Human Food Production as a Process in the Biosphere

Human population growth is mainly the result of increases in food production. This relation raises the question: How many people can the biosphere support without impairment of its overall operation?

by Lester R. Brown

Throughout most of man's existence his numbers have been limited by the supply of food. For the first two million years or so he lived as a predator, a herbivore and a scavenger. Under such circumstances the biosphere could not support a human population of more than 10 million, a population smaller than that of London or Afghanistan today. Then, with his domestication of plants and animals some 10,000 years ago, man began to shape the biosphere to his own ends.

As primitive techniques of crop production and animal husbandry became more efficient the earth's food-producing capacity expanded, permitting increases in man's numbers. Population growth in turn exerted pressure on food supply, compelling man to further alter the biosphere in order to meet his food needs. Population growth and advances in food production have thus tended to be mutually reinforcing.

It took two million years for the human population to reach the one-billion mark, but the fourth billion now being added will require only 15 years: from 1960 to 1975. The enormous increase in the demand for food that is generated by this expansion in man's numbers, together with rising incomes, is beginning to have disturbing consequences. New signs of stress on the biosphere are reported almost daily. The continuing expansion of land under the plow and the evolution of a chemically oriented modern agriculture are producing ominous alterations in the biosphere not just on a local scale but, for the first time in history, on a global scale as well. The natural cycles of energy and the chemical elements are clearly being affected by man's efforts to expand his food supply.

Given the steadily advancing demand for food, further intervention in the biosphere for the expansion of the food supply is inevitable. Such intervention, however, can no longer be undertaken by an individual or a nation without consideration of the impact on the biosphere as a whole. The decision by a government to dam a river, by a farmer to use DDT on his crops or by a married couple to have another child, thereby increasing the demand for food, has repercussions for all mankind.

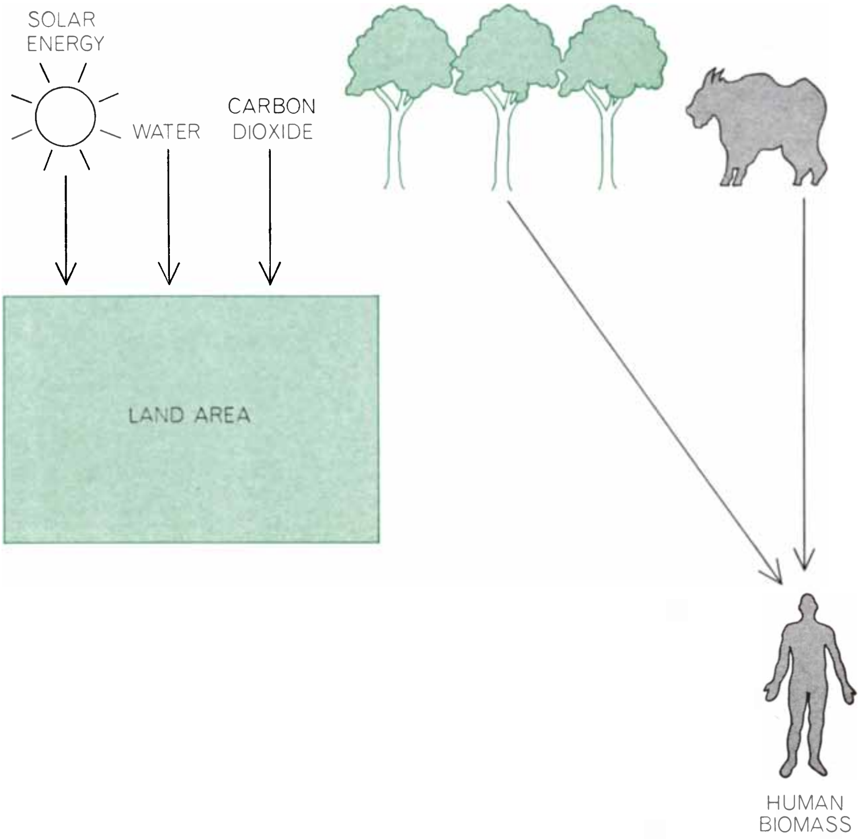
The revolutionary change in man's role from hunter and gatherer to tiller and herdsman took place in circumstances that are not well known, but some of the earliest evidence of agriculture is found in the hills and grassy plains of the Fertile Crescent in western Asia. The cultivation of food plants and the domestication of animals were aided there by the presence of wild wheat, barley, sheep, goats, pigs, cattle and horses. From the beginnings of agriculture man naturally favored above all other species those plants and animals that had been most useful to him in the wild. As a result of this favoritism he has altered the composition of the earth's plant and animal populations. Today his crops, replacing the original cover of grass or forest, occupy some three billion acres. This amounts to about 10 percent of the earth's total land surface and a considerably larger fraction of the land capable of supporting vegetation, that is, the area excluding deserts, polar regions and higher elevations. Two-thirds of the cultivated cropland is planted to cereals. The area planted to wheat alone is 600 million acres—nearly a million square miles, or an area equivalent to the U.S. east of the Mississippi. As for the influence of animal husbandry on the earth's animal populations, Hereford and Black Angus cattle roam the Great Plains, once the home of an estimated 30 to 40 million buffalo; in Australia the kangaroo has given way to European cattle; in Asia the domesticated water buffalo has multiplied in the major river valleys.

Clearly the food-producing enterprise has altered not only the relative abundance of plant and animal species but also their global distribution. The linkage of the Old and the New World in the 15th century set in motion an exchange of crops among various parts of the world that continues today. This exchange greatly increased the earth's capacity to sustain human populations, partly because some of the crops trans-

EXPERIMENTAL FARM in Brazil, one of thousands around the world where improvements in agricultural technology are pioneered, is seen as an image on an infrared-sensitive film in the aerial photograph on the opposite page. The reflectance of vegetation at near-infrared wavelengths of .7 to .9 micron registers on the film in false shades of red that are proportional to the intensity of the energy. The most reflective, and reddest, areas (*bottom*) are land still uncleared of forest cover. Most of the tilled fields, although irregular in shape, are contour-plowed. Regular patterns (*left and bottom right*) are citrus-orchard rows. The photograph was taken by a National Aeronautics and Space Administration mission in cooperation with the Brazilian government in a joint study of the assessment of agricultural resources by remote sensing. The farm is some 80 miles northwest of São Paulo.

ported elsewhere turned out to be better suited there than to their area of origin. Perhaps the classic example is the introduction of the potato from South America into northern Europe, where it greatly augmented the food supply, permitting marked increases in population. This was most clearly apparent in Ireland, where the population increased rapidly for several decades on the strength of the food supply represented by the potato. Only when the potato-blight organism (*Phytophthora infestans*) devastated the potato crop was population growth checked in Ireland.

The soybean, now the leading source of vegetable oil and principal farm export of the U.S., was introduced from China several decades ago. Grain sorghum, the second-ranking feed grain in the U.S. (after corn), came from Africa as a food store in the early slave ships. In the U.S.S.R. today the principal source of vegetable oil is the sunflower, a plant that originated on the southern Great Plains of the U.S. Corn, unknown in the Old World before Columbus, is now grown on every continent. On the other hand, North America is indebted to the Old World for all its livestock and poultry species with the exception of the turkey.



IMPACT OF THE AGRICULTURAL REVOLUTION on the human population is outlined in these two diagrams. The diagram at left shows the state of affairs before the invention of agriculture: the plants and animals supported by photosynthesis on the total land area could support a human population of only about 10 million. The diagram at right shows

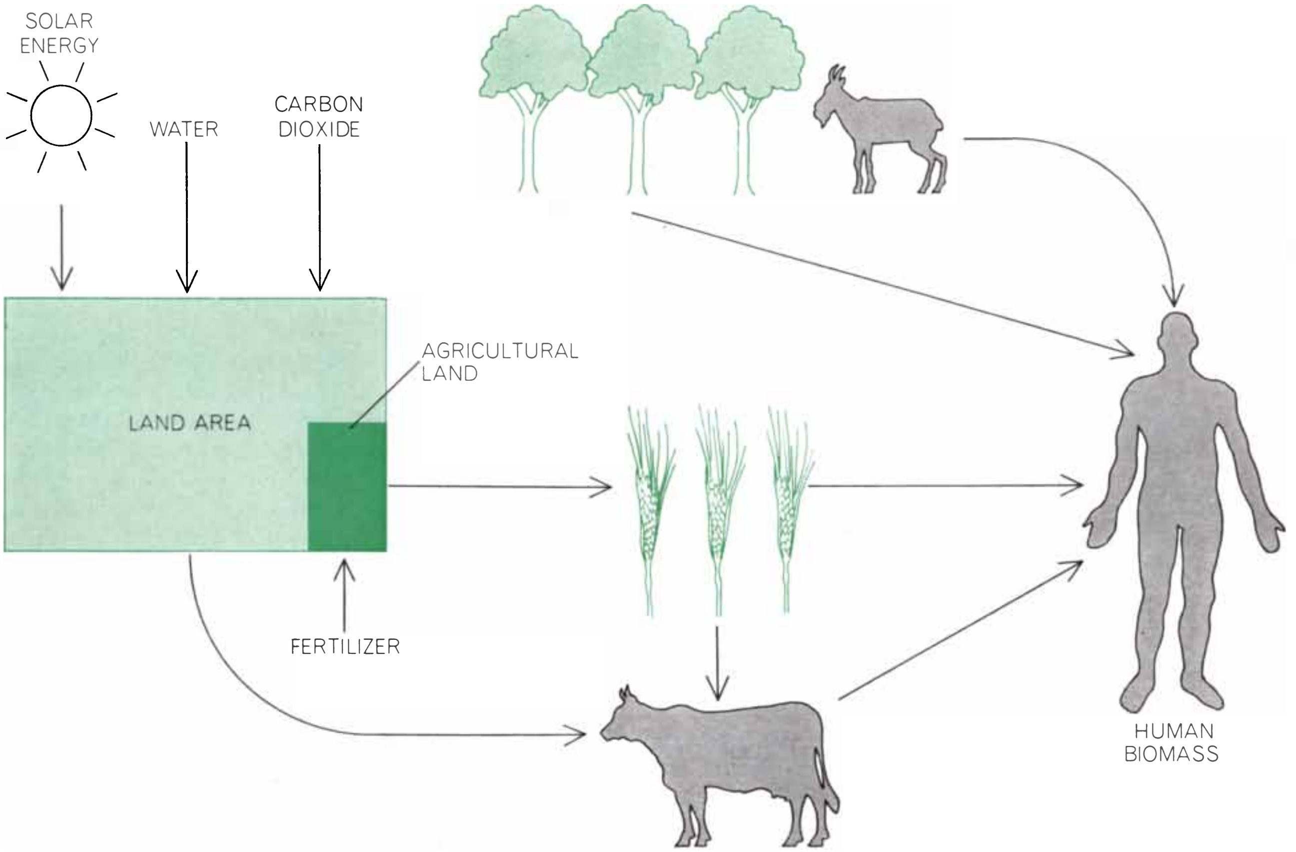
To man's accomplishments in exploiting the plants and animals that natural evolution has provided, and in improving them through selective breeding over the millenniums, he has added in this century the creation of remarkably productive new breeds, thanks to the discoveries of genetics. Genetics has made possible the development of cereals and other plant species that are more tolerant to cold, more resistant to drought, less susceptible to disease, more responsive to fertilizer, higher in yield and richer in protein. The story of hybrid corn is only one of many spectacular examples. The breeding of short-season corn varieties has extended the northern limit of this crop some 500 miles.

Plant breeders recently achieved a historic breakthrough in the development of new high-yielding varieties of wheat and rice for tropical and subtropical regions. These wheats and rices, bred by Rockefeller Foundation and Ford Foundation scientists in Mexico and the Philippines, are distinguished by several characteristics. Most important, they are short-statured and stiff-strawed, and are highly responsive to chemical fertilizer. They also mature earlier. The first of the high-yielding rices, IR-8, matures in 120 days as against 150 to 180 days for other varieties.

Another significant advance incorporated into the new strains is the reduced sensitivity of their seed to photoperiod (length of day). This is partly the result of their cosmopolitan ancestry: they were developed from seed collections all over the world. The biological clocks of traditional varieties of cereals were keyed to specific seasonal cycles, and these cereals could be planted only at a certain time of the year, in the case of rice say at the onset of the monsoon season. The new wheats, which are quite flexible in terms of both seasonal and latitudinal variations in length of day, are now being grown in developing countries as far north as Turkey and as far south as Paraguay.

The combination of earlier maturity and reduced sensitivity to day length creates new opportunities for multiple cropping in tropical and subtropical regions where water supplies are adequate, enabling farmers to harvest two, three and occasionally even four crops per year. Workers at the International Rice Research Institute in the Philippines regularly harvest three crops of rice per year. Each acre they plant yields six tons annually, roughly three times the average yield of corn, the highest-yielding cereal in the U.S. Thousands of farmers in northern India are now alternating a crop of early-maturing winter wheat with a summer crop of rice, greatly increasing the productivity of their land. These new opportunities for farming land more intensively lessen the pressure for bringing marginal land under cultivation, thus helping to conserve precious topsoil. At the same time they increase the use of agricultural chemicals, creating environmental stresses more akin to those in the advanced countries.

The new dwarf wheats and rices are far more efficient than the traditional varieties in their use of land, water, fertilizer and labor. The new opportunities for multiple cropping permit conversion of far more of the available solar energy into food. The new strains are not the solution to the food problem, but they are removing the threat of massive famine in the short run. They are buying time for the stabilization of population, which is ultimately the only solution to the food crisis. This "green revolution"



the state of affairs after the invention of agriculture. The 10 percent of the land now under the plow, watered and fertilized by man, is the primary support for a human population of 3.5 billion. Some of the agricultural produce is consumed directly by man; some is consumed indirectly by first being fed to domestic animals. Some of the food for domestic animals, however, comes from land not under the plow (*curved arrow at bottom left*). Man also obtains some food from sources other than agriculture, such as fishing.

may affect the well-being of more people in a shorter period of time than any technological advance in history.

The progress of man's expansion of food production is reflected in the way crop yields have traditionally been calculated. Today the output of cereals is expressed in yield per acre, but in early civilizations it was calculated as a ratio of the grain produced to that required for seed. On this basis the current ratio is perhaps highest in the U.S. corn belt, where farmers realize a four-hundred-fold return on the hybrid corn seed they plant. The ratio for rice is also quite high, but the ratio for wheat, the third of the principal cereals, is much lower, possibly 30 to one on a global basis.

The results of man's efforts to increase the productivity of domestic animals are equally impressive. When the ancestors of our present chickens were domesticated, they laid a clutch of about 15 eggs once a year. Hens in the U.S. today average 220 eggs per year, and the figure is rising steadily as a result of continuing advances in breeding and feeding. When cattle were originally domesticated, they probably did not produce more than 600 pounds of milk per year, barely enough for a calf. (It is roughly the average amount produced by cows in India today.) The 13 million dairy cows in the U.S. today average 9,000 pounds of milk yearly, outproducing their ancestors 15 to one.

Most such advances in the productivity of plant and animal species are recent. Throughout most of history man's efforts to meet his food needs have been directed primarily toward bringing more land under cultivation, spreading agriculture from valley to valley and continent to continent. He has also, however, invented techniques to raise the productivity of land already under cultivation, particularly in this century, when the decreasing availability of new lands for expansion has compelled him to turn to a more intensive agriculture. These techniques involve altering the biosphere's cycles of energy, water, nitrogen and minerals.

Modern agriculture depends heavily on four technologies: mechanization, irrigation, fertilization and the chemical control of weeds and insects. Each of these technologies has made an important contribution to the earth's increased capacity for sustaining human populations, and each has perturbed the cycles of the biosphere.

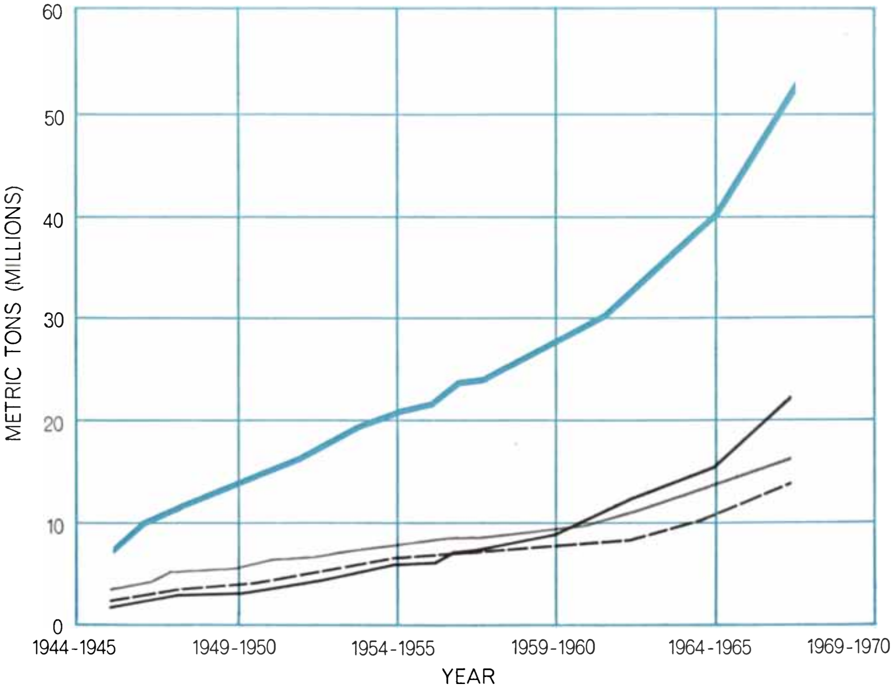
At least as early as 3000 B.C. the farmers of the Middle East learned to harness draft animals to help them till the soil. Harnessing animals much stronger than himself enabled man to greatly augment his own limited muscle power. It also enabled him to convert roughage (indigestible by humans) into a usable form of energy and thus to free some of his energy for pursuits other than the quest for food. The invention of the internal-combustion engine and the tractor 5,000 years later provided a much greater breakthrough. It now became possible to substitute petroleum (the product of the photosynthesis of aeons ago) for oats, corn and hay grown as feed for draft animals. The replacement of horses by the tractor not only provided the farmer with several times as much power but also released 70 million acres in the U.S. that had been devoted to raising feed for horses.

In the highly mechanized agriculture of today the expenditure of fossil fuel energy per acre is often substantially greater than the energy yield embodied in the food produced. This deficit in the output is of no immediate consequence, because the system is drawing on energy in the bank. When fossil fuels become scarcer, man will have to turn to some other source of motive energy for agriculture: perhaps nuclear energy or some means, other than photosynthesis, of harnessing solar energy. For the present and for the purposes of agriculture the energy budget of the biosphere is still favorable: the supply of solar energy—both the energy stored in fossil fuels and that taken up daily and converted into food energy by crops—enables an advanced nation to be fed with only 5 percent of the population directly employed in agriculture.

The combination of draft animals and mechanical power has given man an enormous capacity for altering the earth's surface by bringing additional land under the plow (not all of it suited for cultivation). In addition, in the poorer countries his expanding need for fuel has forced him to cut forests far in excess of their ability to renew themselves. The areas largely stripped of forest include mainland China and the subcontinent of India and Pakistan, where much of the population must now use cow dung for fuel. Although statistics are not available, the proportion of mankind using cow dung as fuel to prepare meals may far exceed the proportion using natural gas. Livestock populations providing draft power, food and fuel tend to increase along with human populations, and in many poor countries the needs of livestock for forage far exceed its self-renewal, gradually denuding the countryside of grass cover.

As population pressure builds, not only is more land brought under the plow but also the land remaining is less suited to cultivation. Once valleys are filled, farmers begin to move up hillsides, creating serious soil-erosion problems. As the natural cover that retards runoff is reduced and soil structure deteriorates, floods and droughts become more severe.

Over most of the earth the thin layer of topsoil producing most of man's food is measured in inches. Denuding the land of its year-round natural cover of grass or forest exposes the thin mantle of life-sustaining soil to rapid erosion by wind and water. Much of the soil ultimately washes into the sea, and some of it is lifted into the atmosphere. Man's actions are causing the topsoil to be removed faster than it is formed. This unstable relationship between man and the land from which he derives his subsistence obviously cannot continue indefinitely.



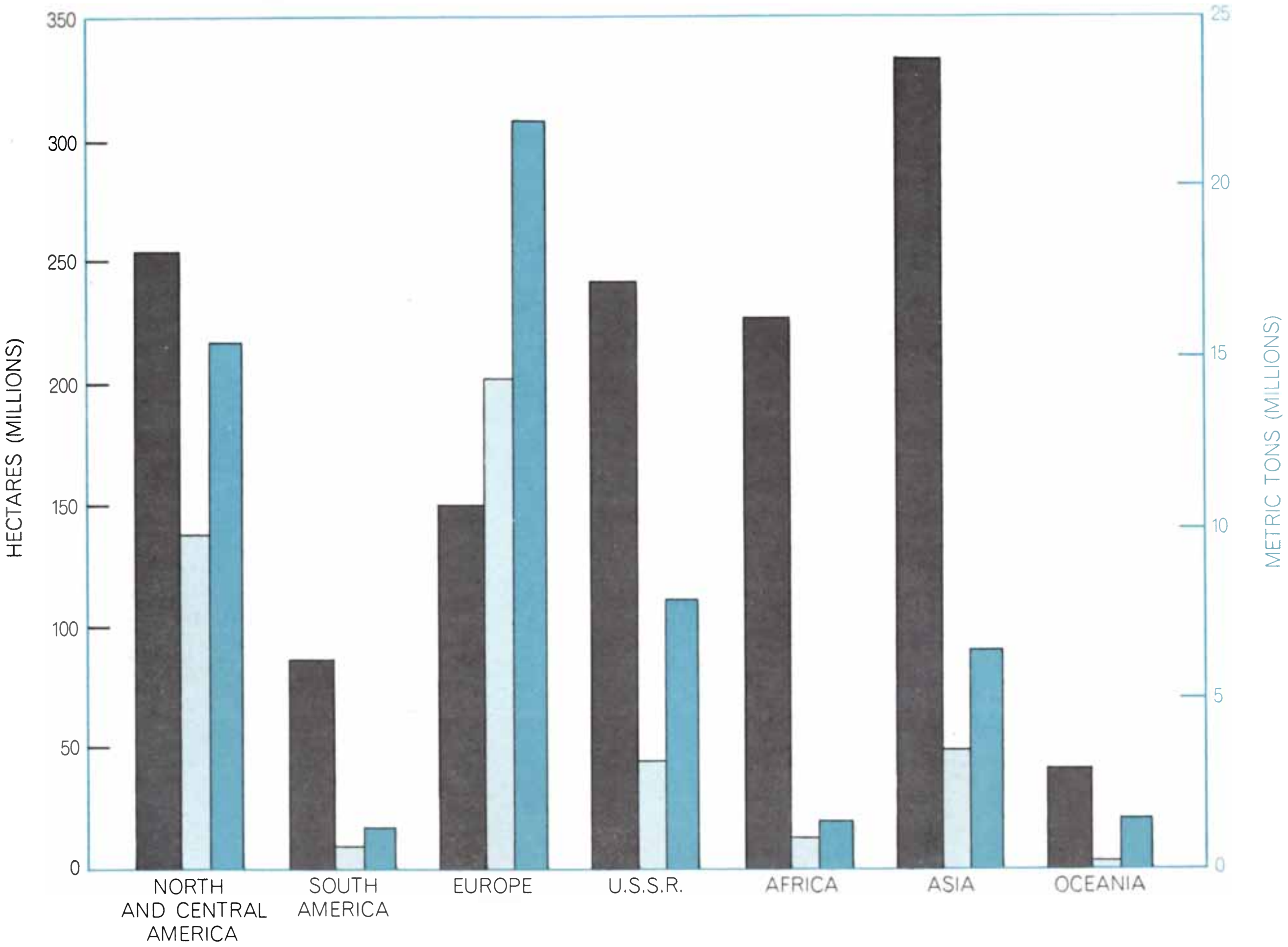
FERTILIZER CONSUMPTION has increased more than fivefold since the end of World War II. The top line in the graph (*color*) shows the tonnage of all kinds of fertilizers combined. The lines below show the tonnages of the three major types: nitrogen (*black*), now the leader, phosphate (*gray*) and potash (*broken line*). Figures, from the most recent report by the UN Food and Agriculture Organization, omit fertilizer consumption in China.

Robert R. Brooks of Williams College, an economist who spent several years in India, gives a wry description of the process occurring in the state of Rajasthan, where tens of thousands of acres of rural land are being abandoned yearly because of the loss of topsoil: "Overgrazing by goats destroys the desert plants which might otherwise hold the soil in place. Goatherds equipped with sickles attached to 20-foot poles strip the leaves of trees to float downward into the waiting mouths of famished goats and sheep. The trees die and the soil blows away 200 miles to New Delhi, where it comes to rest in the lungs of its inhabitants and on the shiny cars of foreign diplomats."

Soil erosion not only results in a loss of soil but also impairs irrigation systems. This is illustrated in the Mangla irrigation reservoir, recently built in the foothills of the Himalayas in West Pakistan as part of the Indus River irrigation system. On the basis of feasibility studies indicating that the reservoir could be expected to have a lifetime of at least 100 years, $600 million was invested in the construction of the reservoir. Denuding and erosion of the soil in the watershed, however, accompanying a rapid growth of population in the area, has already washed so much soil into the reservoir that it is now expected to be completely filled with silt within 50 years.

A historic example of the effects of man's abuse of the soil is all too plainly visible in North Africa, which once was the fertile granary of the Roman Empire and now is largely a desert or near-desert whose people are fed with the aid of food imports from the U.S. In the U.S. itself the "dust bowl" experience of the 1930's remains a vivid lesson on the folly of overplowing. More recently the U.S.S.R. repeated this error, bringing 100 million acres of virgin soil under the plow only to discover that the region's rainfall was too scanty to sustain continuous cultivation. Once moisture reserves in the soil were depleted the soil began to blow.

Soil erosion is one of the most pressing and most difficult problems threatening the future of the biosphere. Each year it is forcing the abandonment of millions of acres of cropland in Asia, the Middle East, North Africa and Central America. Nature's geological cycle continuously produces topsoil, but its pace is far too slow to be useful to man. Someone once defined soil as rock on its way to the sea. Soil is produced by the weathering of rock and the process takes several centuries to form an inch of topsoil. Man is managing to destroy the topsoil



TONS OF FERTILIZER used in seven world areas are compared with the amount of agricultural land in each area. Two tonnages are shown in each instance: the amount used in 1962–1963 (*light color*) and the amount used in 1967–1968 (*solid color*). The greatest use of fertilizer occurs in Europe, the least fertilized area is Africa and the greatest percentage increase in the period was in Australia and New Zealand. Figures, from the Food and Agriculture Organization, omit China, North Korea and North Vietnam.

in some areas of the world in a fraction of this time. The only possible remedy is to find ways to conserve the topsoil more effectively.

The dust-bowl era in the U.S. ended with the widespread adoption of conservation practices by farmers. Twenty million acres were fallowed to accumulate moisture and thousands of miles of windbreaks were planted across the Great Plains. Fallow land was alternated with strips of wheat ("strip-cropping") to reduce the blowing of soil while the land was idle. The densely populated countries of Asia, however, are in no position to adopt such tactics. Their food needs are so pressing that they cannot afford to take large areas out of cultivation; moreover, they do not yet have the financial resources or the technical skills for the immense projects in reforestation, controlled grazing of cattle, terracing, contour farming and systematic management of watersheds that would be required to preserve their soil.

The significance of wind erosion goes far beyond the mere loss of topsoil. As other authors in this issue have observed, a continuing increase in particulate matter in the atmosphere could affect the earth's climate by reducing the amount of incoming solar energy. This particulate matter comes not only from the technological activities of the richer countries but also from wind erosion in the poorer countries. The poorer countries do not have the resources for undertaking the necessary effort to arrest and reverse this trend. Should it be established that an increasing amount of particulate matter in the atmosphere is changing the climate, the richer countries would have still another reason to provide massive capital and technical assistance to the poor countries, joining with them to confront this common threat to mankind.

Irrigation, which agricultural man began to practice at least as early as 6,000 years ago, even earlier than he harnessed animal power, has played its great role in increasing food production by bringing into profitable cultivation vast areas that would otherwise be unusable or only marginally productive. Most of the world's irrigated land is in Asia, where it is devoted primarily to the production of rice. In Africa the Volta River of Ghana and the Nile are dammed for irrigation and power purposes. The Colorado River system of the U.S. is used extensively for irrigation in the Southwest, as are scores of rivers elsewhere. Still to be exploited for irrigation are the Mekong of southeastern Asia and the Amazon.

During the past few years there has been an important new irrigation development in Asia: the widespread installation of small-scale irrigation systems on individual farms. In Pakistan and India, where in many places the water table is close to the surface, hundreds of thousands of tube wells with pumps have been installed in recent years. Interestingly, this development came about partly as an answer to a problem that had been presented by irrigation itself.

Like many of man's other interventions in the biosphere, his reshaping of the hydrologic cycle has had unwanted side effects. One of them is the raising of the water table by the diversion of river water onto the land. Over a period of time the percolation of irrigation water downward and the accumulation of this water underground may gradually raise the water table until it is within a few feet or even a few inches of the surface. This not only inhibits the growth of plant roots by waterlogging but also results in the surface soil's becoming salty as water evaporates through it, leaving a concentrated deposit of salts in the upper few inches. Such a situation developed in West Pakistan after its fertile plain had been irrigated with water from the Indus for a century. During a visit by President Ayub to Washington in 1961 he appealed to President Kennedy for help: West Pakistan was losing 60,000 acres of fertile cropland per year because of waterlogging and salinity as its population was expanding 2.5 percent yearly.

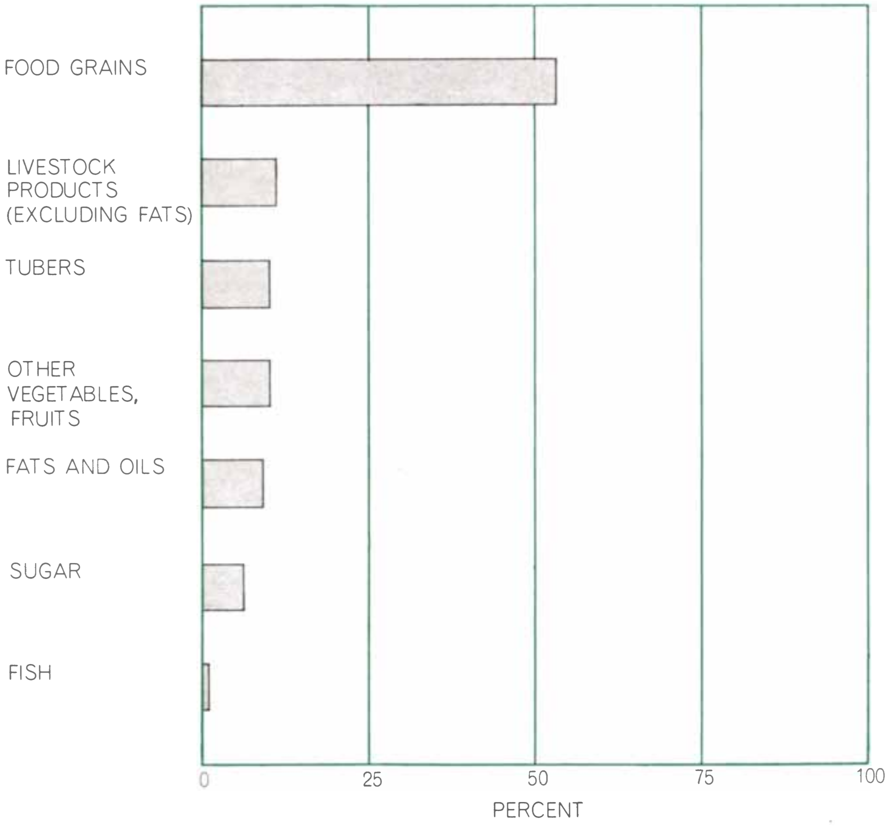
This same sequence, the diversion of river water into land for irrigation, followed eventually by waterlogging and salinity and the abandonment of land, had been repeated many times throughout history. The result was invariably the decline, and sometimes the disappearance, of the civilizations thus intervening in the hydrologic cycle. The remains of civilizations buried in the deserts of the Middle East attest to early experiences similar to those of contemporary Pakistan. These civilizations, however, had no one to turn to for foreign aid. An interdisciplinary U.S. team led by Roger Revelle, then Science Adviser to the Secretary of the Interior, studied the problem and proposed among other things a system of tube wells that would lower the water table by tapping the ground water for intensive irrigation. Discharging this water on the surface, the wells would also wash the soil's salt downward. The stratagem worked, and the salty, waterlogged land of Pakistan is steadily being reclaimed.

Other side effects of river irrigation are not so easily remedied. Such irrigation has brought about a great increase in the incidence of schistosomiasis, a disease that is particularly prevalent in the river valleys of Africa and Asia. The disease is produced by the parasitic larva of a blood fluke, which is harbored by aquatic snails and burrows into the flesh of people standing in water or in water-soaked fields. The Chinese call schistosomiasis "snail fever"; it might also be called the poor man's emphysema, because, like emphysema, this extremely debilitating disease is environmentally induced through conditions created by man. The snails and the fluke thrive in perennial irrigation systems, where they are in close proximity to large human populations. The incidence of the disease is rising rapidly as the world's large rivers are harnessed for irrigation, and today schistosomiasis is estimated to afflict 250 million people. It now surpasses malaria, the incidence of which is declining, as the world's most prevalent infectious disease.

As a necessity for food production water is of course becoming an increasingly crucial commodity. The projected increases in population and in food requirements will call for more and more water, forcing man to consider still more massive and complex interventions in the biosphere. The desalting of seawater for irrigation purposes is only one major departure from traditional practices. Another is a Russian plan to reverse the flow of four rivers currently flowing northward and emptying into the Arctic Ocean. These rivers would be diverted southward into the semiarid lands of southern Russia, greatly enlarging the irrigated area of the U.S.S.R. Some climatologists are concerned, however, that the shutting off of the flow of relatively warm water from these four rivers would have far-reaching implications for not only the climate of the Arctic but also the climatic system of the entire earth.

The growing competition for scarce water supplies among states and among various uses in the western U.S. is also forcing consideration of heroic plans. For example, a detailed engineering proposal exists for the diversion of the Yukon River in Alaska southward across Canada into the western U.S. to meet the growing need for water for both agricultural and industrial purposes. The effort would cost an estimated $100 billion.

Representing an even greater intervention in the biosphere is the prospect that man may one day consciously alter the earth's climatic patterns, shifting some of the rain now falling on the oceans to the land. Among the steps needed for the realization of such a scheme are the construction of a comprehensive model of the earth's climatic system and the development of a computational facility capable of simulating



WORLDWIDE FOOD ENERGY comes in different amounts from different products. Cereals outstrip other foodstuffs; wheat and rice each supply a fifth of mankind's food energy.

and manipulating the model. The required information includes data on temperatures, humidity, precipitation, the movement of air masses, ocean currents and many other factors that enter into the weather. Earth-orbiting satellites will doubtless be able to collect much of this information, and the present generation of advanced computers appears to be capable of carrying out the necessary experiments on the model. For the implementation of the findings, that is, for the useful control of rainfall, there will of course be a further requirement: the project will have to be managed by a global and supranational agency if it is not to lead to weather wars among nations working at cross purposes. Some commercial firms are already in the business of rainmaking, and they are operating on an international basis.

The third great technology that man has introduced to increase food production is the use of chemical fertilizers. We owe the foundation for this development to Justus von Liebig of Germany, who early in the 19th century determined the specific requirements of nitrogen, phosphorus, potassium and other nutrients for plant growth. Chemical fertilizers did not come into widespread use, however, until this century, when the pressure of population and the disappearance of new frontiers compelled farmers to substitute fertilizer for the expansion of cropland to meet growing food needs. One of the first countries to intensify its agriculture, largely by the use of fertilizers, was Japan, whose output of food per acre has steadily risen (except for wartime interruptions) since the turn of the century. The output per acre of a few other countries, including the Netherlands, Denmark and Sweden, began to rise at about the same time. The U.S., richly endowed with vast farmlands, did not turn to the heavy use of fertilizer and other intensive measures until about 1940. Since then its yields per acre, assisted by new varieties of grain highly responsive to fertilizer, have also shown remarkable gains. Yields of corn, the production of which exceeds that of all other cereals combined in the U.S., have nearly tripled over the past three decades.

Experience has demonstrated that in areas of high rainfall the application of chemical fertilizers in conjunction with other inputs and practices can double, triple or even quadruple the productivity of intensively farmed soils. Such levels of productivity are achieved in Japan and the Netherlands, where farmers ap-

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ply up to 300 pounds of plant nutrients per acre per year. The use of chemical fertilizers is estimated to account for at least a fourth of man's total food supply. The world's farmers are currently applying 60 million metric tons of plant nutrients per year, an average of nearly 45 pounds per acre for the three billion acres of cropland. Such application, however, is unevenly distributed. Some poor countries do not yet benefit from the use of fertilizer in any significant amounts. If global projections of population and income growth materialize, the production of fertilizer over the remaining three decades of this century must almost triple to satisfy food demands.

Can the projected demand for fertilizer be met? The key ingredient is nitrogen, and fortunately man has learned how to speed up the fixation phase of the nitrogen cycle [see "The Nitrogen Cycle," by C. C. Delwiche, page 136]. In nature the nitrogen of the air is fixed in the soil by certain microorganisms, such as those present in the root nodules of leguminous plants. Chemists have now devised various ways of incorporating nitrogen from the air into inorganic compounds and making it available in the form of nitrogen fertilizers. These chemical processes produce the fertilizer much more rapidly and economically than the growing of leguminous-plant sources such as clover, alfalfa or soybeans. More than 25 million tons of nitrogen fertilizer is now being synthesized and added to the earth's soil annually.

The other principal ingredients of chemical fertilizer are the minerals potassium and phosphorus. Unlike nitrogen, these elements are not replenished by comparatively fast natural cycles. Potassium presents no immediate problem; the rich potash fields of Canada alone are estimated to contain enough potassium to supply mankind's needs for centuries to come. The reserves of phosphorus, however, are not nearly so plentiful as those of potassium. Every year 3.5 million tons of phosphorus washes into the sea, where it remains as sediment on the ocean floor. Eventually it will be thrust above the ocean surface again by geologic uplift, but man cannot wait that long. Phosphorus may be one of the first necessities that will prompt man to begin to mine the ocean bed.

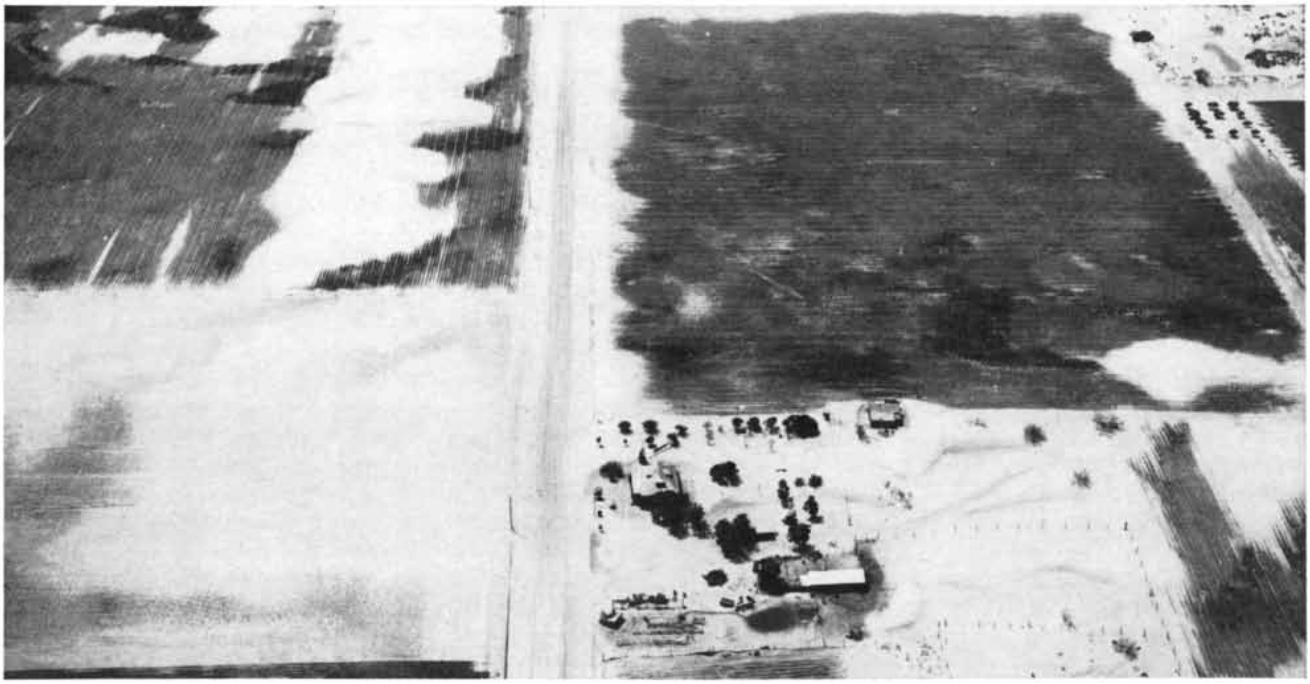
The great expansion of the use of fertilizers in this century has benefited mankind enormously, but the benefits are not unalloyed. The runoff of chemical fertilizers into rivers, lakes and underground waters creates two important hazards. One is the chemical pollution of drinking water. In certain areas in Illinois and California the nitrate content of well water has risen to a toxic level. Excessive nitrate can cause the physiological disorder methemoglobinemia, which reduces the blood's oxygen-carrying capacity and can be particularly dangerous to children under five. This hazard is of only local dimensions and can be countered by finding alternative sources of drinking water. A much more extensive hazard, profound in its effects on the biosphere, is the now well-known phenomenon called eutrophication.

Inorganic nitrates and phosphates discharged into lakes and other bodies of fresh water provide a rich medium for the growth of algae; the massive growth of the algae in turn depletes the water of oxygen and thus kills off the fish life. In the end the eutrophication, or overfertilization, of the lake slowly brings about its death as a body of fresh water, converting it into a swamp. Lake Erie is a prime example of this process now under way.

How much of the now widespread eutrophication of fresh waters is attributable to agricultural fertilization and how much to other causes remains an open question. Undoubtedly the runoff of nitrates and phosphates from farmlands plays a large part. There are also other important contributors, however. Considerable amounts of phosphate, coming mainly from detergents, are discharged into rivers and lakes from sewers carrying municipal and industrial wastes. And there is reason to believe that in some rivers and lakes most of the nitrate may come not from fertilizers but from the internal-combustion engine. It is estimated that in the state of New Jersey, which has heavy automobile traffic, nitrous oxide products of gasoline combustion, picked up and deposited by rainfall, contribute as much as 20 pounds of nitrogen per acre per year to the land. Some of this nitrogen washes into the many rivers and lakes of New Jersey and its adjoining states. A way must be found to deal with the eutrophication problem because even in the short run it can have damaging effects, affecting as it does the supply of potable water, the cycles of aquatic life and consequently man's food supply.

Recent findings have presented us with a related problem in connection with the fourth technology supporting man's present high level of food production: the chemical control of diseases, insects and weeds. It is now clear that the use of DDT and other chlorinated hydrocarbons as pesticides and herbicides is beginning to threaten many species of animal life, possibly including man. DDT today is found in the tissues

EXPERIMENTAL PLANTINGS at the International Rice Research Institute in the Philippine Republic are seen in an aerial photograph. IR-8, a high-yield rice, was bred here.



RUINED FARM in the "dust bowl" area of the U.S. in the 1930's is seen in an aerial photograph. The farm is near Union in Terry County, Tex. The wind has eroded the powdery, drought-parched topsoil and formed drifts among the buildings and across the fields.

of animals over a global range of life forms and geography from penguins in Antarctica to children in the villages of Thailand. There is strong evidence that it is actually on the way to extinguishing some animal species, notably predatory birds such as the bald eagle and the peregrine falcon, whose capacity for using calcium is so impaired by DDT that the shells of their eggs are too thin to avoid breakage in the nest before the fledglings hatch. Carnivores are particularly likely to concentrate DDT in their tissues because they feed on herbivores that have already concentrated it from large quantities of vegetation. Concentrations of DDT in mothers' milk in the U.S. now exceed the tolerance levels established for foodstuffs by the Food and Drug Administration.

It is ironic that less than a generation after 1948, when Paul Hermann Müller of Switzerland received a Nobel prize for the discovery of DDT, the use of the insecticide is being banned by law in many countries. This illustrates how little man knows about the effects of his intervening in the biosphere. Up to now he has been using the biosphere as a laboratory, sometimes with unhappy results.

Several new approaches to the problem of controlling pests are now being explored. Chemists are searching for pesticides that will be degradable, instead of long-lasting, after being deposited on vegetation or in the soil, and that will be aimed at specific pests rather than acting as broad-spectrum poisons for many forms of life. Much hope is placed in techniques of biological control, such as are exemplified in the mass sterilization (by irradiation) of male screwworm flies, a pest of cattle that used to cost U.S. livestock producers $100 million per year. The release of 125 million irradiated male screwworm flies weekly in the U.S. and in adjoining areas of Mexico (in a cooperative effort with the Mexican government) is holding the fly population to a negligible level. Efforts are now under way to get rid of the Mexican fruit fly and the pink cotton bollworm in California by the same method.

Successes are also being achieved in breeding resistance to insect pests in various crops. A strain of wheat has been developed that is resistant to the Hessian fly; resistance to the corn borer and the corn earworm has been bred into strains of corn, and work is in progress on a strain of alfalfa that resists aphids and leafhoppers. Another promising approach, which already has a considerable history, is the development of insect parasites, ranging from bacteria and viruses to wasps that lay their eggs in other insects. The fact remains, however, that the biological control of pests is still in its infancy.

I have here briefly reviewed the major agricultural technologies evolved to meet man's increasing food needs, the problems arising from them and some possible solutions. What is the present balance sheet on the satisfaction of human food needs? Although man's food supply has expanded several hundredfold since the invention of agriculture, two-thirds of mankind is still hungry and malnourished much of the time. On the credit side a third of mankind, living largely in North America, Europe, Australia and Japan, has achieved an adequate food supply, and for the remaining two-thirds the threat of large-scale famine has recently been removed, at least for the immediate future. In spite of rapid population growth in the developing countries since World War II, their peoples have been spared from massive famine (except in Biafra in 1969–1970) by huge exports of food from the developed countries. As a result of two consecutive monsoon failures in India, a fifth of the total U.S. wheat crop was shipped to India in both 1966 and 1967, feeding 60 million Indians for two years.

Although the threat of outright famine has been more or less eliminated for the time being, human nutrition on the global scale is still in a sorry state. Malnutrition, particularly protein deficiency, exacts an enormous toll from the physical and mental development of the young in the poorer countries. This was dramatically illustrated when India held tryouts in 1968 to select a team to represent it in the Olympic games that year. Not a single Indian athlete, male or female, met the minimum standards for qualifying to compete in any of the 36

track and field events in Mexico City. No doubt this was partly due to the lack of support for athletics in India, but poor nutrition was certainly also a large factor. The young people of Japan today are visible examples of what a change can be brought about by improvement in nutrition. Well-nourished from infancy, Japanese teen-agers are on the average some two inches taller than their elders.

Protein is as crucial for children's mental development as for their physical development. This was strikingly shown in a recent study extending over several years in Mexico: children who had been severely undernourished before the age of five were found to average 13 points lower in I.Q. than a carefully selected control group. Unfortunately no amount of feeding or education in later life can repair the setbacks to development caused by undernourishment in the early years. Protein shortages in the poor countries today are depreciating human resources for at least a generation to come.

Protein constitutes the main key to human health and vigor, and the key to the protein diet at present is held by grain consumed either directly or indirectly (in the form of meat, milk and eggs). Cereals, occupying more than 70 percent of the world's cropland, provide 52 percent of man's direct energy intake. Eleven percent is supplied by livestock products such as meat, milk and eggs, 10 percent by potatoes and other tubers, 10 percent by fruits and vegetables, 9 percent by animal fats and vegetable oils, 7 percent by sugar and 1 percent by fish. As in the case of the total quantity of the individual diet, however, the composition of the diet varies greatly around the world. The difference is most marked in the per capita use of grain consumed directly and indirectly.

The two billion people living in the poor countries consume an average of about 360 pounds of grain per year, or about a pound per day. With only one pound per day, nearly all must be consumed directly to meet minimal energy requirements; little remains for feeding to livestock, which may convert only a tenth of their feed intake into meat or other edible human food. The average American, in contrast, consumes more than 1,600 pounds of grain per year. He eats only about 150 pounds of this directly in the form of bread, breakfast cereal and so on; the rest is consumed indirectly in the form of meat, milk and eggs. In short, he enjoys the luxury of the highly inefficient animal conversion of grain into tastier and somewhat more nutritious proteins.

Thus the average North American currently makes about four times as great a demand on the earth's agricultural ecosystem as someone living in one of the poor countries. As the income levels in these countries rise, so will their demand for a richer diet of animal products. For the increasing world population at the end of the century, which is expected to be twice the 3.5 billion of today, the world production of grain would have to be doubled merely to maintain present consumption levels. This increase, combined with the projected improvement in diet associated with gains in income over the next three decades, could nearly triple the demand for grain, requiring that the food supply increase more over the next three decades than it has in the 10,000 years since agriculture began.

There are ways in which this pressure can be eased somewhat. One is the breeding of higher protein content in grains and other crops, making them nutritionally more acceptable as alternatives to livestock products. Another is the development of vegetable substitutes for animal products, such as are already available in the form of oleomargarine, soybean oil, imitation meats and other replacements (about 65 percent of the whipped toppings and 35 percent of the coffee whiteners now sold in U.S. supermarkets are nondairy products). Pressures on the agricultural ecosystem would thus drive high-income man one step down in the food chain to a level of more efficient consumption of what could be produced by agriculture.

What is clearly needed today is a cooperative effort—more specifically, a world environmental agency—to monitor, investigate and regulate man's interventions in the environment, including those made in his quest for more food. Since many of his efforts to enlarge his food supply have a global impact, they can only be dealt with in the context of a global institution. The health of the biosphere can no longer be separated from our modes of political organization. Whatever measures are taken, there is growing doubt that the agricultural ecosystem will be able to accommodate both the anticipated increase of the human population to seven billion by the end of the century and the universal desire of the world's hungry for a better diet. The central question is no longer "Can we produce enough food?" but "What are the environmental consequences of attempting to do so?"