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THE GLOBAL FOOD SYSTEM, THE ENVIRONMENT, AND HUNGER IN GLOBAL ENVIRONMENT

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ABSTRACT

Recent attention to the threat of global environmental change has tended to focus on the possible impacts of a changing environment on agriculture and the implications for global and regional food security. From a policy viewpoint, however, it is also critical to understand the degree to which agriculturally related activities may contribute to global-scale environmental change and the extent to which policies to prevent, mitigate, or adapt to environmental change may themselves affect agriculture and hunger. These two issues are likely to become especially important in making decisions not only about how to reduce the magnitude of human perturbations to the environment but also about how to improve both food security and environmental quality in the more crowded world of the future.

THE PAST: THE ORIGINS OF AGRICULTURE

Humanity has relied solely on hunting, fishing, and gathering for food for most of its two million years of existence. Agriculture---the domestication of plants and animals appeared only about 10,000 years ago, roughly coincident both with a period of widespread climatic and ecological fluctuations (Matthews et al. 1990) and with an acceleration of population growth to on the order of 0.1 percent per year (Hassan 1981). Whether the spread of agriculture was a trigger for more rapid population growth or was itself a response to increasing population or environrnental pressures remains a controversial question. For example, anthropologic evidence, including indicators of nutritional status derived from skeletal remains, suggests that the health of hunter-gatherers tended to be better than that of subsequent farmers in the same region (Cohen 1990; Cohen and Armelagos 1984).

One explanation for this observation is that agriculture and related technological and social innovations may have emerged initially as a way to compensate for an unreliable or declining resource base arising from population pressures, environmental fluctuations, or both. In a sense, such "stress" models of the origins of agriculture suggest that hunger and a changing environrnent may have helped motivate the development and adoption of agriculture, even though in the short term agriculture apparently provided less output per unit of labor input than hunting and gathenng (Hassan 1981; Matthews et al. 1990).

A third "ecologic" view is that human use of plants and animals naturally led to significant: impacts on the local or even regional environment---for example, through the spread of seeds, selective harvesting of "wild" species, and deposit of waste matter. Such modifications to plant and animal habitats and genotypes resulted eventually in a variety of symbiotic, co evolutionary relationships that we now term domestication (Rindos 1984). In essence, the ecologic model raises the possibility of important two-way interactions between environmental stresses and humanity's demographic and technologic development and perhaps even its social development.

These alternative models of the origins of agriculture are instructive because they highlight the intimate links that may have persisted for many millennia among environmental fluctuations, agriculture, and human welfare. In the long term, agriculture has clearly brought the potential for larger populations, expanded exploitation of climatic and other natural resources, and reduced vulnerability to many forms of environmental fluctuation, such as drought and other extremes of weather and climate. At the same time, however, agriculture and thc increasing globalization of food systems may have increased vulnerability to other problems, such as market failures and the unequal distribution of food. For example, nutritional levels as indicated by estimates of human height have been marked by variations of comparable magnitude on time scales of 50-l0,000 years (Kates and Millman 1990). Although it seems likely that environmental factors are now relatively less important contributors to such variations than they were in past millennia, human history provides no guarantee that new forms of environmental change might not emerge as dominant influences on human nutrition and well-being.

THE PRESENT: THE GLOBAL FOOD SYSTEM, THE ENVIRONMENT, AND HUNGER

Sometime after the Second World War, probably during the early 1960s, humanity surpassed what may have been an unprecedented threshold: It collectively produced enough food calories for the world's population, assuming that all calories were distributed evenly and utilized directly by humans--that is, not for animal feed or nonfood uses (Chen and Fiering 1988; Sukhatme 1986; U.S. Panel on the World Food Supply 1967). Since then, the size of the theoretic "surplus" calories has grown to as much as 20 percent above world food requirements as determined by United Nations (U.N.) nutritional standards (WHO 1985), although during 1987 and 1988 it decreased to less than 10 percent above aggregate requirements in part because of weather-related production shortfalls in North America and continuing rapid population growth around the world (Chen 1990; Kates et al. 1989). Current world "carryover" stocks of cereals are extremely low, constituting only about 17 percent of aggregate cereal consumption, roughly the minimum level considered "safe" by the U.N.'s Food and Agriculture Organization (FAO 1990).

Of course, since food production, buying power, and consumption are not distributed evenly with population, large surpluses and deficits exist at regional, national, and sub national levels. For example, in the mid- to late-1980s, as many as 1.5 billion people lived in countries where dietary energy supplies were inadequate to meet national nutritional needs, and some 350-500 million people lived in households too poor to obtain enough calories for minimal adult activity and the healthy growth of children (ACC/SCN 1987; Chen 1990). In contrast, dietary energy supplies in the developed world averaged more than 3,300 calories per person in 1984-1986, of which 30 percent were derived from animal products (FAO 1989). Assuming conservatively that four calories of animal feed are needed to produce one calorie of animal product, the developed world--with only 25 percent of the world's population---in effect consumes at least 40 percent of the total world "primary" food supply in caloric terms.

Growth in food production in recent decades has resulted primarily from increased crop yields per unit of land and to a lesser extent from expansion of cropland. Between 1964-1966 and 1983-1985, total world cropland increased by only 9 percent, but total agricultural production grew nearly 60 percent. Global mean yields of cereals increased by nearly two-thirds during this period, and those of roots and tubers by about one-fourth. These improvements in yield stemmed from a combination of increased agricultural inputs, more intensive use of land, and the spread of improved crop varieties. For example, global mean fertilizer use more than doubled from 34 kg/ha of cropland in 1964-1966 to 86 kg/ha in 1983-1985, and irrigation expanded from 13 to 15 percent of the world's arable land between 1974-1976 and 1984-1986. It is estimated that, in 1986, improved varieties of maize were planted on more than 70 percent of all maize-growing cropland (WRI/IIED 1988).

Marine catches averaged nearly 80 million metric tons in 1985-1987, an increase of 30% percent over 1975-1977 levels. Freshwater catches grew more than 60 percent to 11 mmt during this period (WRI 1990). Roughly 70 percent of world fish production is used for food, with the remainder going into fish meal and oil (Alexandrite 1988).

Concurrent with these production and yield increases has been significant growth of world trade in food and agriculture. Food imports grew from 8 percent of total world production in 1961-1963 to 12 percent in 1983-1985. About 12.5 million metric tons of fish products were traded internationally in 1985, or about one-third of local fish production (Alexandratos 1988). One consequence of this "emerging" global food system may be a decrease in local vulnerability to famine in developing countries through increased reliance on food imports including food aid, but an increase in vulnerability to problems stemming from international trade and integration into the global economy (Millman et al. 1990).

INFLUENCE OF THE GLOBAL FOOD SYSTEM ON THE GLOBAL ENVIRONMENT

The global food system may influence the global environment in a variety of ways. The direct impacts of agriculture on the environment include modification of land for agricultural purposes and byproducts of production such as methane released by rice paddies and livestock. Activities such as food processing, distribution, and preparation use fossil fuels, fuel wood, refrigerants, and other inputs and generate wastes. Indirect impacts include the effects of energy, materials, and pollution entailed in constructing and maintaining equipment, transportation and storage facilities, and other infrastructure used in food production, fisheries, and related activities, and in supporting the populations involved in them. Of course, it is especially difficult to quantify such indirect impacts, to attribute them consistently to particular activities, and to ascertain whether alternative uses of resources would have resulted in greater or lesser impacts.

LAND USE AND CONVERSION

About 11 percent of all land worldwide is used for crops and another 25 percent for pasture. On a regional basis, crop areas range from as low as 6 percent of Africa and 8 percent of South America to 17 percent of Asia and 30 percent of Europe. About 15 percent of all cropland is irrigated, ranging from 6 percent in Africa and South America to 31 percent in Asia (WRI 1990).

As noted previously, cropland expanded only 9 percent between 1964-1966 and 1984-1986. The area of permanent pasture remained constant. World population grew by some 45 percent during this period, leading to a decrease in cropland per capita from 0.4 to 0.3 ha/person (UNEP 1989). Net increases in cropland during the next decade are expected to be modest, despite large reserves of untapped arable land in South America and Africa (Alexandrite 1988).

Of greater concern are changes in biomass and emissions of trace gases associated with deforestation. Estimates of deforestation rates vary widely, primarily because of data limitations and definitional problems. As much as seven million hectares of closed tropical forests may have been cleared annually for agriculture around 1980 and an additional four million hectares of open woodland deforested annually to meet agricultural or fuel wood needs (WRI/IIED 1988; but see Detwiler and Hall 1988). The extent of shifting cultivation and the nature of subsequent land uses are important uncertainties; estimates of closed primary and secondary forest affected by shifting cultivation range from about 5 to 44 million hectares per year (Detwiler and Hall 1988). Recent studies suggest even higher rates of deforestation in some countries, although there may be considerable year-to-year variability because of weather and political and economic factors (e.g., Malingreau and Tucker 1988; WRI 1990).

Much deforestation and other land conversion occurs through burning of biomass, which releases CO2, CO, N2O, CH4, soot, and other trace gases into the atmosphere. Once forests are removed, emissions of CH4, N2O, and other trace gases may continue from exposed soils (Graedel and Crutzen 1989). For example, Goreau and de Mello (1988) report high CH4 fluxes associated with both flooding and the spread of termites on deforested lands. The net environmental impacts of biomass burning depend to a large degree on the subsequent use of the land, which in turn may depend on the objectives and actions of those who initiated the burning (Kates et al. 1990).

CROP PRODUCTION AND FERTILIZER APPLICATION

Various forms of agricultural production may lead to significant trace gas emissions. Tilling of soils permits oxidation of organic matter, producing CO2. Even with no application of nitrogen fertilizers, cultivated soils may emit large amounts of N2O, perhaps as much in the aggregate as that released from fertilized fields (Crutzen and Graedel 1986). Application of fertilizers increases N2O release by plants, although emission rates vary greatly with soil conditions (Harriss 1989). As noted previously, world fertilizer consumption is growing rapidly, and its use is widespread in a variely of different socioeconomic and technologic settings (Kates et al. 1990).

LIVESTOCK PRODUCTION

Animals constitute a second major source of CH4 emissions, which result from microbial breakdown of cellulose and other carbohydrates in their digestive tracts. Cattle in developed countries and Argentina and Brazil produce an estimated 55 kilograms of CH4 per head per year. Cattle in other developing countries are thought to produce less, about 35 kilograrns per year, because of lower feed intakes despite poorer feed quality. Crutzen et al (1986) estimate 1983 cattle populations of some 570 million in the first group of countries and 650 million in the second, yielding a total production of at least 54 million metric tons of CH4 per year. Another 20 million metric tons are produced by more than 120 million buffalo, 1.1 billion sheep, 470 million goats, 17 million camels, 770 million pigs, 64 million horses, and 54 million mules and asses. Applying the Crutzen et al. (1986) emission rates to country-specific data on animal populations, the World Resources Institute (WRI 1990) estimates total 1987 CH4 emissions from livestock to be 76 million metric tons, of which some 60 percent occurs in developing countries. Just six countries--I-ndia, the U.S.S.R, Brazil, the United States, China, and Argentina---account for more than half of all CH4 emissions from livestock. These estimates, together with the estimates for CH4 emissions from biomass burning and paddy fields, indicate that activities primarily associated with food production generate some two-thirds of annual CH4 emissions.

WATER USE

Agriculture is; the largest single consumer of fresh water, although its share of total use has declined significantly during the past century and is expected to continue to decline through the year 2000. On a global basis, total water withdrawals for all purposes constitute less than one tenth of total river runoff, and consumptive uses only one twentieth of this total. Withdrawal rates are much higher in some river basins, leading to significant regional-scale impacts on water level and quality in rivers, lakes, and enclosed seas such as the Aral (WRI 1990). Irrigation has led to high salinity and waterlogging in millions of hectares of irrigated land in arid and semiarid areas of South Asia, the Middle East, the United States, and the U.S.S.R (GEMS 1988).

Water quality and quantity problems are critical from the viewpoint of human health and environrnental quality on local and regional scales, and they undoubtedly have global-scale implications for food production and food security---especially if projected hydrologic and sea level changes do occur. However, they do not as yet appear to have significant influences on the likelihood or timing of global environmental change. This conclusion could change if various proposed mechanisms for biogeochemical feedback prove significant. For example, it has been suggested that aquifers polluted by agricultural, livestock, and other effluents may emit large amounts of N2O (Ronen et al. 1988) and that changes in marine productivity could result from nitrogen pollutants (Fanning 1989).

ENERGY USE

Agriculture is a modest user of energy relative to other economic sectors, accounting for an estimated 3.5 percent of commercial energy use in developed countries and 4.5 percent in developing countries (FAO 1981). These estimates take into account energy used in irrigation, pesticide and fertilizer production, and machinery production and operation, but not energy used in food processing, storage, and transportation (Hrabovszky 1984). When the latter are taken into account along with other food system activities, their share of energy consumption increases significantly. For example, Pimentel (1980) attributes 17 percent of United States fossil-fuel consumption to food-system activities, divided about equally between food production, processing, and preparation. Since the U.S. itself generates about one-fifth of annual world CO2 emissions (WRI 1990), its food-related activities alone contribute a not insignificant 3-4 percent to total annual CO2 emissions.

In developing countries, fertilizers require the highest commercial energy inputs, followed by machinery and irrigation. The Agriculture: Toward 2000 study (FAO 1981) assumed that significant increases in commercial energy application will be needed to boost agricultural yields and farm earnings. Its two scenarios for the year 2000 project an average increase of 7.5 percent per year in commercial energy use in agriculture in 90 developing countries, resulting in more than a quadrupling of energy use between 1980 and 2000. Growth rates in fertilizer consumption in the early 1980s were somewhat below this rate of increase, averaging 6.2 percent per year between 1981--1982 and 1985--1986 (FAO 1985). Given the high costs of importing fertilizers and fossil fuels, it seems likely that developing countries may increasingly turn to alternatives such as biogas and animal power (Goldemberg et al. 1988; Sinha 1986). Biogas consists mostly of methane and hydrogen gases produced by anaerobic fermentation of crop and animal wastes. Usable nitrogen, phosphorus, and potassium are byproducts. Of course, widespread use of biogas would presumably lead to significant methane and N2O emissions.

OTHER FOOD-SYSTEM ACTIVITIES

Other aspects of the food system are expected to have relatively limited impacts on the global environment. CFC releases associated with refrigeration of foodstuffs are relatively small; in the United States; they amounted to less than 6 percent of total CFC emissions in 1976. Recovery of CFCs from large refrigeration units may already be economical, and alternate refrigerants do exist for small home refrigerators and freezers (Laurmann 1989).

THE FUTURE: MORE CROWDED, LESS HUNGRY, AND ENVIRONMENTALLY LIVABLE?

Recent population data suggest that birth rates have not fallen as quickly as expccted in the 1980s. As a result, the UN has recently revised upward its estimates of the eventual total world population, from 10.2 billion in the 1984 medium projection to 11.3 billion in the 1988 projection. By the year 2025, world population is projected to reach nearly 8.5 billion, 60 percent larger than the population in 1990 (Sadik 1990).

Providing adequate nutrition for this larger population will require at least a comparable increase in effective food availability and probably a much higher increase to allow for unequal distribution and better diets (Chen and Fiering 1988). Key issues are (a) whether existing production can be used more efficiently, (b) whether production can be increased without increasing impacts on the global environment, and (c) whether the global food system can adapt to any environmental changes that do occur. Although firm conclusions about any of these issues are not yet possible, a brief discussion of each of them is instructive.

Poor utilization of food calories after food has been consumed may also result in the effective waste of food. For example, even a mild episode of diarrhea in adults may lead to a loss of food calories equivalent to 1-2 percent of annual food requirements, and diarrhea and associated infections among infants and small children can result in weight loss equivalent to 5-10 percent of annual food requirements (Moyer and Powanda 1983). Chen (1983) estimates that small children in the developing world average on the order of three episodes of diarrhea per year, or more than 1.4 billion episodes annually around 1980. Intestinal parasites such as Schistosoma, Giardia lamblia, Ascaris lumbricoides, Trichuris trichiura, Strongyloides stercoralis, and hookworm may also cause or enhance malnutrition through a combination of reduced food intake, malabsorption, anemia, and other nutrient loss (Tromkins and Watson 1989). Schistosomiasis alone is estimated to affect some 200 million people in the developing world (UNEP 1987).

Large effective losses of food calories also occur because of inefficiencies in converting raw animal feed into edible animal food products. Net conversion efficiencies observed in breeding populations of farm animals range from 3 to 6 percent for sheep and beef cattle to 11-12 percent for pig meat, milk, and eggs (Holmes 1980) Overall efficiencies are at best about 17 percent, that is, about 600 calories of feed are needed to produce 100 calories of animal products (Blaxter 1986; Miller 1980). Of course, animal production may produce foods with higher contents of protein, minerals, and fats than the raw feed could have provided and may also generate other benefits such as the work performed by animals and a mechanism for storing food and household assets.

Nevertheless, these estimates of losses and inefficiencies suggest that there may be substantial room for improvement in the delivery of nutrition, which is presumably one of the primary objectives of the global food system. As recognized in the energy field in recent decades (e.g., Goldemberg et al. 1988), it is important to focus on the end use efficiency of production---in this case, the level of food production and associated inputs needed to provide a desired set of "services," such as a minimum number of calories per person each day and some degree of dietary quality and diversity. The most practical and cost-effective way to increase delivered nutrition may not be to increase gross production but to reduce pre- and post-harvest losses, find lower-input methods for producing high-protein and other desired food products, and improve the capability of households and individuals to process and utilize food efficiently. A major benefit of such, a "food conservation" strategy---akin to present-day energy conservation efforts--should be the overall reduction of the environmental stresses stemming from use of agricultural inputs, disposal of agricultural wastes, and other food-system activities.

Other opportunities for improving the efficiency of food use include improvement in postharvest food storage, more efficient food preparation at the household level, and improvements in the health of individuals to minimize losses caused by diarrhea, parasites, and incomplete digestion. For example, new storage methods such as a hermetically sealed "cube" developed by the Volcani Institute in Israel promise reduced grain losses caused by pests and moisture while at the same time lowering pesticide use (Donahaye 1990). In the United States, a number of organizations utilize volunteer labor to "glean" crops missed by mechanical harvesters, thereby salvaging foodstuffs that would other wise go to waste. New types of cooking stoves in developing countries can significantly reduce the fudwood needed for food preparation and help improve food digestability (Harrison 1987). More widespread use of oral rehydration therapy, promotion of breastfeeding, and other efforts to combat diarrheal-related disease help reduce nutritional losses even after food consumption (Grant 1990).

Improving overall end use efficiency will not only require recognition of opportunities of this kind, but also---as evident from ongoing efforts to promote energy conservation arround the world---restructuring of market and regulatory incentives, for example, to reflect more realistically the environmental "externalities" of agricultural production and to remove explicit and implicit subsidies of limited resources and entrenched technologies (c.g., NRC 1989). Resulting changes in markets and food prices would undoubtedly have significant distributional effects, both between and within countries---but how levels and patterns of hunger might change is difficult to predict.

Increased production on existing cropland has in the past been achieved primarily through more intensive application of fertilizer, expansion of irrigation, and improved crop varieties. As noted previously, the first option may entail releases of N2O and the second, especially for wet rice production, releases of methane. Clearly, new methods for providing nitrogen such as intercropping with nitrogen-fixing plants or genetic manipulation to add nitrogen-fixing abilities to crops could significantly reduce the use of nitrogen fertilizers. Reducing methane emissions from wet rice production is more problematic, since present methods for dry rice production have significantly lower yields (e.g., Sanchez 1989); however, new strains of rice may reduce the need for flooding and therefore lower emissions of methane (WRI 1990).

The third option, improved crop varieties, will depend greatly on the pace and direction of agricultural research, the availability and diversity of genetic resources, advances in genetic manipulation, success in disseminating new varieties, and other factors. Concern is growing over recent trends towards more modest yield gains---or even small declines---in areas such as the

United States and Pakistan (e.g., Ruttan 1989). On the other hand, as Pimentel (1989) and others have pointed out, present-day agriculture relies on only 15 species of plants and 8 species of livestock for 90 percent of world food production, out of millions of plant and animal species and at least 75,000 edible plants. Both improved forms of existing foods and entirely new foods are possible (Myers 1989). Triticale, for example, is a hybrid of wheat and rye that performs significantly better than wheat in areas of marginal soils and climate (WRI 1990).

CAN THE GLOBAL FOOD SYSTEM ADAPT TO ENVIRONMENTAL CHANGE

The potential impacts of environmental change on the global food system and the responses and adaptations that could mitigate such impacts are not well understood. Research to date has focused largely on a small set of environmental changes (e.g., in atmospheric CO2 and in temperature and precipitation patterns), a narrow range of agricultural impacts (e.g., impacts on grain yields), a limited repetoire of technologic and socioeeonomic adjustments (e.g., increased irrigation), a sprinkling of countries and regions (e.g., the United States or climatically "marginal" regions), and a relatively short time frame (e.g., unpacts on present-day agricultural technologies and food systems). Many important issues have been addressed only in qualitative terms. For example, little is known about the combined impact of climatic changes, higher levels of atmospheric CO2, increased ultraviolet radiation, and increasing acid deposition and air pollution on crops, animals, and plant and animal pests and diseases (Chen 1989; Oppenheimer 1989). Only limited attention has been given to potential changes in international agricultural competitive advantage, differential vulnerability to environmental change, implications for food access and hunger within countries, and the full range of technologic, economic, and social responses available to farmers and other socioeconomic units (e.g., Chen 1990; Clark 1988, 1990; Crosson 1989; Liverman 1990; Mabbutt 1989). Not much is known about the potential impacts of changing atmospheric and oceanic conditions on marine ecosystems and fisheries, including possible effects of increased ultraviolet radiation on krill and other Antarctic species (Bakun 1990; Chen and Pally 1988; WRI 1990). Even more poorly understood are the many complex links and feedbacks that are likely to exist between (a) food system activities that contribute significantly to environmental change, (b) food system activities that would be directly or indirectly affected by environmental change, (c) impacts in related activities such as energy production and transportation, and (d) actions taken to reduce or modify the effects of any of these activities. For example, a traditional response to climatic variability has been to increase irrigation---but the latter often requires large amounts of energy to move irrigation water and may lead to increased methane emissions. Irrigation also competes for water supplies with municipal and industrial water demands and evaporative losses all of which could grow even faster than expected in a warming climate. Without enough water, both the effectiveness of other agricultural inputs, such as fertilizers, and the yield benefits from CO2 enrichment may be reduced (Pimentel 1986; Schneider and Rosenberg 1989). Complex linkages of this kind may exist throughout the food system. Higher air temperature and humidities imply increased refrigeration loads at the same time that potentially less energy-efficient refrigerants may be in widespread use to limit emissions of CFCs thought to damage the stratospheric O3 layer. Increased prices for fossil fuels or restrictions on fossil fuel use would increase input costs throughout the food system but should, among other things, lower crop damage caused by air pollution and acid deposition. Efforts to promote production of biomass fuels as a substitute for fossil fuels and reforestation to sequester atmospheric CO2 could lead to displacement of food production, reduced income and standards of living on the part of farmers and laborers, and increased levels of environmental stress and resource degradation (Pimentel et al. 1988). Biogas production, which may make sense in terms of reduced fossil fuel and fuelwood. demands and increased fertilizer availability, could increase CH4 and N2O emissions. In developing new crop varieties, complex trade offs will be necessary to deal with changes in climatic variability and stresses, altered patterns of plant pests and diseases, changing availability of various agricultural inputs, and evolving food production, harvesting, storage, and processing methods. However, the genetic diversity upon which new varieties depend may itself be threatened by deforestation and other land use changes and by local, regional, and global environmental change.

CONCLUSION

Thus, It is clear that the problem of providing more food to more people during the next several decades is greatly complicated by the threat of global environmental change. Measures to prevent such change or to improve adaptive capabilities could conceivably have effects on the global food system as profound as some of the expected effects of global environronmental change itself---and whether larger or smaller numbers of people would end up hungry is difficult to predict. For example, efforts to protect forests and species diversity might well limit access to important common resources on the part of landless and land--short populations in developing countries. Limits on livestock and irrigation and increases in energy prices could affect the livelihood and food security of billions of people in both rural and urban areas. Moreover, since preventive measures may not succeed in preventing environrnental change immediately and completely---or at all---it is certainly plausible that the global food system might have to adapt not only to significant changes in energy and fertilizer consumption, land use, and production methods, but also to some degree of local, regional, and global environmental change. Developing robust alternatives that simultaneously (a) stabilize or reduce contributions on the part of the global food system to global environmental change and (b) permit increased levels of delivered nutrition to the growing world population in the face of substantial environmental and other uncertainties will not be an easy task. However, failure to develop such alternatives could have dire consequences for hunger and world food security. To draw a lesson from the origins of agriculture, increased hunger could be inevitable if human society is only able to adapt under conditions of stress or evolutionary pressure. Instead, it may well be necessary to respond now to the perceived threat of global environmental change and to find and implement solutions before any changes or their adverse impacts become too damaging or irreversible. This is likely to be the best hope for reducing hunger and maintaining a livable environment in the more crowded world of the future.

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