries are projected to increase their withdrawals by 43 percent over the same period and to experience a significant structural change in their demand for water, reducing the share for agricultural uses.

The costs of developing new sources of water are high and rising, and nontraditional sources such as desalination, reuse of wastewater, and water harvesting are unlikely to add much to global water availability, although they may be important in some local or regional ecosystems. So how can the rapid increases in water demand be met? The rapidly growing domestic and industrial demand for water will have to be met from reduced use in the agriculture

sector, which is by far the largest water user, accounting for 72 percent of global water withdrawals and 87 percent of withdrawals in developing countries in 1995 (Rosegrant, Ringler, and Gerpacio 1997). Reforming policies that have contributed to the wasteful use of water offers considerable opportunity to save water, improve efficiency of water use, and boost crop output per unit of water. Required policy reforms include establishing secure water rights for users; decentralizing and privatizing water management functions; and setting incentives for water conservation, including markets in tradable water rights, pricing reform and reduction in subsidies, and effluent or pollution charges (Rosegrant 1997). Failure to address the gap between tightening supplies and increasing demand for water could significantly slow growth in food production.

Escalating Concerns about Food Safety

Concerns about food safety are not new. Since time immemorial, human beings have worried about whether they have sufficient food to eat and whether the food they consume is safe and healthy. However, food safety concerns are escalating, particularly in industrialized countries, as evident by the growing demand for organic foods; by the strengthening public backlash against genetically modified organisms; by the extraordinarily high level of interest by consumers in the precise origin and modes of producing and processing the food they consume; and by the proliferation of regulations of producing, processing, storing, and transporting foods. There have been a series of well-publicized outbreaks of food-borne illnesses and massive food recalls in recent years, particularly in the United States. In developing countries, however, where food- and water-borne health risks are a major cause of illness and death, particularly among infants and children, food safety concerns do not seem to have garnered increased attention.

Yet, developing countries could be significantly affected by the increased concerns in industrialized countries in at least two major ways: first, because exports of their food commodities could be exposed to new and more demanding food safety standards partly through changes in the Codex Alimentarius and partly through unilateral demands by importers (thus, food safety requirements may become a hindrance to developing countries for realizing benefits from exports, either because unreasonable standards cannot be met or because food safety would be used as a nontariff barrier by importing countries); and second, because changing attitudes toward and legislation for food safety in industrialized countries could spill over into developing countries without due attention to local conditions and constraints and influence, among other things, availability of and access to food (for example, legislation to curtail or prohibit the use of fertilizers or chemical plant protection methods could have a negative effect on food security by increased unit costs of productions).

The Role of Biotechnology

Modern science offers humankind a powerful instrument to assure food security for all. Through enhanced knowledge and better technologies for food and agriculture, science has contributed to astonishing advances in feeding the world in recent decades. If we are to produce enough food to meet increasing and changing food needs, to make more efficient use of land already under cultivation, to better manage our natural resources, and to improve the capacity of hungry people to grow or purchase needed food, we must put all the tools of modern science to work.

Modern agricultural biotechnology is one of the most promising developments in modern science. Used in collaboration with traditional or conventional breeding methods, it can raise crop productivity, increase resistance to pests and diseases, develop tolerance to adverse weather conditions, improve the nutritional value of some foods, and enhance the durability of products during harvesting or shipping. With reasonable biosafety regulations, this can be done with little or no risk to human health and the environment. Yet little modern agricultural biotechnology research is taking place in or for developing countries. Most such research is occurring in private firms in industrialized countries, focuses on the plants and animals produced in temperate climates, and aims to meet the needs of farmers and consumers in industrialized countries. It is essential that agricultural biotechnology research be relevant to the needs of farmers in developing countries and to conditions in those countries, and that the benefits of that research are transmitted to small-scale farmers and consumers in those countries at affordable prices. Otherwise, developing countries will not only fail to share in the benefits of agricultural biotechnology, but will be seriously hurt as industrialized countries improve their agricultural productivity.

The attitude toward risk among the non-poor in both industrialized and developing countries is a constraint to the use of agricultural biotechnology in and for developing countries. Among people whose children are not starving, considerable resistance to agricultural biotechnology has arisen on the grounds that it poses significant new ecological risks and that it has unacceptable social and economic consequences. Although no ecological calamities have occurred, some people fear that transgenic crops will develop troublesome new weeds or threaten crop genetic diversity. Of course, any new products that pose such risks should be carefully evaluated before they are released for commercial development. But we should not forget that by raising productivity in food production, agricultural biotechnology will reduce the need to cultivate new lands and could therefore actually help conserve biodiversity and protect fragile ecosystems. Developing countries should be encouraged to adopt regulations that provide a reasonable measure of biosafety without crippling the transfer of new products into the field.

Public pressure in Western Europe is likely to move governments to introduce legislation that will constrain or prohibit full use of the opportunities offered by genetic engineering and other tools of modern science for food production and processing. There is a trend in several countries toward seeing the application of science to agriculture as part of the problem rather than part of the solution. Combined with this view is a failure to appreciate the need for productivity increases in food production. While the application of modern science, including genetic engineering and other biotechnology research, to solving human health problems is applauded and encouraged, there is an increasing suspicion that the application of such scientific methods to food production and processing will compromise agricultural production systems, food safety, and the health of current and future generations. In fact, modern science methods, including molecular biology-based methods, offer tremendous opportunities for expanding food production, reducing risks in food production, improving environmental protection, and strengthening food marketing in developing countries. Should legislation constraining modern agricultural science spread within the developed countries, the consequences for long-term food supplies in developing countries could be severe, partly because of reduced exports by developed countries and partly because similar policies might be adopted in developing countries as well.

As for the social and economic consequences of biotechnology, some are concerned that large-scale and higher-income farmers will be favored because they will have earlier access to and derive greater benefits from agricultural biotechnology. These concerns are remarkably similar to those raised about the Green Revolution. Whatever the shortcomings, real or alleged, of the Green Revolution, it did avert widespread starvation and helped many millions of people to escape hunger once and for all. With more pro-poor institutions and policies, many more poor people could benefit. Similarly, agricultural biotechnology can contribute to feeding many more people in a sustainable way. The new technologies, through appropriate policies, can be made accessible to small-scale farmers. Instead of rejecting the solutions offered by science, we should change policies to assure that the solutions benefit the poor.

The global community must keep its sights set on the goal of assuring food security for all. Condemning biotechnology for its potential risks without considering the alternative risks of prolonging the human misery caused by hunger, malnutrition, and child death is unwise and unethical. In a world where the consequence of inaction is death of thousands of children, we cannot afford to be philosophical and elitist about any part of a possible solution, including agricultural biotechnology. Modern science by itself will not assure food for all, but without it the goal of food security for all cannot be achieved.

REFERENCES

L. Brown, *Who Will Feed China?* (New York: W. W. Norton, 1995)

D, Byerlee and C. K. Eicher, eds., *Africa's Emerging Maize Revolution*. (Boulder: Lynne Rienner, 1997)

C. Carter and Z. Funing, "China's Past and Future Role in the Grain Trade." *Economic Development and Cultural Change* 39 (1991): 791–814

CGIAR (Consultative Group on International Agricultural Research), "Phenomenal Increase in Maize Production in West and Central Africa," *CGIAR News* 4 (1997): 1, 14, 15

L.Y. Chen and A. Buckwell, *Chinese Grain Economy and Policy* (Wallingford, U.K.: CAB International, 1991)

FAO (Food and Agriculture Organization of the United Nations), *Investment in Agriculture: Evolution and Prospects*, World Food Summit Technical Background Document 10, (Rome: FAO, 1996a)

_____ *Rome Declaration on World Food Security and World Food Summit Plan of Action*

_____ *FAOSTAT database*, <http://faostat.fao.org>, accessed August and September 1997

_____ *FAOSTAT database* <http://faostat.fao.org/default.htm>, Accessed May

_____ Various years, *Food Outlook* (Rome: FAO)

G. Fischer, K. Frohberg, M. L. Parry and C. Rosenzweig, "Impacts of Potential Climate Change on Global and Regional Food Production and Vulnerability," in *Climate Change and World Food Security*, ed. T. E. Downing, NATO ASI Series, Vol. 37, (Berlin: Springer Verlag, 1996)

R. Garnaut, and G. Ma, "Grain in China: A Report" (Canberra, Australia: Department of Foreign Affairs and Trade, East Asian Analytical Unit, 1992)

F. Mei, "China Can Feed Its Population," *China Daily*, April 29, 1995

Population Action International, "Sustaining Water: An Update" (Washington: PAI, 1995)

P. Pinstrup-Andersen, R. Pandya-Lorch and S. Babu, "A 2020 Vision for Food, Agriculture, and the Environment in Southern Africa," in *Achieving Food Security in Southern Africa: New Challenges, New Opportunities*, ed. L. Haddad (Washington: International Food Policy Research Institute, 1997)

M.W. Rosegrant, "Water Resources in the Twenty-First Century: Challenges and Implications for Action," *Food, Agriculture, and the Environment Discussion Paper 20* (Washington: International Food Policy Research Institute, 1997)

M.W. Rosegrant, C. Ringler and R. V. Gerpacio, "Water and Land Resources and Global Food Supply," paper prepared for the 23rd International Conference of Agricultural Economists, Sacramento, California, 10–16 August.

C. Rosenzweig, and M. L. Parry, "Potential Impact of Climate Change on World Food Supply," *Nature* 367 (January 13, 1994): 133–138

S. Rozelle, and M. W. Rosegrant, “China's Past, Present, and Future Food Economy: Can China Continue to Meet the Challenges?” *Food Policy* 22 (1997): 191–200

R. Tyers, “Economic Reform in Europe and the Former Soviet Union: Implications for International Food Markets,” *Research Report 99* (Washington: International Food Policy Research Institute, 1994)

UN (United Nations), *World Urbanization Prospects: The 1994 Revisions* (New York: UN, 1995)

_____ *World Population Prospects: The 1996 Revisions* (New York: UN, 1996)

World Bank, *1997 World Development Indicators* (Washington: World Bank, 1997)

_____ *World Development Report 1997* (New York: Oxford University Press for the World Bank, 1997)

ENDNOTES

1. Thomas Malthus' basic argument was that the world's natural resources could not assure expansions in food supply that would match population growth. Region after region has disproved his prediction. While Malthus argued that the population would grow geometrically and food production would grow arithmetically, the extrapolation shown in Figure 14 are based on a nonlinear regression. Such a function showed a better fit than linear functions for either of the two variables. Extrapolations based on Malthus's argument would result in a larger gap.

2. Their annual internal renewable water resources are less than 1,600 cubic meters per person per year.

3. Approximated by water withdrawals because of a lack of consistent data on consumptive use of water at national or regional levels.