Proc. Natl. Acad. Sci. USA
Vol. 96, pp. 5903–5907, May 1999
Colloquium Paper

This paper is the introduction to the following papers, which were presented at the National Academy of Sciences colloquium "Plants and Population: Is There Time?" held December 5–6, 1998, at the Arnold and Mabel Beckman Center in Irvine, CA.

Plants and population: Is there time?

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Historical Background

The year 1998 was the 200th anniversary of the publication of Malthus's famous first essay on population (1). Malthus argued that agriculture could not increase production as fast as the lust between the sexes would inevitably increase population size, and therefore that humans were condemned to poverty, famine, pestilence, and vice. Malthusian worries have been echoed by many since Malthus first wrote. Today discussions about the future growth of food supply and population are increasingly informed by the awareness that human activities impinge on the Earth's ability to sustain them. There is concern about the ecological and environmental consequences of expanding the food supply further to feed the still rapidly growing numbers of humans.

In 1968, a young Stanford biologist named Paul Ehrlich published a short book called *The Population Bomb* (2). This widely read book warned of the dangers of continuing rapid population growth, especially in the poor countries of the world. In the same year, 1968, J. George Harrar, President of the Rockefeller Foundation, gave a talk entitled "Plant Pathology and World Food Problems" before the First International Congress of Plant Pathology in London (3). Harrar celebrated the cultural and material achievements of humans but emphasized the need for scientists to help solve the persistent problems of "wars, . . . , hunger, poverty, disease, ignorance, social and cultural deprivation, and overpopulation." Harrar noted that there were then just under 3.5 billion people in the world and anticipated 6 billion by the year 2000. He urged the development of improved forms of contraception. "If there is evidence that birth rates can and will be reduced, vast effort to augment world food supplies will then become increasingly meaningful" (ref. 3, p. 587).

Harrar described the past contributions of plant pathology to the increase of crop production and the need to apply recent progress in biology to increase food production. "Genetic manipulation of plant species is as old as plant breeding, but its modern aspects offer exciting new possibilities for disease control as well as for greater productivity. It is becoming increasingly possible to map and identify the genes controlling a variety of functions and to introduce or extract genetic factors for a variety of traits, including disease resistance, increased yields, tolerance to heat, cold, and drought, photoperiod insensitivity, and increased amino acid content of food products. Currently, efforts are also being made to collect, identify, and store genes. Scientists can then draw on these 'germplasm banks' as they are needed" (ref. 3, p. 593).

After discussing "one highly interesting form of biological engineering," the then new IR8 rice variety, "which has been remarkably successful in most rice-producing regions," Harrar noted public concern about problems of food and population. He concluded "with cautious optimism." His optimism was limited by "the alarming fashion in which scientific and social advances are changing the quality of our environment, [including] the destruction of our soils and water courses, negative interference with the food cycle, and positive pollution of our air envelope . . . Agriculture, too, complicates the ecological pattern . . . " Thus "scientific and social advances" were and are accompanied by negative as well as positive effects. The challenge of finding a desirable balance among the inevitable tradeoffs remains.

In retrospect, Harrar's assessment seems surprisingly prescient and modern. The rice variety IR8 was a leading entry in the Green Revolution. Complex changes in varieties planted, farmer education, farm management, credit institutions, agricultural extension, irrigation, and chemicals applied as biocides and fertilizers combined to increase food production faster than population grew in certain areas. Since 1968, despite rising total numbers of people, increased food production and changes in the distribution of access to food have reduced the absolute number and the fraction of people estimated to be chronically undernourished in every region of the world except sub-Saharan Africa. Yet despite this remarkable progress, an estimated three-quarters of a billion people still suffer from undernutrition.

Demographic Situation and Prospect: The Challenge

The global population growth rate reached an all-time high of 2.1% per year just as Ehrlich and Harrar were writing. The annual rate of increase has since declined by about one-third to roughly 1.4% (4). Global population size is expected to pass 6 billion in 1999. Apart from the catastrophic effects of AIDS across the middle of Africa and the collapse of the economy of the former Soviet Union, life expectancies have increased almost everywhere, indicating overall better human health. These increases in life expectancy are largely attributable to improvements in sanitation, diet, reductions of environmental hazards, behavior, and, to a limited extent, improvements in medical care. The clouds that Harrar foresaw on the environmental horizon have cleared in some places and darkened in others. Although the quality of air and water have improved in some developed countries, they have deteriorated in many less developed countries. Moreover, in some areas, withdrawals of water for agriculture are unsustainable; in many places, water use in agriculture is both technically and economically inefficient. The adverse effects of treating common resources (such as marine fisheries, water supplies, biological diversity, the atmosphere, and some land and forest areas) as unlimited and free have become more evident. Human interventions in global geochemical cycles of water, nitrogen, carbon, methane,

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and other compounds and elements have outpaced scientific capacity to anticipate reliably the effects of these interventions.

Will the food supply keep up with human population growth over the next half century, and if so, at what costs to other aspects of the quality of life for present and future generations? Answers will depend on economics, environments, and cultures as much as on population sizes. Answers will differ depending on whether the query is local, national, or global. Nevertheless, it is helpful to start with a rough picture of population sizes that can reasonably be anticipated, as well as their distribution. Currently the global population of nearly 6 billion is increasing by about 80 million people per year. Were growth to continue at this annual rate of 1.4%, the population size would double to 12 billion in roughly 50 years. Most demographers view this scenario as unlikely because the rate of increase in population size has been declining for several decades and the absolute number of people added annually to the global population has been dropping since roughly 1990. It now appears unlikely that 6 billion more people will be added to today's 6 billion. At the opposite extreme, if the annual increase in population were to drop linearly from today's 80 million to zero over 50 years, then the average annual increase would be 40 million per year for 50 years. Population would increase by 2 billion people to give a population size of 8 billion in the year 2050. This optimistic scenario requires continuing and accelerating declines in fertility in presently poor countries with high fertility rates. Between these extremes, it is plausible to imagine a population size in 2050 of 9 or 10 billion (5, 6). Remembering that the human population numbered only 3 billion as recently as 1960, these numbers can only be viewed with awe.

In 1998, roughly 1.2 billion people—one person in five—lived in the developed countries, defined as North America north of the Rio Grande, Europe, Japan, Australia, and New Zealand, and sometimes including some smaller Asian countries. Most of these countries have fertility rates below replacement levels (6) and little if any of the next half century's population growth is expected to occur in these countries. But unless the pace of economic and educational development accelerates markedly, the fraction of people living in developing countries will increase from 4 in 5 at the end of the 20th century to as many as 9 in 10 by 2050. The population density in the developed countries is currently about 22 people per km^2, whereas that in the developing countries is roughly 55 people per km^2. The latter number will roughly double to 100 people per km^2 if global population grows to 10 billion, largely as a result of increases in the developing countries. This is one person per hectare. Attaining acceptable qualities of life in developing countries at such population densities will be a challenge of unprecedented proportions.

About 3 billion people presently live in the rural areas of developing countries. According to some demographic projections, this number is not expected to change much over the next half century, whereas the number of urban people in developing countries is expected to grow enormously, by as many as 3–5 billion (5). If these expectations are realized, then in the developing world roughly the same number of rural people will have to provide a very much larger number of urban people with food and fiber or these products of agriculture will need to be acquired from the developed world by trade or gift.

In 1998, the distinguished Australian plant physiologist Lloyd T. Evans reviewed the intertwined history of human population growth and agricultural development (7). He wrote: ". . . not only has agricultural evolution made increase in population possible—indeed it has been blamed for it—but also . . . population growth has driven the development of agriculture. . . . [Nevertheless,] the path to feeding the ten billion in a sustainable way is still by no means clear."

Colloquium Goals and Structure

The National Academy of Sciences Colloquium titled "Plants and Population: Is there time?" was organized to shed light on how the world will feed its still expanding population in a sustainable way while maintaining enough wildlands to support and preserve essential ecosystems services and biodiversity. The magnitude and activities of the human population make the task more complex than ever—and more critical. The Colloquium brought together economists, demographers and other social scientists, as well as agronomists, biotechnologists, geneticists, and ecologists.

Ismail Serageldin, the Vice President for Special Programs of the World Bank, provided a forward-looking overview in his after-dinner address. He emphasized that the currently rich countries have agricultural and institutional needs that differ importantly from those of the currently poor countries. The responses of the rich countries will not automatically satisfy the needs of the poor. He emphasized the need to design an international system of intellectual property that balances the private-property interests of the rich countries with the public-good needs of the poor.

The four scientific sessions focused on: demographic and economic projections of food demand and supply; limits on land, water, energy, and biological resources in agriculture; plant biotechnology; and biodiversity and multiple land use demands. Dominated by representatives of a single discipline, each session produced a markedly different vision of our planetary future.

Insights from the Colloquium

Different disciplines approached the Colloquium's central question from very different perspectives, made widely different assumptions, and applied different yardsticks to measure success. Participants' spirits were alternately lifted by projections of sustained expansion of productivity and of as yet barely imaginable improvements in both the health and healthfulness of crop plants, then dashed by predictions of the swiftly approaching limits of plant productivity, constraints on the availability of land, water, and other resources, and threats to the sustainability of natural and anthropogenic ecological processes and systems.

The first session, dominated by economists, examined the forces that shape agricultural production today. Cereal production per person world-wide peaked in the mid-1980s, declined over the next decade, then began to grow again in the mid-1990s, according to speaker Nikos Alexandratos. Historical economic analyses showed that the decline, far from being a first harbinger of inadequate world food supply, was largely the result both of deliberate efforts to decrease overproduction in Europe and North America, where prices fell because production capacity exceeded demand, and of the collapse of the Soviet Union. Intentional cutbacks in production, despite persistent undernutrition in some parts of the world, resulted from the difference between effective demand—cash exercised in the market—and the need for calories and nutrients adequate for health, which does not depend on income. Speaker Tim Dyson addressed the profound differences in progress toward food self-sufficiency in different parts of the world. Speaker Gale Johnson pointed out that low grain prices on world markets have been a signal for some governments and international donors to reduce support of agricultural research, thereby hampering the capacity of the agricultural system to respond to future changes. Dyson noted that much agricultural research has bypassed Africa, where needs for additional food are most acute.

Speakers Tim Dyson, Robert Evenson, Gale Johnson, and Nikos Alexandratos all agreed that the growth in the world's effective demand for food with increasing population could be

met by the world's agricultural system as a whole, although they differed in the optimism of their projections. Alexandratos reported projections that the average cereals yield of the developing countries would grow at 1.5% per year until 2010, down from 2.2% per year in the past. Based on macroeconomic projections that the currently poor countries will not achieve the levels of income of the currently rich countries within the next few decades, Alexandratos pointed out that a decline in global cereal production per person will not necessarily mean an equivalent decline in the average calories consumed per person. This apparent paradox arises because population will grow predominantly in the less developed countries where people consume three to four times fewer primary plant calories per day (as plant and animal products) than do people in developed countries. These projections assume, therefore, that current differences between countries in primary caloric consumption rates will persist. All of the speakers in this session acknowledged that population increases in some of the least agriculturally productive countries were not likely to be met by local increases in production and would require increased transfer of agricultural products through trade. How the less developed countries would become rich enough to buy the food required to feed their people was not addressed. However, speaker Robert Evenson emphasized that delaying the development and use of biotechnology to increase local grain yields would adversely affect poor countries far more than rich.

Participants in the second session, drawn from agronomy, plant breeding, agricultural economics, ecology, and other disciplines, addressed what would be required for world agriculture to continue the yield increases of recent decades. Speaker Vernon Ruttan pointed out that many of the gains in yield that could easily be imagined half a century ago have now been achieved. These gains were attributable to spectacular increases in crop planting density made possible by changes in plant architecture, marked jumps in harvest indices (the weight of usable food product as a fraction of total plant weight), transitions to harvesting multiple crops per year in many areas, introduction of strains with greater responsiveness to fertilizer, improvements in management practices, and expansion of irrigated area. Many of these improvements cannot be repeated. Panelist Thomas Sinclair emphasized that plants' ability to capture and fix energy is inherently limited by the physics of intercepting photons and capturing carbon dioxide, the biochemistry of photosynthesis, and the physiology of nutrient uptake and utilization.

Although perhaps ultimately changeable, it is not clear that these limits can be changed rapidly enough to keep food production ahead of need and demand. The extraordinary agronomic improvements of recent decades have moved present agriculture closer to theoretical limits. Speaker Kenneth Cassman presented evidence that the yield potential of two of the three most important cereal crops, rice and maize, has changed little in response to plant breeding in the past three decades. He argued that the performance of cereals was reaching 80% of theoretical limits in some geographic areas already, and that continuing increases in productivity per hectare would occur only if average yields achieved by farmers rose to comparable levels in the major cereal production systems worldwide. He suggested that although this rise might be attainable, it would require a profoundly deeper understanding of crop physiology and soil science than we now have. Information-intensive management of inputs and natural resources will be required to achieve these yield levels while preserving environmental quality.

Speaker David Hoisington suggested that major gains in productivity could still be made by accelerating the transfer of plant genes from diverse sources by using the techniques of molecular biology. Speaker Matthew Thomas argued that productivity could be increased immediately and substantially by pest management that takes better account of all interactions among plants, herbivorous insect pests, and natural enemies of pests. Local ecological interactions need to be understood better in the context of larger ecosystems. The effects of biotechnology and gene manipulations on a single plant or at one site are an inadequate basis for effective area-wide prescriptions. Thomas and panelist William Murdoch noted that more analytical work could be done on past biological control efforts to derive information that could improve future ones.

Panelist Vaclav Smil pointed out that a large fraction of food is still lost to spoilage and waste and suggested that significant food gains could still come from improvements in postharvest storage and distribution systems. Panelist Catherine Woteki emphasized the need for more attention to the production of a health-promoting mix of crops and to the safety of crops for consumers. Overall, the second session brought the sobering realization that future productivity gains would be more difficult to achieve than past gains and would require more basic knowledge, better institutional support, and increasingly sophisticated management practices.

Optimistic presentations by molecular biologists in the third session sought to dispel an earlier undertone of pessimism about the potential of biotechnology. Speaker Ganesh Kishore articulated a vision of a future for agriculture and human health based on a combination of information technology and biotechnology. He spoke of crops that will produce food better suited to the nutritional needs of both humans and animals, will remedy widespread nutrient deficiencies, will improve human health, and will protect environmental quality. He reported that unanticipated yield increases have already resulted from the new weed management practices used with genetically engineered herbicide-resistant soybeans. Speakers Kishore and John Ryals noted that transgenic crops expressing the insecticidal *Bacillus thuringiensis* endotoxin gene also showed surprising increases in productivity, apparently because reduced insect damage indirectly increases disease resistance.

Ryals sketched out the rapid progress in plant genomics that promises to make available an unprecedented variety of individual plant genes useful for improving crop plants. Speaker Ilya Raskin described uses of plants to remediate environmental pollution and produce nonfood products. Plants can extract and concentrate compounds from the soil to clean up land and water contaminated with uranium and other heavy metals. Plants also have the potential to become low-input biological factories through their ability to secrete small molecules and macromolecules into the surrounding medium. Panelist Richard Meagher described using bacterial genes to create transgenic plants that detoxify mercury-contaminated soils. Panelist Brian Staskawicz discussed recent progress in identifying plant disease-resistance genes. He expected that impending understanding of underlying molecular mechanisms would soon make it possible to enhance many different crop plants with durable disease resistance very quickly by genetic engineering techniques.

Speaker Luis Herrera-Estrella concluded the session with an assessment of the disparate biotechnological needs of agriculture in differently developed countries. He pointed out that, compared with developed countries, the developing countries have many more small farmers, a different interdependence of culture and agricultural practices, and a variety of problems, many of which are of little interest to the agronomic and biotechnological sectors of developed countries. For example, acid soils comprise 40% of the world's arable land. A common problem in the acid soils of many tropical countries is high levels of aluminum. Herrera-Estrella described recent success in making local crop plants that tolerate high soil aluminum levels by introducing bacterial genes that enhance the plants' ability to secrete small organic acid molecules to chelate the

aluminum. He articulated the need to accelerate the transfer of biotechnology from developed to less developed countries by easing restrictions on intellectual property rights, which increasingly limit the use of each component of a gene construct. He argued that biotechnology could make a culturally acceptable contribution to the welfare of small farmers if the yields of local varieties could be increased through genetic engineering. Export taxes could pay back biotechnology companies holding the patents if productivity increased enough for farmers to export produce. Panelist Donald Roberts pointed out that one-third of the world's food is not cereals. In West Africa, cassava has replaced maize as the staple subsistence crop. He suggested that noncereal crops deserve more attention from biotechnologists.

Herrera-Estrella's emphasis on improving food production among poor farmers with small areas to cultivate reinforced a point raised in earlier discussion. Several of the economists, including panelist Kenneth Arrow, pointed out that today's chronic widespread hunger results largely from inadequate cash incomes among the poor, not from inadequate global production of food. Given appropriate governmental policies, increasing the capacity of poor farmers to grow food could raise their incomes at the same time that it would increase the local food supply. Apart from the effects of chronic poverty, acute widespread hunger today often results from the breakdown of public order because of civil wars or other violent political instability.

The fourth and final session, dominated by ecologists, focused on the larger environment. The human population and its activities bring different demands on natural resources into conflict. Water management practices are inadequate to cope with sometimes mutually exclusive demands from agriculture, industry, and urban populations. Speaker Robert Socolow identified a need to assess and manage the global nitrogen cycle, just as ongoing efforts are devoted to assessing and managing the global carbon cycle. Nitrogen from agriculture and the burning of fossil fuels contributes to greenhouse gases, stratospheric ozone depletion, and eutrophication and can result in the effective sterilization of coastal waters through oxygen depletion. Based on an analysis of trends in the past 35 years, speaker David Tilman suggested that another doubling of agricultural production will have profound effects on nonagricultural ecosystems because of massive inputs of nitrogen and phosphorus, and because nonagricultural ecosystems will have to be converted to agriculture. Panelist Ronald Sederoff pointed out that current projections fail to take account of the growing demand for wood and wood products, particularly paper. The demand is likely to be met in the future only if trees are domesticated and rapidly growing varieties are developed and farmed.

Several participants, including speaker David Tilman and panelist Wes Jackson, stressed the vulnerability of monocultures, which dominate agricultural practices in developed countries. Tilman and Jackson encouraged greater crop diversity to decrease the risk of crop failure. But speaker Daniel Janzen pointed out that monocultures occur throughout nature in a wide variety of circumstances, and Ruttan pointed to examples of monocultural systems, such as east Asian wet rice culture, that have been sustained over several centuries. Other participants noted that in both natural plant communities and agriculture, a mixed culture can produce more biomass per unit area than a monoculture because of partitioning of utilization of resources.

Panelist Dennis Avery emphasized that our future ability to maintain current wildland area and meet the food needs of the still growing human population depends on further increases in the productivity of the land already under cultivation. Indeed, the net area under cultivation worldwide has changed very little over the past 30 years. Most of the best land is already in cultivation, and additions are generally offset by losses to urbanization, salinization, and desertification. Thus the goal of increasing food production while preserving current wildland area requires future crops and crop systems to be more productive per unit of land area than are today's. The alternative of major increases in the area under cultivation would have significant social and economic costs, as well as negative ecological impacts.

Speakers Arturo Gomez-Pompa and Daniel Janzen considered how to integrate conservation efforts throughout the world with the support of local, national, and international populations. Janzen warned that tropical wildlands would survive only if tended as multipurpose "gardens." These gardens should provide protective stewardship for and access to biodiversity as well as essential ecological services and should receive payment for the goods and services they provide. Janzen proposed new mechanisms to generate income from both biodiversity and ecological services and stressed the importance of returning income to the local stewards of the gardens.

There were profound and sobering differences of opinion about humanity's future ability to feed the human population while sustaining ecosystem services and preserving wildlands. The question has changed and grown more complex as the magnitude and impact of human activities have expanded. Panelist Walter Reid pointed out that when the scale of agriculture was small, and undisturbed ecosystems were vast, the underlying ecosystems seemed limitless, and what has recently come to be called their "services" could be freely available to everyone. Humans concentrated on optimizing food supply, often with little concern for the ecological consequences. Now the competing demands of the human population for ecosystem services and the direct and indirect environmental costs of our activities are no longer negligible. Yet efforts to value the planet's ecosystem services are relatively new, controversial, and have as yet had little real impact.

Concluding Perspective

The Colloquium must be viewed as a step near the beginning, not the end, of a journey. Both more knowledge and better institutions will be required to continue the journey toward a better fed world. The Colloquium focused on food production and sustainability, leaving equity and other aspects of the quality of life for future discussion.

We lack the knowledge to resolve the differences in perspective that startled many participants in the Colloquium. Many questions raised during discussion went begging for answers. How reliable are global statistics on the extent of hunger, the extent of desertification, the amount of land used for agriculture? How and how much does soil erosion impair agriculture in various parts of the world? How much carbon and nitrogen must farmers return to the land from crops to maintain optimum soil fertility? How rapidly will resistance to pesticidal proteins, such as the *Bacillus thuringiensis* endotoxin, emerge in insect pests? How can intellectual property rights be managed to optimize the balance between the interests of biotechnology firms in developed countries and poor farmers in developing countries? How extensive are postharvest losses of food? How can the existing information about improved farming practices and materials be diffused more effectively to farmers in countries with very different levels of education and technological sophistication? How important to food production are regional variations in topography, climate, soil, biotic environments, institutions, and individual behaviors? Which are the best targets for intervention? If there are substantial uncertainties about future climate change and about the effects of each possible change on agricultural production, what strategies of response make the most sense for national governments and international organizations?

We also lack the human institutions required to define, develop, integrate, and apply the requisite knowledge. Ruttan wrote: "If the world fails to meet the challenge of a transition to sustainable growth in agricultural production, the failure will be at least as much in the area of institutional innovation as in the area of resource and environmental constraints. . . . At our present stage of knowledge, institutional design is analogous to driving down a four-lane highway looking out of the rear-view mirror. We are better at making course corrections when we start to run off the highway than using foresight to navigate the transition to sustainability." Panelist Dennis Ahlburg further pointed out that we do not know how to design "better policies" like market reforms, as experience in Eastern Europe attests. Where are useful models for developing the institutions and knowledge needed to manage agricultural and wildlands in a way that sustains global ecosystem services and promotes human well-being?

Although the Earth's biogeochemical cycles ensure that local practices have distant and even global impacts, our thinking is far from integrative and global. Scientific models are just beginning to grapple with the realization that complex systems, whether geological, biological, or human, often exhibit nonlinear responses. These include abrupt shifts in oceanic circulation and climate, mutations that increase the virulence of pathogens, extinctions of species, and rapid changes in human fertility, mortality and migration. In addition, dilemmas of population, equity, food, and environmental quality are local in many important respects, as panelist Billie Lee Turner emphasized. These realizations must inform our information-gathering, our institution-building, and our thinking about the kinds of changes that would lead to sustainable practices in agriculture and all other spheres of human activity.

Our ability to gather local data on a global scale and to work locally while integrating our activities across vast geographic distances has never been better. It will continue to improve in the future as satellite imaging techniques develop and computer networks expand. Molecular biology and biotechnology open new vistas for understanding and altering the properties of all organisms on which humans depend, including plants. The potential pace of change could not even have been imagined 30 years ago. Whether and how this potential is realized—and whether it is accepted by people—cannot yet be foreseen. Finding solutions will require collaborative efforts of a broad array of disciplines and constituencies. Success will depend profoundly on what we do now and in the immediate future. What is very clear is that there is no time to lose.

A previous draft of this summary was sent for review to all speakers and panelists in the Colloquium. We thank the following for helpful comments: Dennis Ahlburg, Nikos Alexandratos, Kenneth Cassman, Tim Dyson, Paul R. Ehrlich, Daniel Janzen, William Murdoch, Walter Reid, Don Roberts, Vernon Ruttan, Robert Socolow, Matthew Thomas, David Tilman, and Catherine Woteki. We thank the National Academy of Sciences for sponsoring this Colloquium. J.E.C. acknowledges support of National Science Foundation Grant DEB9207293.

1. Malthus, T. R. (1798/1970) *An Essay on the Principle of Population*, ed. Flew, A. (Penguin, London).
2. Ehrlich, P. R. (1968) *The Population Bomb* (Ballantine Books, New York).
3. Harrar, J. G. (1970) *Persp. Biol. Med.* **13,** 583–596.
4. Population Reference Bureau (1998) *1998 World Population Data Sheet* (Population Reference Bureau, Washington, DC).
5. United Nations, Population Division (1997) *Urban and Rural Areas 1996* (United Nations, New York), Publication ST/ESA/SER. A/166.
6. United Nations, Population Division (1998) *World Population Estimates and Projections, 1998 Briefing Packet* (United Nations, New York).
7. Evans, L. T. (1998) *Feeding the Ten Billion: Plants and Population Growth* (Cambridge Univ. Press, Cambridge, U.K.).