31. E. F. Meyer, Jr., *et al.*, *Fed. Proc.* **33**, 2402 (1974).
32. L. Kätz and C. Levinthal, *Annu. Rev. Biophys. Bioeng.* **1**, 465 (1972).
33. A. Arnone *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **64**, 420 (1969).
34. J. R. Herriott, K. D. Watenpaugh, L. C. Sieker, L. H. Jensen, *J. Mol. Biol.* **80**, 423 (1973).
35. We use the average change in phase angle, $<\Delta\alpha>$, to corroborate the trend in R. Consequently, the ideal contribution to $<\Delta\alpha>$ from data without previous phase angles would be based on comparison of α_{calc} with random angles. The tabulated values of $<\Delta\alpha>$ include the approximately equivalent comparisons of α_{calc} with 0.0 for these data.
36. It is a pleasure and a duty to acknowledge contributions by several other persons. M. Brice and M. Legg have contributed to the development of the phase refinement procedure and to the practical application of this and the computer graphics to the rubredoxin and nuclease structures. S. M. Swanson and H. J. Bernstein (of Brookhaven National Laboratory) have participated in developing the computer graphics system. Financial support for this work came from the National Institutes of Health, Institute of General Medical Sciences (grant GM-19455 to F.A.C. and E.E.H., Jr.), the Robert A. Welch Foundation (grant A494 to F.A.C.), and the National Science Foundation (grant GJ33248X to E.F.M., Jr.).

The World Food Prospect

The worldwide food shortages of recent years, assumed to be temporary, could become more or less chronic.

Lester R. Brown

As we make the transition from the third to the final quarter of this century, the world food economy appears to be undergoing a fundamental transformation. Two developments stand out. One, the comfortable reserve of surplus stocks and excess production capacity which the world has enjoyed over the past generation may now be a passing incident in its history. Two, the world is becoming overwhelmingly dependent on North America for food supplies. These two changes point to a new role and responsibility for North America.

Within a span of a few years the world's surplus stocks and excess production capacity have largely disappeared. Today the entire world is living hand to mouth, trying to make it from one harvest to the next.

Grain exports from North America, a measure of growing worldwide food deficits, have doubled during the 1970's, expanding from 56 million tons in 1970 to nearly 100 million tons during the current fiscal year. Of the 115 countries for which data are readily available, all but a few now import grain. Of the countries that remain significant exporters, two dominate: the United States and Canada. During the current fiscal year the two together will export enough grain to feed the 600 million people of India.

The reasons for growing dependence on North American food supplies include ecological deterioration of food systems because of growing population pressure, mismanagement of agriculture, soaring population-induced demands, and sharp increases in demand as a result of newfound wealth, as in the Organization of Petroleum Exporting Countries (OPEC). The causes of the growing deficits vary, and often a combination of factors is responsible, but the effects are the same—ever greater pressure on North American food supplies.

As a result of these trends, North America today finds itself with a near monopoly of the world's exportable grain supplies. In a world of food scarcity, where there may not be enough food to go around, North America must decide who gets how much food and on what terms. The governments of the United States and Canada have not consciously sought this responsibility, any more than the countries of the Middle East have planned their geographical location astride the world's richest oil fields.

In recent years shortages of food have contributed to global double-digit inflation and to severe nutritional stress among low-income people everywhere. In some of the poorer countries, shortages have led to a rise in death rates, reversing postwar trends. National political leaders in the food-deficit countries, rich and poor alike, are becoming uneasy over future access to food supplies. Profound changes in the world food economy have brought into question the basic assumptions underlying North American food policies, particularly at the international level.

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New Sources of Global Food Insecurity

Throughout much of the period since World War II, the world has had two major food reserves: stocks of grain held by the principal exporting countries and cropland idled under farm programs in the United States. During the 1960's and early 1970's some 50 million acres out of a total U.S. cropland base of 350 million acres was held out of production to support prices (*1*). Stocks of grain held by the exporting countries were readily available for use when needed. Cropland idled under farm programs in the United States could be brought back into production within a year. Together grain stockpiles and cropland reserves provided security for all mankind, a cushion against any imaginable food disasters.

As recently as early 1972, it seemed likely that surplus stocks and cropland idled under farm programs would be part of the landscape for the foreseeable future. Then, suddenly, the global demand for food, fueled by the relentless growth of population and by rising affluence, began to outstrip the productive capacity of the world's farmers and fishermen. The world fish catch, which had tripled between 1950 and 1970 and had moved to a new high each year, turned downward for three consecutive years. Although most of the idled U.S. cropland was released for use in 1973 and the remainder thereafter, food reserves have not been rebuilt.

In 1961, the combination of reserve stocks of grain in exporting countries and idle cropland in the United States amounted to the equivalent of 105 days of world grain consumption. In 1972 stocks still equaled 69 days of world consumption. Then reserves began to drop rather abruptly—to 55 days in 1973 and still further to 33 days in 1974. The 1975 carry-over stocks remain precariously low, and all hopes for rebuilding them to safe levels have vanished with the poor 1975 Soviet harvest. Current U.S. Department of Agriculture estimates of carry-over stocks in 1976, already largely determined by the 1975 harvest, indicate an even lower level than in 1975 (*2*) (Table 1).

A third factor leading to global food insecurity and instability in the mid-1970's is

the near total dependence of the entire world on one region, North America, for food supplies. Both countries within the region are affected by the same climatic cycles, with a poor crop in one all too often associated with a poor crop in the other.

A fourth factor contributing to instability was a decision made by Soviet political leaders to offset crop shortfalls with imports. Since recent year-to-year fluctuations in the Soviet grain harvest have exceeded the average annual gains in the world grain crop, their decision further destabilizes the world food economy. This policy, apparently made in early 1972, may not be irreversible, but neither will it be easily abandoned. Soviet herds and flocks have been building steadily throughout the 1970's as a result of this policy. So too have the expectations and appetites of Soviet consumers.

The high costs of this food price instability are economic, political, and social. Consumers, particularly the poor, suffer. Most families do not find it easy to adjust to wide fluctuations in food prices. These same fluctuations, in turn, make it more difficult for producers to decide how much to plant and how much to invest in inputs. Dairymen and cattlemen everywhere have been caught in a bind between the price of milk or beef and the cost of grain. Thousands of these producers have been driven out of business, leading to erratic flows of milk and meat to market, and to discontent among consumers.

Governments also find it difficult to operate in a world of violent fluctuations in food prices. Unstable markets wreak havoc with foreign exchange budgets, particularly those of developing countries heavily dependent on food imports, and undermine government efforts to combat inflation.

Emergence of the North American Breadbasket

North America has emerged as the world's breadbasket only since World War II. Its rise is best measured by examining the net grain trade flows among various geographic regions. An aggregate of all grains is a useful indicator of food trends, since grains supply more than half of man's food energy supply when consumed directly, and a sizable segment of the remainder when consumed indirectly. On the production side, they occupy more than 70 percent of the world's cropland area. Net regional data, which exclude trade among countries within a region, are used in order to isolate more clearly the basic trends in the world food economy.

Prior to World War II, all geographic regions, except Western Europe, were net exporters. North America was not the only exporter nor even the leading one. From 1934 to 1938, Latin America was exporting an average of 9 million tons per year, while North America exported only 5 million tons. Eastern Europe, including the Soviet Union, was exporting 5 million tons annually, exactly the same as North America (*3*).

All this has now changed. Asia has developed a massive deficit. It is now importing some 50 million tons of grain per year, most of it taken by three countries—Japan, China, and India. Africa, Latin America, and Eastern Europe (including U.S.S.R.) have all become food-deficit regions. Western Europe, continually a major importer, has been the only stable element through the period; its imports rarely moved outside the range of 20 to 30 million tons.

North America's unchallenged dominance as a global food supplier began in the 1940's. The scale of exports expanded gradually during the 1950's and 1960's. During the 1970's, North American grain exports have nearly doubled in response to the explosive growth in import demand from around the world (Table 2).

Most countries today obtain part of their food supplies from North America. Dependence has increased rapidly over the past decade and shows every indication of continuing to grow. The worldwide movement of countries outside of North America from export to import status is a one-way street. No country has gone against this trend over the past quarter century. Scores of countries have become important food importers, but not one new country has emerged as a major cereal exporter during this period.

Not only are more and more countries becoming importers, but the degree of dependence on outside supplies by the food-deficit countries is growing. More and more countries, both industrial and developing, are actually importing more food than they produce. Among the countries which now import more than half of their grain supply are Japan, Belgium, Senegal, Libya, Saudi Arabia, Venezuela, Lebanon, Switzerland, and, at least temporarily, Algeria. Other countries rapidly approaching primary dependence on imported foodstuffs include Portugal, Costa Rica, Sri Lanka, South Korea, and Egypt (*2*).

This rate of ever-growing dependence on North America by the rest of the world cannot continue for much longer. North America has doubled its grain exports within the past decade, but the world should not count on a repeat performance during the next decade. Unless recent dependence trends are altered, the restriction of grain exports from North America will become commonplace. In mid-July the Canadian Wheat Board banned further exports of wheat until the size of the 1975 harvest was known. Political pressures forced the United States to limit exports of grain to the Soviet Union and Poland in the late summer of 1975. This pattern is beginning to repeat itself—first in 1972, then in 1974, and again in 1975—three out of the past four years. It occurred in the last two years despite the release of 50 million acres of idle cropland in the United States for production.

As we enter the fourth year of precariously balanced food supplies, the international community must at least prepare for the possibility that the current situation may not be temporary. The obvious question is: Why has one region emerged as a supplier of food to the rest of the world? If I were to select the single dominant factor reshaping world trade patterns in

Table 1. Index of world food security, 1961 to 1976.

Year	Reserves (million metric tons)			Reserves as days of world grain consumption
	Grain*	Grain equivalent of idled U.S. cropland	Total	
1961	163	68	231	105
1962	176	81	257	105
1963	149	70	219	95
1964	153	70	223	87
1965	147	71	218	91
1966	151	78	229	84
1967	115	51	166	59
1968	144	61	205	71
1969	159	73	232	85
1970	188	71	259	89
1971	168	41	209	71
1972	130	78	208	69
1973	148	24	172	55
1974	108	0	108	33
1975	111	0	111	35
1976†	100	0	100	31

*Based on carry-over stocks of grain at beginning of crop year in individual countries for year shown. The USDA has recently expanded the coverage of reserve stocks to include importing as well as exporting countries, thus the reserve levels are slightly higher than those heretofore published (*2*). †Preliminary estimates by USDA.

recent decades, it would be varying rates of population growth. Certainly the conversion of Asia, Africa, and Latin America to deficit status was closely related to population growth. This factor has been less influential in Eastern Europe, and one of the keys to Western Europe's stability as a food importer has been its modest population growth.

A comparison of North America and Latin America with respect to world food trade illustrates the effects of rapid population growth. In 1950, North America and Latin America had roughly equal populations, 163 and 168 million, respectively. While North America's population growth has slowed substantially since the late 1950's, Latin America's has exploded. For example, Mexico, Venezuela, Peru, and Brazil have population growth rates of about 3 percent per year, a rate which, if it continues, would lead to a 19-fold population increase within a century. If North America's 1950 population had expanded at 3 percent per year, it would now be 341 million rather than the actual 236 million. At current per capita consumption levels, those additional 105 million people would absorb virtually all exportable supplies and North America would be struggling to maintain self-sufficiency.

Some Key Actors on the Global Scene

Japan. Japan is the world's largest grain importer, importing more than any other two countries combined. The government there is upgrading diets for a population equal to nearly half that of North America and squeezed into an area smaller than California. This year Japan will import nearly 20 million tons of grain, mostly feed grains and wheat, making it more dependent on imports of grain than on its own production (Fig. 1).

Japan was formerly able to restrict its cereal imports. As population pressure began to mount several decades ago, the Japanese began to reserve their limited land resources for the intensive production of rice and turned to the oceans for their animal protein in the form of fish. As a result, they now grow the rice they need, but make increased claims on the world's fisheries.

Postwar prosperity has enabled Japanese consumers to enrich their diets, but, as a result, they now make increased claims on the world's grain supply. As their incomes and purchasing power have risen, many Japanese consumers have begun to develop a taste for livestock products. Japanese production and consumption of pork and poultry products are now on a par with that of other industrial countries, and still expanding (*4*). Beef consumption has been nominal (only 9 pounds per capita per year) and could expand substantially.

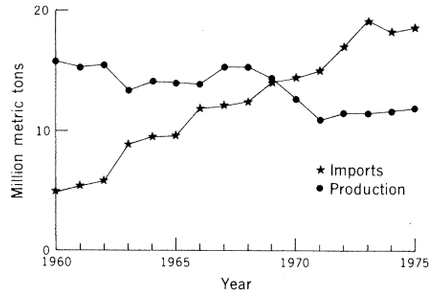

Fig. 1. Japan: production and imports of all grains, 1960 to 1975 (*2*).

Japanese economic projections for the coming decades show food imports continuing to rise as a result of further moderate population growth and rising incomes. If prices remain reasonable it seems safe to predict that Japanese consumers will continue to increase their purchases of livestock products. Speculation about when Japan's cereal imports might level off is problematical, contingent as it is upon their future prosperity and rate of population growth.

On the population front, Japan received a great deal of credit for the sharp reduction in its birth rate during the years immediately after World War II. Since then, however, its population has continued to grow at 1 percent or more per year, and is now nearly double the North American rate of natural increase. Recent signs suggest that the Japanese are again preparing to actively discourage population growth, and they could quite reasonably move toward population stability over the next decade if they decide to do so.

China. Recent visitors to China almost always comment on the excellent nutritional condition of the population. Journalists, economists, scientists, and doctors all come away with the same impression. The obvious clinical signs of malnutrition, present in almost every other low-income country, appear to be almost wholly absent in China.

The success of Chinese efforts in nutrition is probably due more to improvements in distribution than to production gains. The latter have been creditable but not spectacular. China has imported several million tons of grain per year since 1960, a total of 78 million tons from 1960 to 1975. In fact, from 1970 to 1975 it imported more grain than India (*2*). The difference is that China has apparently achieved both a higher per capita production and availability of grain and a more equitable distribution.

Chinese success in agriculture cannot be viewed apart from the social reforms and regimentation that have resulted in a rare degree of social equity, not only within the rural sector but between the rural and urban sectors as well. Another strength of the Chinese system is that the production teams are organized to permit the mobilization of excess or seasonally idle labor for rural road construction, reforestation, and the construction of terraces and irrigation reservoirs and canals. Enormous earth-filled irrigation dams have been built almost entirely by human muscle power.

Nevertheless, pressures on agricultural resources are evident in the shift of land from soybeans to cereals. As recently as the 1930's, China has supplied 90 percent of the soybeans entering the world market. Within the last few years it has not only lost this exportable surplus, but has even begun to import soybeans, almost exclusively from the United States.

The seriousness with which the Chinese leaders view the agricultural problem is evident in their willingness to compromise ideologically and turn to foreign engineering firms, primarily American, to build fertilizer plants for them. The 13 massive new nitrogen fertilizer complexes under construction should virtually eliminate China's heavy dependence on imported fertilizer. Nonetheless, returns on additional fertilizer use in China are dependent on comparable increases in other inputs and on further progress in basic agronomic

Table 2. The changing pattern of world grain trade.

Region	Grain exports (+) and imports(−)* (million metric tons)				
	1934–38	1948–52	1960	1970	1976†
North America	+5	+23	+39	+56	+94
Latin America	+9	+1	0	+4	−3
Western Europe	−24	−22	−25	−30	−17
Eastern Europe and U.S.S.R.	+5		0	+1	−25
Africa	+1	0	−2	−5	−10
Asia	+2	−6	−17	−37	−47
Australia and New Zealand	+3	+3	+6	+12	+8

*Data are from FAO (*3*) and USDA (*2*). †Author's estimates for fiscal year are derived from preliminary USDA data (*2*).

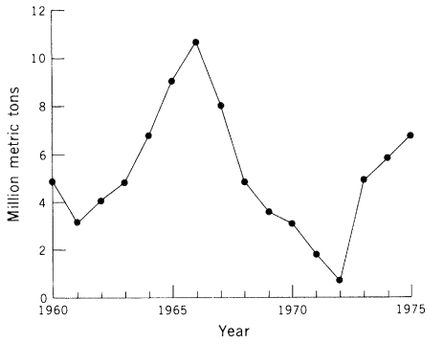

Fig. 2. India: grain imports, 1960 to 1975 (*2*).

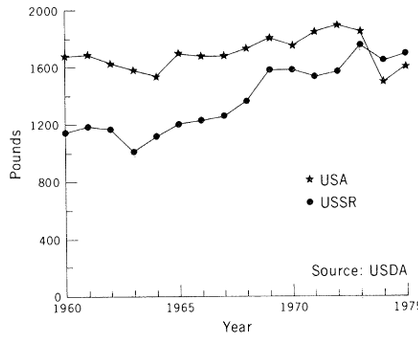

Fig. 3. United States and Soviet Union: per capita annual grain use, 1960 to 1975 (*2*).

research. Without these, the returns on additional massive quantities of fertilizer will diminish rapidly.

China may ultimately solve its food problem, but probably as much by its aggressive action on the population front as on the food front. Rough estimates of current population growth (not even the Chinese seem to have precise data) hover around 1.4 percent per year, and this rate appears to be declining. If it is 1.4 percent per year, it is comparable to that of the United States in the late 1950's.

The Chinese leaders have been among the first to perceive the need to sharply curtail population growth. With the possible exception of Singapore, no government has confronted the population threat so directly as that of China. The leadership has not only provided family planning services, but it has also reshaped important economic and social policies in order to discourage large families. The birth rate appears to be dropping sharply and, if it continues, China's population growth rate could dip to 1 percent by the end of this decade or shortly thereafter. If China can continue to move toward the clearly defined goal of population stability, then it could ultimately solve its food problem, and, by eliminating the need for imports, contribute to solving the world's food problem.

India. The outlook for India's future food situation appeared bleak in the mid-1960's until the government reshaped its food policies and priorities, giving agriculture the support it deserved. This reshaping of economic policies, combined with the availability of the high-yielding strains of wheat and rice, gave Indian agriculture a dramatic boost. During the six-year span between 1966 and 1971, India succeeded in doubling its wheat crop, a performance unmatched by any other major country. By 1972, India was on the brink of being self-sufficient in cereals (Fig. 2). Malnutrition was still rampant among the poor, but India's farmers were producing about all that the market would absorb. It actually provided substantial food aid to refugees from Bangladesh and to the newly independent nation itself.

Since that high watermark for Indian agriculture, in the early 1970's, there have been numerous setbacks, some external to the Indian economy. In the spring of 1975, the U.S. Department of Agriculture estimated that the Indian wheat crop was reduced by a million tons simply because of a shortage of fuel to operate irrigation pumps. Then too, India, more than most other countries, has been adversely affected by the short supply and high price of fertilizer. Heavy dependence on fertilizer imports is due in part to the inefficiency of India's domestic fertilizer plants. The problem is not lack of agricultural potential; India is capable of producing far more food than is now produced. But India has not been able to put together the resources, the priorities, and the policies to maintain its earlier agricultural momentum.

The economic problems of the 1970's are exacerbated by the negative effects of ecological abuse. Deforestation, overgrazing, desert encroachment, and increased flooding due to the destruction of natural vegetation are beginning to take their toll on India's food production. The productivity of a vast semiarid area, covering a fifth of the country, is threatened by these forces. Soil erosion and the silting of irrigation reservoirs are having a perceptible negative effect on food output.

India has succeeded in modestly reducing its birth rate, but it still has a long way to go. It remains to be seen whether India can reduce its dependence on imported foodstuffs or whether this dependence will become absolute and crippling in the years ahead as a result of continuing high birth rates, unfavorable economic forces, and negative ecological trends.

The U.S.S.R. The agricultural production potential of the Soviet Union is severely constrained both by its natural environment and by the organization of its agriculture. Soviet agriculture is, by and large, low rainfall agriculture comparable to that of the Great Plains of Canada and the United States. The U.S.S.R. has severe winters and a short growing and grazing season. It has no choice region like the U.S. corn belt that combines rich soils and high, dependable rainfall.

On top of these natural constraints Soviet agriculture is confronted with some basic institutional inefficiencies. Among these are the weaknesses of central agricultural planning, a lack of management skills at the local level, poor equipment maintenance, the inefficient use of the vast agricultural labor force, and an overall lack of incentives for those working on the land. Planting and harvesting often lag behind schedule, resulting in reduced yields and in crop losses. Perhaps the most telling statistic is the grain-meat ratio. Beginning in 1974, Soviet per capita grain use (both that consumed directly and that consumed indirectly, in the form of livestock products) moved above that of the United States (Fig. 3). Nonetheless, despite great demand, per capita meat consumption in the Soviet Union is scarcely half that in the United States. In addition to the natural handicaps such as the short grazing season, inefficiency in the livestock industry is compounded by reliance on dual-purpose breeds of livestock for milk and meat.

The Soviet decision to offset crop shortfalls with massive imports rather than via belt tightening is the most destabilizing single factor in the world food economy today, because of its enormous cost to consumers everywhere. The instability derives not so much from the scale of Soviet grain imports as from the erratic occurrence of their demands. The question now before the international community is how to reconcile the erratic need for imports with the urgent need to maintain some semblance of stability in the world grain market.

There are signs that the Soviet Union will be importing grain for the foreseeable future. A recent speech by Soviet spokesman and agricultural leader, Fedor Kulakov, which was published in full in both *Pravda* and *Izvestia*, suggests that the return on heavy investment in Soviet agriculture over the past decade has been much lower than the leadership had hoped. Indeed, the Soviets may be contemplating a shift in investment emphasis toward the exploitation of minerals and other raw materials for export. Even after a decade of heavy investment in agriculture, they still find that satisfying consumer needs requires large grain imports. There is little to suggest any reduction in Soviet dependence on food imports in the years ahead,

so that North America must gear both its production and export policies to the new reality of heavy Soviet dependence on imported grain (*1*).

Brazil. For at least a generation, writings on world food prospects have alluded to the potential of Brazil and particularly of the Amazon Basin as a source of food for the world (*5*). Unfortunately, as we face global food shortages and are forced to reassess reality, it is becoming clear that Brazil is by no means a cornucopia. Although it is now exporting soybeans in significant quantities, it is far from fulfilling its once promising potential as a major supplier of food for the world. Indeed, in 1973 Brazil imported more grain than any country in the Western Hemisphere. Even with food from abroad, Brazil's northeast still contains one of the largest areas of abject poverty, hunger, and malnutrition found anywhere in the world.

What has happened to the notion that Brazil could someday feed the world? First, only a minute percentage of the area of the vast Amazon Basin is potentially cultivable with present food prices and prospective farming technologies. Even development of the pockets of agriculturally promising land will require extensive investment in transportation, drainage, research, and credit and marketing facilities. The problem is not so much that Brazil has not been able to expand its food production; it has, and at a fairly impressive rate. But Brazil is faced with an unprecedented growth in the demand for food, because the population of Brazil grows at nearly 3 percent per year. In addition, its economy has been growing at an impressive 8 to 10 percent yearly over the past decade. Together these two sources of growth in demand are increasing food needs by some 4 percent per year (*2*).

This means that to be self-sufficient Brazil needs to increase agricultural output far more rapidly than any major country has yet succeeded in doing. A sustained 4 percent annual growth in food production makes essential a heavy continuing investment in agriculture. In addition, it requires rapid innovation in agriculture which in turn requires the development of new technologies, and their rapid dissemination and acceptance by farmers. With an agricultural research system that is underdeveloped and underfinanced and a rural population which is still partly illiterate, the problems involved here are evident. And finally, with land holdings highly concentrated among a small percentage of the population, a redistribution of land is urgently needed to give those who work it a stronger incentive to raise its productivity.

But even all this is not enough. At its present growth rate of nearly 3 percent, Brazil's population (now 108 million) will be nearly 2 billion in a century, just four generations hence. Brazil could have to contend with a population larger than that of China and India combined well before this time in the next century. Without a strong commitment to family planning, Brazil is not likely to be a major supplier of grain to the world.

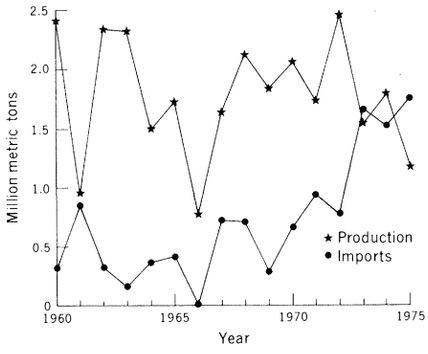

Fig. 4. Algeria: production and imports of all grains, 1960 to 1975 (*2*).

OPEC: New Claimants on Food Supplies

The unprecedented accretion of wealth and purchasing power in oil-exporting countries over the past few years is now reflected in their expanding food imports. Not only is the increase in purchasing power a very sharp one, but the number of people involved also represents a substantial portion of the world's population. The 13 OPEC countries have a combined population of 268 million, nearly half this number being in Indonesia. Per capita food consumption, epecially of high protein foods, among OPEC country populations is modest. Thus, much of the new income and purchasing power will be spent on food.

In countries where oil exports are large and populations relatively small, as in Iraq, Iran, or Venezuela, food consumption per person is likely to rise in a meteoric fashion. Overall, the scale of food imports into OPEC countries seems certain to increase dramatically in the years ahead. If oil prosperity begins to spread beyond the urban elite, diets will be rapidly upgraded. In view of the longtime neglect of agriculture in most of these countries, any sharp increase in demand will have to be satisfied initially by imports.

Most OPEC countries are semiarid and many face the effects of severe ecological stresses in agriculture. Both Algeria and Nigeria suffer from overgrazing, deforestation, and the spread of the Sahara Desert. Nigeria, with a population variously estimated at from 60 to 80 million people, is confronted with intense population pressures at a time when the system of traditional slash-and-burn cultivation is being overexploited in some areas. As recovery periods between plantings are shortened to keep pace with the demand for food, soils are no longer able to regenerate their fertility.

One of the most important uses of the new oil wealth is investment in agriculture. Ecuador, Nigeria, Iran, and Iraq are intensifying their investment in agriculture severalfold. But continuing rapid growth in food output requires more than capital. The support system for agriculture must include an indigenous research capacity, technical advisory services, farm credit services, roads and markets, and, in many instances, reforms in land tenure.

The rate of expansion in agricultural output of the OPEC countries will accelerate, but the question is how fast the acceleration will be relative to that of the demand for food. Nearly all OPEC countries have food deficits, and in some they are substantial. Algeria, for example, relies heavily on imported wheat to sustain its population. The poor 1975 wheat harvest of 700,000 tons may result in an import need of close to 2 million tons, more than double the average of the past ten years (*6*) (Fig. 4).

As increased purchasing power in OPEC countries converts into greater demand for livestock products, including poultry, many countries are implementing programs of rapid expansion of food production. Some expect to double poultry and egg output within a period of two or three years; Iraq, for example, which has not traditionally imported feed grains, is projected to import nearly a million tons annually by the end of the current decade in order to support its burgeoning poultry and livestock industry (*7*).

Ecuador has expanded its food output only 5 percent over the past three years. Yet, while production limps along, the demand for food is soaring, both because of population growth and the infusion of oil money into the economy. The result, as of mid-1975, is an acute domestic shortage of food and a need for a sharp increase in imports.

One of the unknowns in the food outlook in OPEC countries is Indonesia. If the oil dollars begin to filter down to the lower-income groups, they will convert almost immediately into a demand for additional food. Can the Indonesian agricultural economy respond to this growth in demand? In the short run at least it is doubtful. Because Indonesia supports a large

population, even modest increases in per capita food import requirements would result in a large market demand for food imports.

From a social point of view, increasing the purchasing power of more than a quarter of a billion of the world's lower-income people is unquestionably desirable. New buying power would enhance both the quantity and quality of food intake and greatly reduce malnutrition. From an analytical point of view, the claims on the world's exportable food supplies are very steep and abrupt, and they come at a time when there is little slack in the world farm economy.

Green Revolution Countries: Population Overrunning Technology

The so-called Green Revolution countries deserve special attention. The mid-1960's witnessed the launching of a remarkable effort to expand food production in the food-deficit poor countries, an effort centered around the development and international dissemination of high-yielding dwarf wheats and rices. Highly responsive to fertilizer, these new strains were capable of doubling yields of indigenous varieties if managed properly.

Coming at a time when per capita food production in the developing world was declining and requests for food aid were beginning to pour in, the Green Revolution was heralded as an exciting advance. India doubled its wheat crop in a six-year period, a feat unmatched by any major country in history. Mexico, the Philippines, Pakistan, and Turkey all increased cereal production dramatically.

The Green Revolution enabled many countries to cut back grain imports and some to become exporters. India, riding the crest of the Green Revolution, was on the verge of cereal self-sufficiency in the early 1970's. Mexico exported 10 percent of its grain crop between 1965 and 1969, but the production gains were overwhelmed by one of the world's fastest population growth rates (Fig. 5).

By the mid-1970's, Mexico was importing one-fifth of its grain needs. The Green Revolution enabled the Philippines to end a half century of dependence on imported rice and to become a net exporter of rice during the late 1960's. Today it is again importing rice on a large scale. The advances made in these countries were being eaten up by the relentless growth in population.

During the early years of the Green Revolution many of those involved in launching it, including Norman Borlaug, the originator of the dwarf wheats, and myself, cautioned that the new seeds should not be viewed as a solution to the food problem. The only ultimate solution to the food problem in these countries was to put the brakes on population growth. The new seeds were simply buying time, perhaps another 15 to 20 years, to get population growth under control. Half of that time has now passed. Although there has been some progress in family planning, the above data indicate that it is not nearly enough, and that time will not be bought so cheaply again.

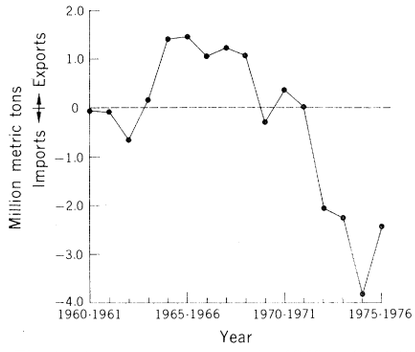

Fig. 5. Mexico: net grain trade, 1960 to 1976 (*2*).

A Disturbing Reversal

One of the most disturbing trends in the world food economy during the 1970's has been the downturn in grain output per hectare (Fig. 6). This new trend shows up in recent U.S. Department of Agriculture data on all grains except rice, for which reliable yield data are not yet available. If the average world grain yield during the period from 1960 to 1975 is plotted as a three-year sliding average in order to smooth out the fluctuations associated with weather, a disturbing trend emerges. From 1960 until 1972 this three-year average increased each year, but then in 1973 it turned downward, dropping further in 1974 and still further in 1975. At its peak in 1972, the average grain yield per hectare was 1.91 metric tons, but over the next three years it dropped to 1.84 metric tons, a decline of 4 percent.

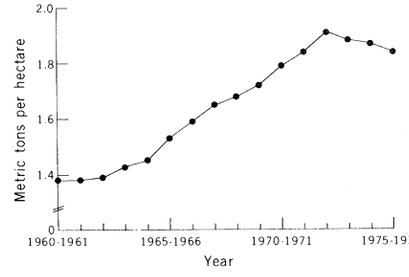

Fig. 6. World grain yield per hectare, 1960 to 1976 (*2*) (excludes rice; plotted as three-year sliding averages).

Aside from weather, which may have been a major factor, there are at least five other factors which may have contributed to this downturn in world grain yields per acre: (i) the release for production of the 50 million acres of U.S. idled cropland, most of it below average fertility; (ii) the high cost and tight supply of energy; (iii) the high cost and tight supply of fertilizer; (iv) the shortening of the slash-and-burn cycle in some densely populated areas, thus preventing soil regeneration; and (v) the increasing use of animal dung as fuel rather than as fertilizer.

Assessing Future Food Prospects

The conditions under which the world's farmers and fishermen will attempt to expand food output during the final quarter of this century are quite different from those prevailing during most of the quarter century just ending. In most respects it will be more difficult to increase food production than it was in the past. None of the basic resources required to expand food output—land, water, energy, fertilizer—could be considered abundant today. The enormous growth of both economic and agricultural output during the second quarter of this century depended largely on a seemingly boundless supply of cheap energy. There is no prospect of a return to cheap energy in the foreseeable future.

Expanding the cultivated land area is also becoming more difficult and costly. Indeed, in some countries, the area under cultivation is actually declining as a result of desert encroachment, soil erosion, or urban sprawl. There are only a few places in the world where fertile new land awaits the plow: the Republic of Sudan, the tsetse fly belt in sub-Saharan Africa (assuming the tsetse fly can be eradicated), and parts of the interior of Latin America.

Scarce though new land is, the lack of water may be the principal constraint on future efforts to expand world food output. From 1950 to 1970 there was a great expansion in irrigated areas as large new irrigation projects were undertaken in China, India, and numerous other developing countries. The total irrigated area was expanding by nearly 3 percent per year, but the annual increase from now until the end of the century will be scarcely 1 percent, since most of the choice dam sites have already been exploited.

The real cost of fertilizer, particularly widely used nitrogen fertilizer, declined substantially throughout most of the peri-

od since World War II. Cheap fertilizer played a major role in the impressive expansion of food production in the industrial countries of North America, Europe, and Japan, but because the cost of fertilizer is closely tied to the cost of energy, we cannot expect a return to cheap fertilizer.

At mid-century the world fishing industry was brimming with optimism. Seemingly inexhaustible supplies of fish could be netted as fast as fishing technologies improved and capital investment expanded. This optimism was well founded. The world fish catch expanded from 22 million tons in 1950 to 70 million in 1970. Then suddenly, with little warning, the world fish catch declined for two consecutive years, at least partly as a result of overfishing. An increasingly common phenomenon, overfishing now affects oceanic fisheries as widely separated as the haddock fishery in the North Atlantic and the anchovy fishery in the South Pacific (*1*). Some marine biologists think the world catch of table-grade fish may be approaching its maximum sustainable limit. Others envision brighter prospects, but not even the most hopeful foresee future gains even remotely approaching those of the past 25 years.

In a number of oceanic fisheries, efforts to expand the catch further have led to overfishing, depletion of stocks, and an actual decline in catch. Additional investment in fishing capacity for many fisheries today brings not merely a diminishing return per unit of investment, but an actual negative return. What is not yet widely realized is that a similar predicament may engulf agriculture in parts of the world where population pressure is building. Extending food production onto marginal land is already leading to overgrazing, deforestation, desert expansion, soil erosion, silting of irrigation reservoirs, and increased flooding (*8*).

In some developing countries, these negative forces may soon override the drive to step up food output by means of additional capital investment and technological innovation. We may witness in the not too distant future sustained absolute declines in national food production in some developing countries, namely those with the most rapid population growth, because of these ecological stresses. This backsliding will be without precedent in the modern world and, I dare say, our success in anticipating such a reversal may not be any greater than our success in anticipating the declining catch in some of the major oceanic fisheries.

In the industrial countries, diminishing returns on key agricultural inputs such as fertilizer and energy may severely constrain efforts to expand food output rapidly. In the early 1950's, each additional pound of fertilizer in the American corn belt raised corn yields by 15 to 20 pounds. Today an additional pound of fertilizer applied in the same cornfield may yield only an additional 5 pounds of grain. The use of chemical fertilizer has not yet reached the saturation point in any of the industrial countries, but for some the point may not be far off. By contrast the production response to fertilizer in the developing countries, where usage rates are low, is still quite high.

Summary

The scarcity of basic resources required to expand food output, the negative ecological trends that are gaining momentum year by year in the poor countries, and the diminishing returns on the use of energy and fertilizer in agriculture in the industrial countries lead me to conclude that a world of cheap, abundant food with surplus stocks and a large reserve of idled cropland may now be history. In the future, scarcity may be more or less persistent, relieved only by sporadic surpluses, of a local and short-lived nature. The prospects are that dependence on North America will be likely to continue to increase, the increase probably being limited only by the region's export capacity.

References and Notes

1. L. R. Brown and E. P. Eckholm, *By Bread Alone* (Praeger, New York, 1974).
2. U.S. Department of Agriculture, Foreign Agricultural Service Grain Division, R & D computer printout of 14 July 1975. This printout contains country-by-country figures for the 1960 to 1975 period on area harvested, yields, beginning stocks, total production, imports, exports, feed consumption, and total consumption of wheat and coarse grains (barley, corn, rye, oats, sorghum).
3. United Nations Food and Agriculture Organization, *Production Yearbook* (Food and Agriculture Organization, Rome, 1960).
4. U.S. Department of Agriculture, Foreign Agricultural Service, *Foreign Agriculture Circular FLM-7-75—Livestock and Meat* (U.S. Department of Agriculture, Washington, D.C., 1975).
5. C. F. Marbut and C. B. Manifold, "The soils of the Amazon Basin in relation to agricultural possibilities," *Geographical Review* **16**, No. 3 (1926).
6. H. S. Steiner, "Maghreb grain crops decline—Import needs on the rise," *U.S. Dep. Agric., Foreign Agriculture* **13** (42), 2 (1975).
7. J. D. Parker, Jr., "Rapid growth continues in U.S. farm exports to Iraq," *ibid.* **13** (15), 2 (1975).
8. E. P. Eckholm, *Losing Ground: Environmental Stress and World Food Prospects* (Norton, New York, in press).