Eds., *Hydrides for Energy Storage* (Pergamon, New York, 1978).
5. G. L. Holleck, J. R. Driscoll, B. E. Paul, *J. Less Common Metals* **74**, 379 (1980); C. Folonari, G. Iemmi, F. Manfredi, A. Rolle, *ibid.*, p. 371; K. Videm, in (*4*), p. 463; A. Percheron-Guégan, J. C. Achard, J. Sarradin, G. Bronoël, in (*4*), p. 485.
6. J. H. Swisher and E. D. Johnson, *J. Less Common Metals* **74**, 301 (1980).
7. H. H. van Mal and A. R. Miedema, in (*4*), p. 251.
8. M. A. Pick, M. G. Greene, M. Strongin, *J. Less Common Metals* **73**, 89 (1980).
9. H. H. van Mal, K. H. J. Buschow, A. R. Miedema, *ibid.* **35**, 65 (1974).
10. D. Shaltiel, I. Jacob, D. Davidov, *ibid.* **53**, 117 (1977); J. Shinar, I. Jacob, D. Davidov, D. Shaltiel, in (*4*), p. 337.
11. A. R. Miedema, *J. Less Common Metals* **32**, 117 (1973); ———, R. Boon, F. R. de Boer, *ibid.* **41**, 283 (1975); A. R. Miedema, *Philips Tech. Rev.* **36**, 217 (1976).
12. D. L. Douglass, in (*4*), p. 151; B. Vigeholm, J. Kjoeller, B. Larsen, *J. Less Common Metals* **74**, 341 (1980); F. G. Eisenberg, D. A. Zagnoli, J. J. Sheridan III, *ibid.*, p. 323.
13. I. Sheft, D. M. Gruen, G. J. Lamich, *J. Less Common Metals* **74**, 401 (1980).
14. E. R. Bauminger *et al.*, *Physica B86–88*, 201 (1977).
15. F. W. Oliver, K. W. West, R. L. Cohen, K. H. J. Buschow, *J. Phys. F* **8**, 701 (1978).
16. A. F. Andresen, in (*4*), p. 61.
17. A. Furrer, P. Fischer, W. Haelg, L. Schlapbach, *ibid.*, p. 73.
18. A. Percheron-Guégan, C. Lartigue, J. C. Achard, P. Germi, F. Tasset, *J. Less Common Metals* **74**, 1 (1980).
19. G. K. Shenoy, D. Niarchos, P. J. Viccaro, B. D. Dunlap, A. T. Aldred, G. D. Sandrock, *ibid.* **73**, 171 (1980).
20. A. Blasius and U. Gonser, *Appl. Phys.* **22**, 331 (1980).
21. F. Stucki and L. Schlapbach, *J. Less Common Metals* **74**, 143 (1980).
22. M. Ron, D. Gruen, M. Mendelsohn, I. Sheft, *ibid.*, p. 445.
23. G. D. Sandrock and P. D. Goodell, *ibid.* **73**, 161 (1980).
24. W. E. Wallace, R. F. Karlicek, Jr., H. Imamura, *J. Phys. Chem.* **83**, 1708 (1979).
25. R. L. Cohen, K. W. West, J. H. Wernick, *J. Less Common Metals* **73**, 273 (1980).
26. J. J. Reilly, in (*4*), p. 301; ——— and R. H. Wiswall, *Inorg. Chem.* **13**, 218 (1974).
27. J. C. McCue, *J. Less Common Metals* **74**, 333 (1980).
28. I. Sheft, D. M. Gruen, G. J. Lamich, L. W. Carlson, A. E. Knox, J. M. Nixon, M. Mendelsohn, in (*4*), p. 551.
29. J. Toepler, O. Bernauer, H. Buchner, *J. Less Common Metals* **74**, 385 (1980).
30. H. Buchner, *Prog. Energy Combust. Sci.* **6**, 331 (1980).
31. F. E. Lynch, *J. Less Common Metals* **74**, 411 (1980).
32. E. L. Huston and G. D. Sandrock, *ibid.*, p. 435.
33. We thank D. M. Gruen, R. F. Karlicek, G. G. Libowitz, and J. J. Reilly for comments on the manuscript.

The World Food Situation and Global Grain Prospects

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As we proceed further into the 1980's, a review of the world food situation and global grain prospects is timely. The public tendency to view world food problems only in terms of crisis has done a profound disservice to the world's growth in Africa. However, the magnitude of weather-related fluctuations and the resulting problems should not obscure the basic facts underlying developments in the world food situation in the past three decades.

Summary. The basic realities of the distribution of the world's population, wealth, and agricultural production base are not conducive to an automatic stabilizing process for the world's hungry. Increasing volatility in world grain production in the 1980's could create a problem of major proportions. By 1990, the developed world will account for 24 percent of the world's population, 85 percent of the world's economic activity, and around 50 percent of the world's grain production and consumption. On a per capita basis, the developed world will consume nearly three times as much grain as the developing countries which account for three-fourths of the world's population. Increased food aid, which is essential, is not the solution to the basic problem. The low-income countries need a massive infusion of capital investment, research support, and education if they are to build infrastructures that have the capacity to produce, distribute, and market food supplies. Other options serve only to prolong and aggravate the current disparities.

hungry. Peaks and troughs of such public interest do not provide an environment conducive to productive assessment of the basic problems. Food crises do occur but they often are only warning episodes of a critical underlying trend (*1–5*). Today's world is not without a food crisis—witness the recent effects of weather-reduced production and rapid population

From 1950 to 1980, world food production doubled, with the increase in the developing countries actually exceeding that of the developed countries (Table 1). At the same time, population in developing countries grew at more than twice the rate evidenced in the developed world. In developed countries, food production nearly doubled whereas population increased around a third. As a result, per capita food production increased nearly 50 percent. In developing countries, where food production increased nearly 120 percent since the early 1950's, population almost doubled and gains in per capita food production were limited (*6*). Although food production in the developing world grew at a compound rate nearly 15 percent higher than the developed world over the past three decades, the disparity in population growth rates permitted the developed countries to increase per capita food production nearly three times faster than the developing countries.

Food production has doubled since 1950, and during the same period world food trade has increased fourfold. Since 1970, the annual rate of growth in food trade was about three times faster in the developing countries than the developed world, with the developed world acting as the major supplier of the world food trade. The developing countries, through increased food trade, have considerably narrowed the gaps with the developed world in per capita food consumption.

The Food and Agriculture Organization of the United Nations (FAO) estimates that on a per capita basis, levels of calorie and protein intake from vegetable products were very similar among the three major economic classes in 1977 (Table 2). The per capita intake of 2016 calories from vegetable products in the developing countries was only 264 calories or 13 percent less than in the developed world, but the protein intake of 42.9 grams from these vegetable products was nearly 10 percent higher. The major difference in nutritional levels among the developed, developing, and

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centrally planned countries occurs in the animal products, with the developed world consuming about five times as much as the developing countries, both in daily calorie and protein intakes. Future world food prospects could be strongly influenced by the direction the world, especially the developing countries, takes to improve human nutrition. Greater consumption of animal products would lead to a more rapid increase in grain requirements (*7*, *8*).

Changing Production Patterns

This analysis of population versus production trends is not new. Conclusions reached in the early 1970's when "crisis" reviews were conducted have not changed greatly over the past decade. What is new is a pattern evidenced over the past 10 years with regard to the variability in food production (Fig. 1). A simple trend analysis of food production data indicates that the variability around the trend has increased in each successive decade since 1951 (*9*).

World food production did not decline in any single year between 1950 and 1970, although the developed world experienced declines in 1961 and 1969. Since 1970, the world has experienced 3 years in which production declined. The developing countries recorded declines in 1972 and 1979, whereas the developed world slipped in 1979 and 1980. In both cases, large grain reserves were in position to cushion the impact and world production recovered in succeeding years. The production and population trends of the previous two decades continued in the 1970's as disparate population growth rates led to very different growth rates in per capita food production between the developed and developing worlds.

Most major developed countries have shown a strong upward trend in per capita food production (Fig. 2). From 1950 to 1970, the greatest increases occurred in Europe and the Soviet Union as output rebounded after World War II. In the United States and Canada, growth rates were slower because of production constraints imposed by government to avoid further accumulations of already large agricultural surpluses. In the 1970's, U.S. output accelerated as land was returned to production, but the United States, Canada, Oceania, and the Soviet Union suffered from variations in weather which caused wide year-to-year fluctuations in output. Both Eastern and Western Europe continued to show consistent gains.

With the exception of the continued deterioration in per capita food production in Africa (excluding South Africa), most of the developing countries have experienced improvement in per capita output, particularly in the late 1960's and mid-1970's. During the 1970–1979 period, food production in 27 of the 53 African countries was not keeping pace with the annual rate of growth in population. Eight had negative growth rates in food production in the 1970's. In Central and South America, much of the gain in output has been confined to Argentina and Brazil. In South Asia, gains associated with the Green Revolution in the late 1960's have been maintained in the face of continued rapid population growth; India is the outstanding example. However, output has been subject to weather variation and little further gains on a per capita basis are evident for the region as a whole in the past decade. West Asia has experienced marked gains since the early 1970's, particularly in Indonesia and Thailand. East Asia is a high growth region which has used an expanded area and yield-enhancing inputs to boost output gains.

Although data are limited, preliminary assessments indicate that China's production of most major food items grew at a faster rate than population in the last 25 years. But per capita improvements generally were small between 1955–1957 and 1977–1979, with much of the gain occurring in 1978 and 1979.

Sources of Increase in Grain Production

Cereal grains are the most basic and important source of human nutrition being used directly for consumption and as feedstuffs for livestock. In 1977, nearly 50 percent of the world's per capita calorie and protein intake were obtained from cereal grains for direct human consumption (*10*). In addition, about 13 percent of per capita calories and 30 percent of per capita protein were obtained from consumption of animal products, excluding fish and fish products. Thus, growth in world food production is closely tied to growth in total cereal grain production.

In the 1950's, total world grain production grew at a 3.6 percent annual rate. Nearly 60 percent of this output gain was due to an expansion in area under utilization (Fig. 3). The 138-million hectare increase in cultivated areas in developing countries accounted for all the expansion

Table 1. Total and compound annual rates of increase in food production, population, and per capita food production, 1951–1953 to 1978–1980 and selected periods. The data exclude China. Three-year averages were used in all growth rate calculations when data were available; N.A., comparable data were not available. [Source: (*13*), (*19*), and (*20*)]

Item and region	1951–1953 to 1978–1980		Compound annual rates of increase (%)			
	Total increase (%)	Compound annual rate (%)	1951–1953 to 1959–1961	1959–1961 to 1969–1971	1969–1971 to 1978–1980	1973–1975 to 1978–1980
Food production						
World	102.0	2.6	3.3	2.5	2.1	2.1
Developed countries	95.0	2.5	3.3	2.4	2.0	1.8
Developing countries	117.0	2.9	3.0	2.9	2.8	3.1
Population						
World	64.0	1.8	1.8	1.9	1.9	1.8
Developed countries	33.0	1.1	1.3	1.1	0.9	0.8
Developing countries	88.0	2.4	2.1	2.5	2.4	2.4
Per capita food production						
World	24.0	0.8	1.6	0.6	0.3	0.4
Developed countries	47.0	1.4	2.0	1.3	1.1	0.9
Developing countries	15.0	0.5	0.8	0.5	0.2	0.4
Total agricultural trade						
World	397.0	5.3	5.3	3.7	5.0	5.0
Developed countries	N.A.	N.A.	N.A.	4.0	3.0	2.8
Developing countries	N.A.	N.A.	N.A.	3.6	8.0	9.1

in world grain acreage, with many of the developed countries actually idling land to limit an unwanted accumulation of grain stocks. Yields in the developed countries, however, expanded at three times the rate of the developing world.

In the 1960's and 1970's, the continued increase in output in both the developed and developing countries resulted more from gains in yields than from area expansion. Nearly 90 percent of the increase in world grain output in the 1960's and slightly more than 70 percent in the 1970's came from increased yields. These yields have resulted from increased use of fertilizer, adoption of higher-yielding varieties, improved production practices, and increased use of irrigation to moderate the influence of weather variability. However, the disparity in yields remains. Yields in the developed world expanded much faster in the 1960's than in the developing world. In contrast, the developing countries continued to improve yields through the 1970's while the developed countries made little progress. In 1961–1962, yields in the developed world were 70 percent higher than in the developing world. Nearly 20 years later, in 1978–1980, that disparity still remains.

The diversity of progress among regions underscores this reliance on increasing productivity as well as area (Table 3). Regions such as Oceania, Central and South America, and East Asia have expanded their cropping areas or increased double cropping. In the United States, acreage that had been idled to limit the accumulation of excess supplies was brought back into production in the late 1970's. The slowing of area expansion of the 1970's in the developing world was offset by an increased rate of growth in yields in all but the Middle East and West Asia. In fact, yields increased faster in the developing world than for developed countries during the 1970's.

Although data for China in the early 1960's are limited and difficult to evaluate, it appears that higher yields generated most of the growth in crop production in that country. There was some expansion, however, in area planted for wheat and rice, largely because of increased multiple cropping. Yield increases for wheat, rice, and coarse grains were rapid, because of improved varieties, expanded irrigation, and—particularly during the 1970's—increased use of chemical fertilizer. Coarse grain yields were also boosted by substantial shifts of area from sorghum and millet to higher-yielding corn.

World Grain Production Prospects

An examination of the source of gains in output of total grains (*11*) over the past three decades reveals that the constraints the world faces in the future revolve around land, water, yield-enhancing technology, and the weather. The basic question of input productivity potentials—which has plagued all sectors of the world's economies—clouds prospects for world food production.

For the 1980's, the reliance on productivity growth throughout the world will continue and may have to increase if the world is to maintain the growth in output recorded in the 1970's. Expanded harvested area, which accounted for 30 percent of the production gains in the 1970's, is unlikely to be as great a factor in the future. Virtually all the readily available, relatively fertile cropland in the developed and centrally planned countries is already in use and the pace of expansion has been progressively slower. Further expansion will require substantial financial incentive since it

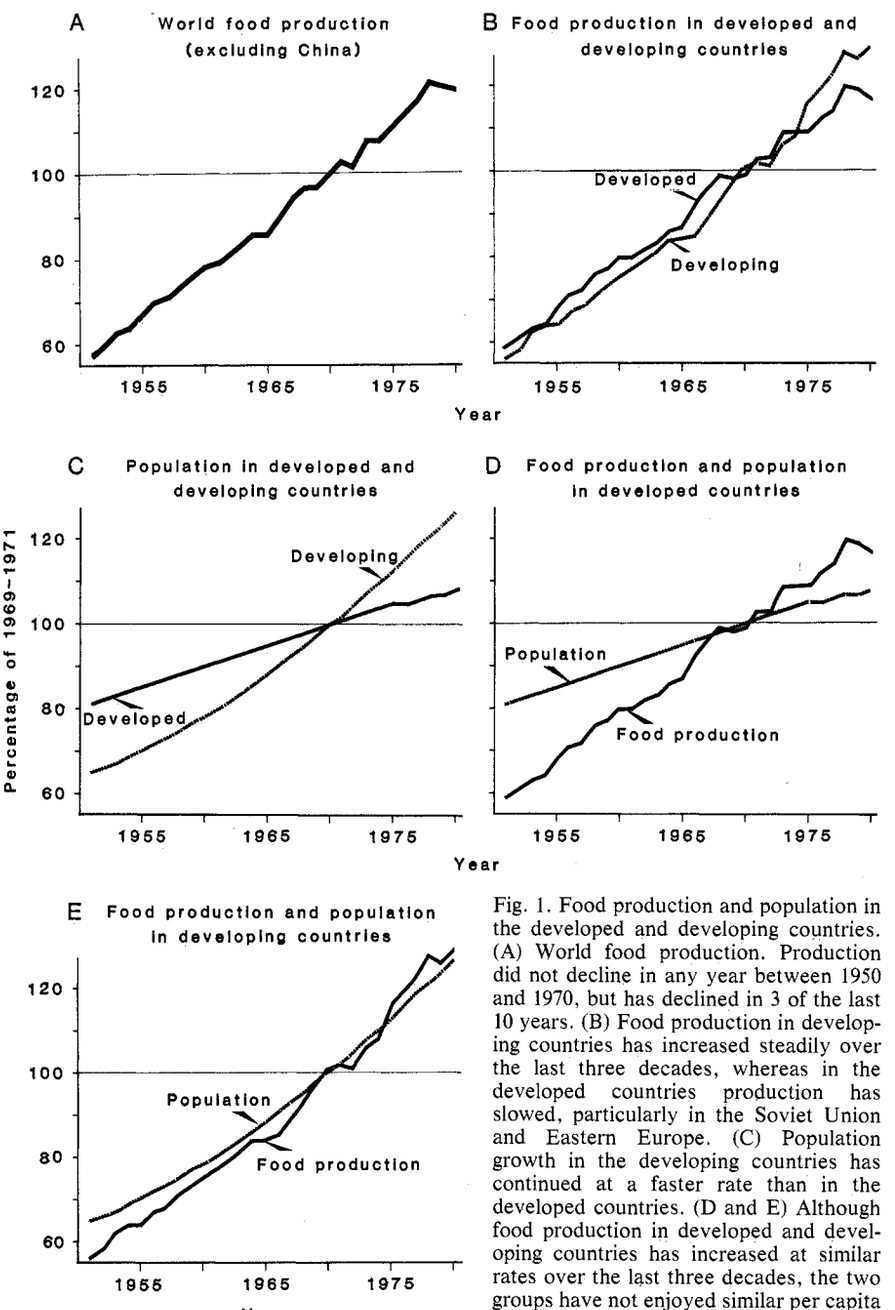

Fig. 1. Food production and population in the developed and developing countries. (A) World food production. Production did not decline in any year between 1950 and 1970, but has declined in 3 of the last 10 years. (B) Food production in developing countries has increased steadily over the last three decades, whereas in the developed countries production has slowed, particularly in the Soviet Union and Eastern Europe. (C) Population growth in the developing countries has continued at a faster rate than in the developed countries. (D and E) Although food production in developed and developing countries has increased at similar rates over the last three decades, the two groups have not enjoyed similar per capita gains. In developed countries food production has increased twice as fast as population. In developing countries, population increases have absorbed more than four-fifths of the gain in food production, leaving little improvement in per capita output.

Table 2. Per capita food supply by economic classes and major regions and countries, 1977. [Source (*10*)]

Economic class and region	Per capita calorie supply (cal/day)			Per capita protein supply (g/day)		
	Vegetable products	Animal products	Total	Vegetable products	Animal products	Total
Developed countries	2280	1073	3353	39.3	57.7	97.0
United States	2266	1312	3578	33.1	73.3	106.4
Canada	1938	1429	3368	35.1	66.2	101.3
Western Europe	2267	1109	3376	40.7	54.1	94.8
South Africa	2507	414	2921	49.8	27.3	77.1
Japan	2399	547	2946	45.6	42.4	88.0
Oceania	2034	1364	3398	34.0	73.5	107.5
Developing countries	2016	188	2203	42.9	12.0	54.9
Latin America	2111	446	2557	38.6	26.8	65.5
Far East (excluding Japan and the Peoples Republic of China)	1914	114	2029	41.2	7.4	48.7
Near East	2372	249	2620	57.9	15.5	73.5
Africa (excluding South Africa)	2060	146	2205	44.1	10.9	55.0
Centrally planned	2235	447	2682	50.9	22.7	73.7
Eastern Europe and Soviet Union	2492	989	3481	51.7	51.6	103.3
China	2141	246	2386	51.0	11.4	62.5
World	2136	435	2571	44.8	23.9	68.8

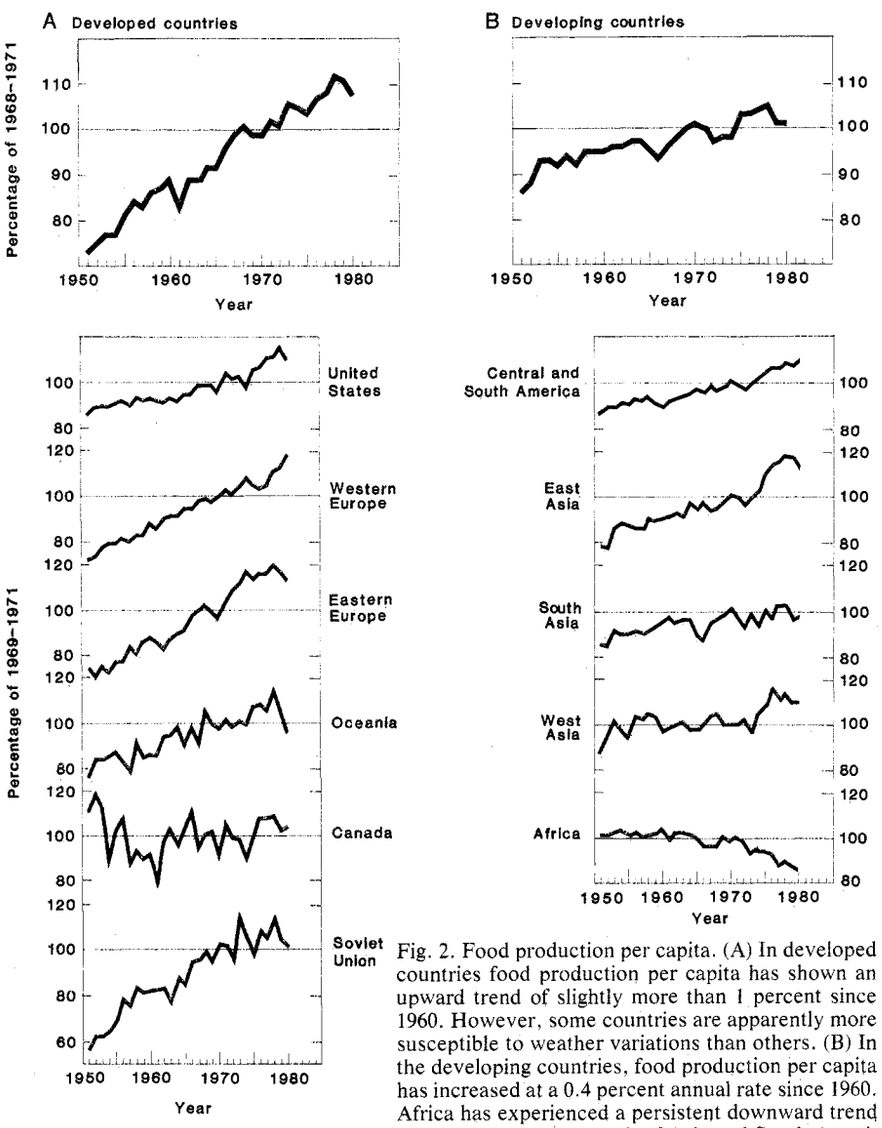

Fig. 2. Food production per capita. (A) In developed countries food production per capita has shown an upward trend of slightly more than 1 percent since 1960. However, some countries are apparently more susceptible to weather variations than others. (B) In the developing countries, food production per capita has increased at a 0.4 percent annual rate since 1960. Africa has experienced a persistent downward trend since 1961, whereas much of Asia and South America recorded good gains in the mid-1970's.

will have to occur in marginal areas where yields will be lower and costs higher. Increases in area in the developing countries also are likely to be limited, particularly in the high population and land-poor areas of Asia, North Africa, and the Middle East. South America and Africa offer the best potential for area increases.

In view of the limited potential for expansion in the effective resource base, accelerating the growth of productivity is clearly the key to the future. Since new technological breakthroughs are not likely to be implemented in the next decade, accelerated adoption of current technology is fundamental. The potential for output gains is certainly present when one examines differences in yields in various parts of the world. For example, Thailand, a net exporter, has maintained a nearly 4 percent annual rate of growth in grain production since the early 1960's; with around 85 percent of the increase being due to increased area. Thailand, with its relatively abundant area and good tropical weather pattern, has not been under great pressure to adopt high-yielding crop varieties and applies roughly 9 kilograms of fertilizer per hectare of rice, its major crop. The Republic of Korea, on the other hand, uses the higher-yielding varieties and applies about 200 kilograms of fertilizer per hectare of rice and has averaged close to U.S. grain yields. Korea has maintained a rate of growth in grain production at 2.4 percent since the early 1960's despite some declines in harvested acreage.

However, the cost of productivity gains in the next decade is likely to continue to increase, with prices of energy-based inputs—including fertilizer, pesticides, and fuels—unlikely to remain stable for any extended period. High-income growth regions may keep pace with such costs, but a large portion of the world lacks the financial resources to acquire such inputs even at today's prices. At the same time, productivity could be enhanced by better production management practices and increased adoption of existing lower-cost technology.

The world's limited agricultural land base and rising costs of productivity gains are likely to result in some slowing of output growth rates noted in the past 20 years. This slowing, coupled with the interannual fluctuations in production that the world has seen in the 1970's, clearly indicates that one factor will play a key role in future improvement in world food production prospects—climate and weather variability.

Grain Production and Climate

Although the complex interrelationship between food production and technology and climate is not fully understood, a recently published study (*12*) attempts to answer questions on climatic change and global food production. The study concludes, on the basis of a survey of the world's leading climatologists, that there is a 30 percent probability of a slight warming trend by the year 2000. This warming will have a negligible effect on 15 "key" crops, according to the study. While the expected changes vary from crop to crop, Canadian and Soviet wheat have the greatest potential for being affected either adversely or favorably. Improved technology is expected to have a much greater effect on crop yields than any projected climatic change.

Weather or climatic variability, however, must be viewed as a major factor in

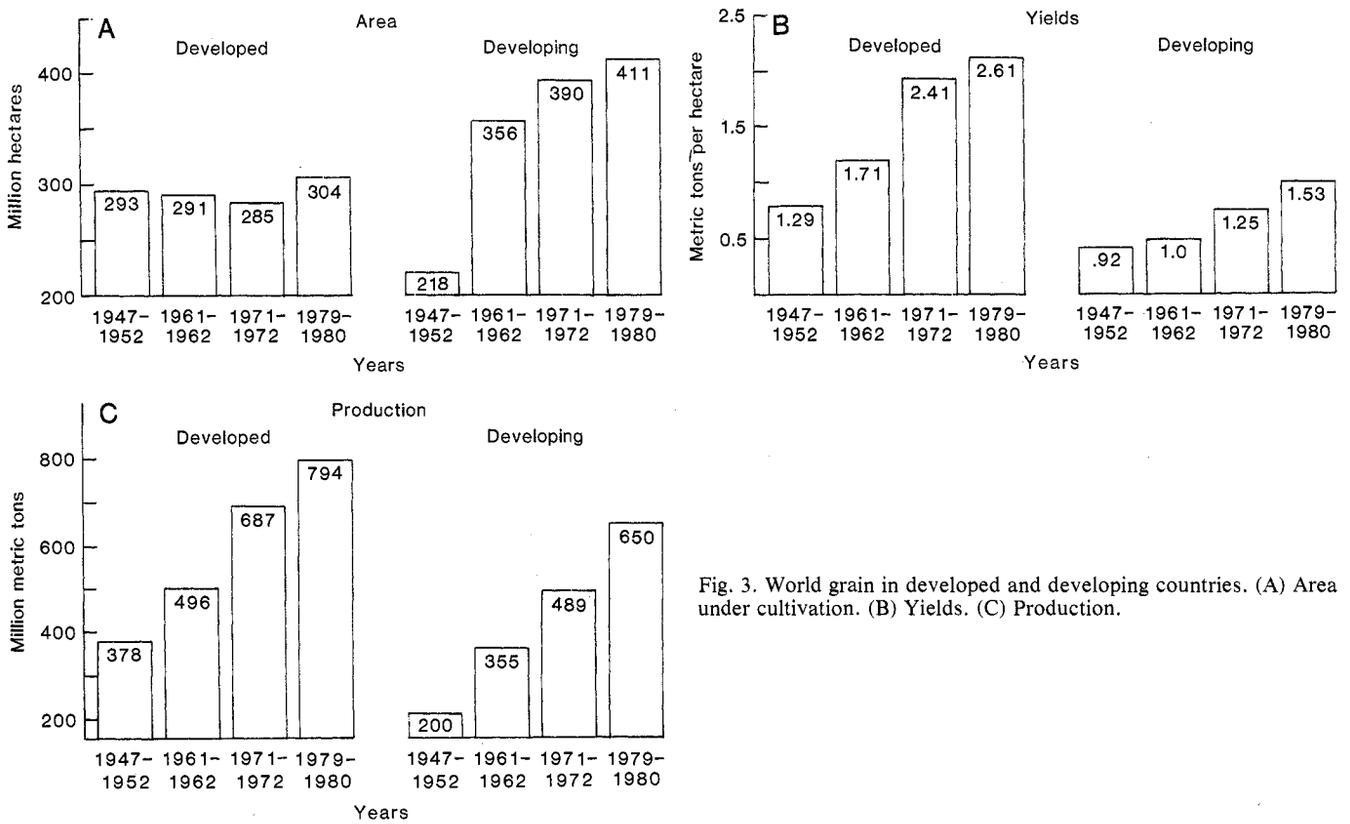

Fig. 3. World grain in developed and developing countries. (A) Area under cultivation. (B) Yields. (C) Production.

Table 3. Sources of growth in total grain production. [Source (*20*)]

Region	Compound annual growth rates (%)								
	Production			Area			Yields		
	1961–1962 to 1979–1980	1961–1962 to 1971–1972	1971–1972 to 1979–1980	1961–1962 to 1979–1980	1961–1962 to 1971–1972	1971–1972 to 1979–1980	1961–1962 to 1979–1980	1961–1962 to 1971–1972	1971–1972 to 1979–1980
World	2.7	3.3	2.4	0.5	0.4	0.7	2.2	2.9	1.7
Developed countries	2.5	3.3	1.8	0.2	−0.2	0.8	2.3	3.5	1.0
United States	3.2	3.6	2.6	0.6	−0.1	1.5	2.6	3.9	0.9
Western Europe	2.8	3.7	1.8	0.0	0.1	−0.2	2.8	3.6	1.6
South Africa	4.2	2.3	6.7	0.2	0.3	0.2	4.0	1.8	6.8
Oceania	3.8	2.5	5.5	0.5	3.0	3.8	3.3	−0.5	1.8
Soviet Union	2.3	2.6	2.0	0.1	−0.5	0.9	2.2	3.1	2.0
Eastern Europe	2.8	4.1	1.2	−0.5	−0.5	−0.5	3.4	4.6	1.8
Developing countries	3.0	3.3	3.2	0.8	0.9	0.6	2.3	2.3	2.5
Central and South America	3.7	3.7	3.7	2.0	2.5	1.4	1.7	1.2	2.2
Africa	2.1	2.1	2.1	1.1	1.4	0.7	1.0	0.7	1.4
Middle East	2.5	2.8	2.7	0.5	0.2	0.9	2.0	2.7	1.2
South Asia	2.6	2.6	2.8	0.7	0.7	0.8	1.9	1.8	2.0
India	2.5	2.6	2.4	0.6	0.6	0.6	1.9	1.9	1.8
East Asia	3.1	2.6	3.8	1.4	1.2	1.8	1.6	1.4	2.0
Indonesia	3.2	2.8	4.4	0.9	0.6	1.3	2.2	1.7	3.0
Thailand	3.8	3.4	4.3	3.2	2.9	3.5	0.6	0.6	0.7
Republic of Korea	2.4	2.2	2.8	−0.7	0.0	−1.7	3.2	2.2	4.6
West Asia	−0.9	0.1	−2.2	−1.5	−1.3	−1.7	0.6	1.5	−0.6
China	4.3	4.5	4.0	0.1	0.5	−0.4	4.2	3.9	4.5

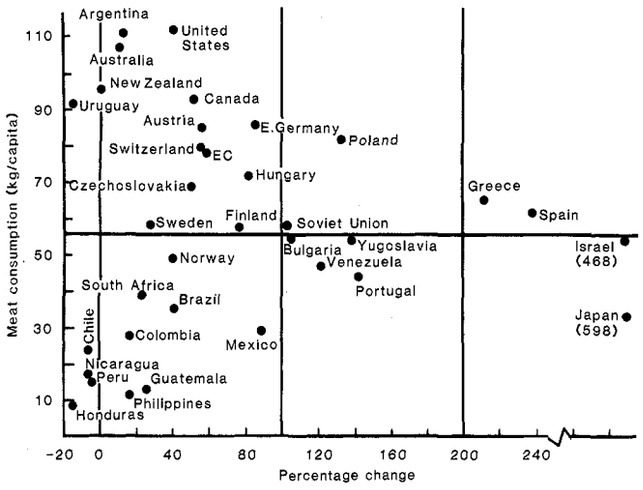

Fig. 4. Per capita meat consumption and percentage change, 1961 to 1980; *EC*, European Community.

year-to-year variability in crop production. In the 1970's, this variability was significantly greater than at any time since the mid-1950's. More limited variability in world grain production from 1950 into the early 1970's can be related to at least three factors: a relatively benign weather pattern which augmented production; government acreage adjustment programs which idled the more marginal acreage; and a rapid employment of new technology such as hybrid seeds which produced well with the existing weather patterns.

Since the early 1970's, variability in crop production increased primarily because of reversal in the trends of the same three factors. First, weather patterns have produced a series of record-setting deviations: the record U.S. cold, wet spring and early fall freeze in 1974; the most severe drought of the century in Europe and the Soviet Union in 1975; extended drought in the United States in 1976–1977; droughts in Australia in 1980; and the unprecedented heat wave and drought in the southern United States in 1980. At the same time, excessive moisture reduced crop production in portions of China and the Soviet Union. Second, acreage adjustments returned idled land to production and added marginal areas where crops may be more susceptible to disease and weather variability. And third, the increased cost of yield-enhancing inputs and new technology has limited the offsetting gains in productivity.

No one can predict the weather, yet it seems clear that with the use of more marginal land, higher-yielding plant varieties and other selective technology, and with limited water resources, the world is forming an increasingly susceptible production base that will generate excellent harvests with favorable weather but sharply lower output with unfavorable weather patterns. Irrigation systems, increased mechanization, and better management practices have reduced vulnerability in many countries. However, further technological breakthroughs are not likely to be implemented in the near term but may become more feasible with improved economic conditions or increased incentives. This volatility in world production is likely to generate increased problems in the coming decade.

With the underlying growth rate in world grain production unlikely to exceed the average pace of the 1970's by any significant margin without the benign weather patterns of the 1960's, the forces that will shape consumption growth in the future hold the key to the magnitude and distribution of the imbalance or gap between production and consumption that may evolve by the 1990's. Population growth and other demographic factors coupled with world economic conditions and government policies will determine the consumption patterns that will evolve in the 1980's.

Population and Economic Growth

World population growth was the single most significant factor providing impetus to rapid increases in demand for total grains over the past three decades. Although population growth was not evenly distributed, and many areas simply could not provide the grain to keep pace with population increases, it seems certain that the population factor accounted for about half to two-thirds of the increase in grain consumption over the past three decades.

Population growth may slow somewhat, but the pattern is not going to change greatly in the next decade (*13*). By 1990, more than 75 percent of the world's population will reside in the developing world, including China (Table 4). Population increases in the developing world will account for 90 percent of annual increases in world population expected over the next 10 years. In the decade of the 1980's, the world's population is projected to increase by about 86 million people per year (*13*).

Population growth in the developed countries continued to slow in each decade since 1950. The developed world, including the Soviet Union and Eastern Europe, is likely to continue to grow at less than a 1 percent compound annual rate through the 1980's, adding 9 million people per year. In contrast, the developing world population—exclusive of China—is likely to continue to grow at around the 2.5 percent level evidenced over the last 20 years. These countries will add more than 65 million people per year to the world population over the next 10 years. China's population growth rate is likely to continue declining toward 1.2 percent per year. However, China still will add an additional 12 million people per year in the 1980's.

These population gains will continue to add to the total demand for food, and will be compounded by the small increases in per capita caloric food requirements associated with the countries' changing age composition. As a result, growth in grain consumption in the 1980's attributable to population growth will very likely match that of the 1970's.

While population increases have been dominant in the past decades in increasing grain consumption, a growing share of the increases in world grain consumption has come as a result of economic conditions and improved diets. Economic growth, particularly in the 1960's and early 1970's, generated average annual increases of 3 percent in real per capita incomes. This increasing affluence coupled with low relative commodity prices accelerated indirect grain consumption and led to dramatic shifts in diets.

A most striking feature of the changing world food situation since 1960 is the dramatic increase in meat consumption, particularly poultry and other animal protein (Fig. 4). This transition, which has been a characteristic of increasing affluence in all parts of the world, has been most apparent in the centrally planned countries and many of the oil-producing and high-income, rapidly developing countries.

World meat consumption grew at an annual rate of close to 3 percent since the

Table 4. World population, actual and projected. [Source (*13*)]

Region or country	Compound annual growth rates (%)			Absolute population (millions)			Annual increase in people (millions)		
	1960–1970	1970–1980	1980–1990	1970	1980	1990	1960–1970	1970–1980	1980–1990
Developed	1.06	0.80	0.68	728	788	843	7.3	6.0	5.5
United States	1.25	0.80	0.95	205	222	244	2.4	1.7	2.2
Canada	1.55	1.34	1.18	21	24	27	0.3	0.3	0.3
Western Europe	0.82	0.47	0.29	357	374	385	2.8	1.7	1.1
South Africa	2.61	2.80	2.74	22	29	38	0.5	0.7	0.9
Japan	1.02	1.10	0.59	104	116	123	1.0	1.2	0.7
Oceania	1.73	1.93	1.23	19	23	26	0.3	0.4	0.3
Centrally planned	1.68	1.29	1.07	1173	1334	1484	18.0	16.1	15.0
Eastern Europe	0.60	0.66	0.53	103	110	116	0.6	0.7	0.6
Soviet Union	1.32	0.90	0.90	244	267	292	3.0	2.3	2.5
China	1.93	1.48	1.18	826	957	1076	14.4	13.1	11.9
Developing	2.55	2.59	2.55	1776	2293	2949	39.6	51.7	65.6
Central and South America	2.79	2.66	2.65	283	368	478	6.8	8.5	11.0
East Asia (excluding Japan and China)	2.46	2.14	1.89	51	63	76	1.1	1.2	1.3
South Asia	2.50	2.51	2.40	1110	1422	1803	24.3	31.2	38.1
Africa (excluding South Africa)	2.55	2.86	3.01	332	440	592	7.4	10.8	15.2
World total	1.96	1.85	1.80	3677	4415	5276	65.0	73.8	86.1

early 1960's and poultry consumption at 5 to 6 percent. High-income countries in North Africa and the Middle East increased poultry consumption 10 percent annually during the 1960's and 20 percent annually in the past decade. Japan, the Soviet Union, Eastern Europe, and the high-income East Asian countries registered phenomenal gains in per capita poultry and total meat consumption in the past 20 years. However, their levels of consumption remain well below that of the United States.

This shift from direct consumption of grains to indirect consumption—that is, livestock product consumption—implies increased demand for feedgrains, oilseeds, and other feedstuffs. Five calories of grain products, on the average, yield only one calorie of livestock product. Even the most efficient converters of grains—poultry—involve a three- or four-to-one ratio. While forage consumption can offset grain requirements, there remains a limited land base for most countries. Feed use as a percentage of total grain and oilseed production increased sharply in the 1960's (from 43 to 50 percent of production) and held even in the face of rising prices through the 1970's.

Prospects for economic growth in the 1980's appear less favorable than in the 1960's and early 1970's. A slower growth period plagued by persistent problems of inflation and unemployment is likely in the early 1980's. However, the pattern of economic recovery will vary from country to country. Diet shifts are likely to continue, though at somewhat slower rates in high-income and rapidly growing areas, offsetting a somewhat limited growth in lower-income areas. In the developing countries, growth in grain consumption is likely to remain near the rates of the past two decades. In the lowest-income countries, problems are likely to become worse unless favorable weather continues, because these countries lack the indigenous production capacity and financial reserves to purchase the substantial grain or yield-enhancing inputs that are needed to keep pace with population growth.

Policy Limits to Consumption Growth

The final ingredient in the potential for growth in grain consumption in the 1980's is government policies. The Soviet Union made overt policy decisions in 1972 to enhance domestic consumption by means of trade rather than modify plans for consumption gains in the face of a reduced harvest (*14*). The Soviets have continued to pursue that objective through the 1970's. China recently opened its doors to increased imports. Adjustments in the European Community have altered grain production and trade patterns, both within and outside the European Community. At the same time some countries, such as Japan, have limited the expansion in wheat consumption with internal price levels well above world markets. All of these actions have served to create an increasingly interdependent world economy which in recent years has been buffeted by oil price hikes, wide swings in exchange rates, and volatile commodity markets. As we look toward mid-decade, a significant shift toward protectionism and insulation can be envisaged that would be designed to limit the vulnerability of many importing countries.

Agricultural trade has been an area of particular concern for both importers and exporters. Currently some 55 to 60 million metric tons of grain are scheduled to move under bilateral or multilateral agreements which will effectively insulate these grain movements from market fluctuations. This constitutes nearly 30 percent of the world's wheat and coarse grain trade. This has the effect of forcing the rest of the world to make adjustments to production shortfalls or windfalls within a much smaller total trade volume with a resulting increase in the potential volatility of world grain prices. A continuation of these trends could be particularly damaging for the more vulnerable, less-affluent countries and could dramatically alter the pace of growth in consumption as each country is forced to reappraise its posture in world markets.

Grain Prospects for the 1980's

From the foregoing review of the factors that determine the potentials for growth in world grain consumption, it is clear that grain prospects and the world food situation are not merely questions of the technology to produce, nutritional requirements, and population. However, the complexity of the international food and agricultural system should not be permitted to interfere with identification of the fundamental problems the world is to face in the future.

Although a more complex analysis of

global food balances would be necessary before postulating specific solutions, a simple trend analysis of production and consumption patterns in key areas of the world for the period 1960–1980, and an extension of the trend to 1990, presents the world's dilemma very effectively in terms of the magnitude and distribution of the food gaps by regions (Fig. 5). Alternative assessments of world grain prospects for the 1980's can be derived from this basic trend analysis by adjusting, on the basis of an evaluation of the factors already identified, implied future projected growth rates for production and consumption. Some recent analyses have indicated a stronger rate of growth in consumption and thus larger and more significant gaps that put additional pressure on the developing world (*15*). Conversely, a more rapid rate of production growth coupled with slower population gains may alleviate the near-term problem.

The basic conclusions of the simple unadjusted trend analysis suggest that the world can indeed produce sufficient grain to permit some limited improvement in per capita consumption. However, distribution of world food supplies was not consistent with the world population distribution and growth. Prospects suggest that the imbalance for nearly 50 percent of the world's population will only become increasingly severe in the 1980's.

The developed countries, excluding the Soviet Union and Eastern Europe, will continue to be the surplus suppliers to the rest of the world. The Soviet Union and Eastern Europe, and to some degree China, are an enigma because of internal political influences in the food consumption trends. Since 1972, the Soviet Union has attempted to meet a commitment for improved diets for its people, particularly increased meat consumption. If this pattern continues, the Soviet Union will remain a major importer of grain and in years of shortfall will be a major participant in bidding for available supplies.

High-income developing regions, such as the Republic of Korea, Hong Kong, Singapore, Taiwan, and others, have the financial resources to continue to expand consumption levels through purchase of yield-enhancing technology or direct purchase of grain in world markets.

In coming years, the rate of growth of Chinese grain production is unlikely to exceed historical growth rates, although a declining population growth rate may permit a small gain in per capita supplies (*16*). Little further expansion of cultivated area is expected and opportunities for increased multiple cropping are limited. Growth in grain production must come almost exclusively from higher yields. However, if current policies continue to stress improved consumption levels, China will be a major bidder to the limit of its uncertain financial reserves for available world grain supplies. China simply lacks the production base and infrastructure to keep pace with both population growth and improving diets.

The remaining 48 percent of the world's population in the low-income developing countries not only lacks a current production base to maintain per capita production gains but also does not have financial reserves to aggressively bid grain out of world markets in periods of tight world supplies (*17*). The gap has persisted over the past 10 years and can only become worse given potential population growth, the increased cost of higher-yielding technology and inputs, and the economic conditions likely to prevail in the 1980's. It is estimated that the current economic slowdown in the developed countries and oil price adjustments have reduced exchange earnings of the low-income developing countries by $6 billion (*18*). It is further estimated that each $1-per-barrel increase in the price of oil will add $2 billion to the import bill of these countries. This drain on financial reserves limits not only grain purchases but also the progress on building an infrastructure that could handle increased imports or distribution of domestic production. Many of the low-income countries lack the logistical capability to move grain to their people even if it were given to them.

This review of the past three decades and the prospects for the 1980's serves only to reinforce earlier findings and to introduce an additional element that will serve to aggravate the prospects for the world's undernourished and hungry. Increased variability in production is a double-edged sword that could cut deeply irrespective of the direction of the swing without increased international cooperation in confronting the underlying factors.

When an exceptional or windfall production year occurs, it does offer a great-

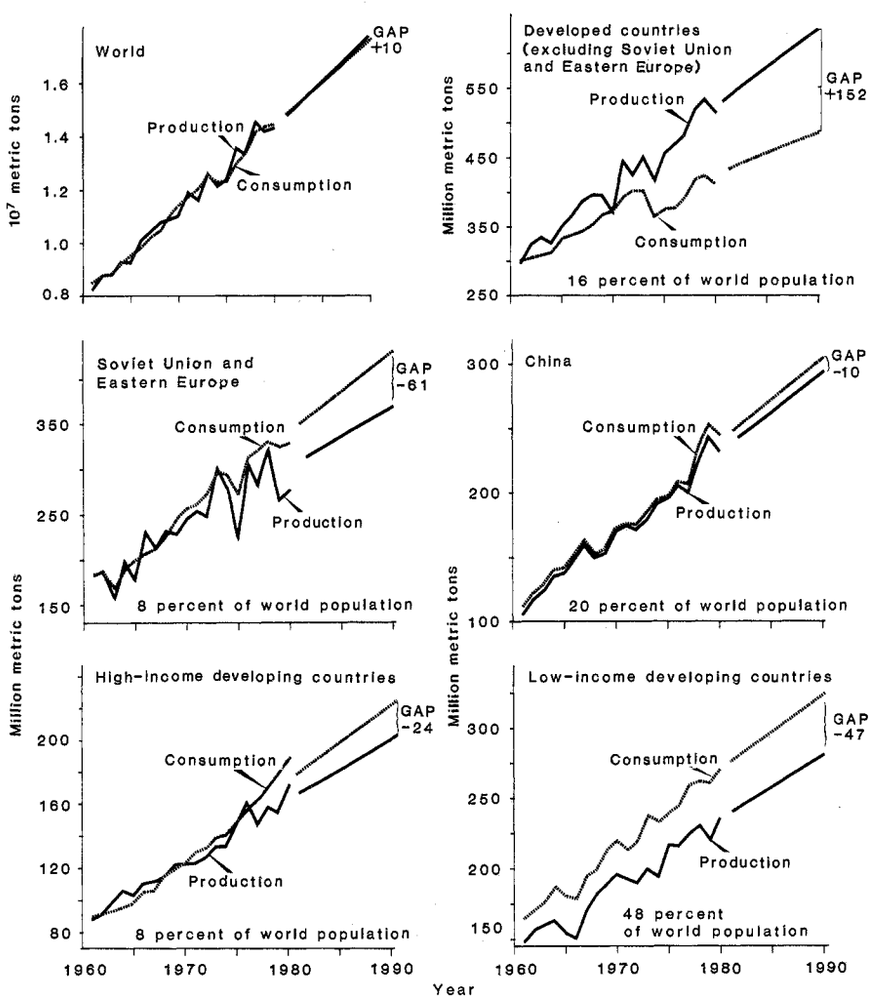

Fig. 5. Total grain production and consumption, and food gaps projected to 1990.

er opportunity for the lower-income countries to purchase more grain or receive more concessional sales. This serves to boost the consumption levels of the low-income countries possibly at the expense of increased dependence on foreign trade. However, the response from countries experiencing unwanted accumulations of stocks and low prices is quite different. These countries experience cost-price squeezes that make farming unprofitable. The solutions to date have been a combination of increased government subsidies or concessional sales or acreage adjustment programs that idle productive capacity.

Current inflationary prospects and the need to control government outlays in many countries could limit the policy options available. Weaker demand in the face of large production could lead to declining real grain prices. The result could be succeeding years in which acreage is idled and grain is successively more expensive in relative terms. The increasing use of grain reserves as one buffer to insulate excess supplies in the market has proved to be an effective method of transition to be used before acreage adjustments occur. However, successive years of large world production or weak demand could erode the effectiveness of this method as these reserves approach unacceptable levels. In addition, it should be remembered that reserves designed for other than emergency food aid are price-enhancing, with price triggers at levels that are likely to limit opportunities for the poor countries in world markets. Even food aid reserves are not a solution to the world food problem of inadequate long-run consumption levels in poor countries; they are only a stopgap stability measure which does not fundamentally change the underlying longer-term trends.

When shortfalls occur, the world marketplace makes grain available to the highest bidder; in the event of an extreme shortfall a developed country may limit exports. In either event, the lowest-income countries are least likely to acquire necessary supplies. Historical evidence indicates that as incomes increase, people consume less grain directly and substitute livestock products for grain in their diet. Thus, the livestock inventory serves in part as a grain reserve which could be liquidated in extreme conditions. However, even in periods of shortfall, the affluent countries can bid away the grain supply to satisfy their preference for meat. In addition, bilateral grain agreements serve to protect a significant share of the available supplies for the more affluent countries, making the remaining market volume smaller and thus prices more volatile in years of reduced production.

In the last 20 years, the largest shortfall in world production (1972) resulted in a draw down in world stocks of 42 million metric tons. But world grain stocks throughout the period never fell below 140 million metric tons including working and pipeline stocks. Grain supplies are available in the world to cover shortfalls, but the pricing mechanism limits the participation of low-income countries. When the ratios of grain stocks to utilization go below 15 percent, prices begin to increase to ration available supplies. The concern with low ratios of stocks to utilization is not that of having insufficient grain to feed the world, but the inability to distribute it effectively in the lower-income areas.

The basic realities of the distribution of the world's population, wealth, and agricultural production base are not conducive to an automatic stabilizing process for the world's hungry. By 1990, the developed world will account for 24 percent of the world's population, 85 percent of the world's economic activity, and around 50 percent of the world's grain production and consumption. On a per capita basis, this part of the world consumes more than three times as much grain as the developing countries, including China, which account for three-fourths of the world's population. Any solution under these constraints will require a greater degree of international cooperation and flexibility than has been evident to date.

This cooperation must come in areas other than food aid and grain reserves which, while critically needed in many years, only serve to mask the underlying problems. The low-income countries need to build internal infrastructures that give them the capacity to produce, distribute, and market grain. This will require each country to invest significant capital in all sectors of its economy including grain handling and transportation systems, chemical inputs, and irrigation systems. It will also require increased research support and education to implement existing technology in areas such as multiple cropping and higher-yielding varieties.

References and Notes

1. Current world food prospects are monitored closely by numerous agencies including the U.S. Department of Agriculture (USDA) and the Food and Agricultural Organization of the United Nations (FAO) [for example, see (2–5)].
2. Food and Agricultural Organization of the United Nations, *The State of Food and Agriculture, 1979* (FAO, Rome, 1980).
3. _____, *The State of Food and Agriculture, 1980* (FAO, Rome, Council Report, November 1980).
4. U.S. Department of Agriculture, *Food Problems and Prospects in Sub-Saharan Africa: The Decade of the 1980's* (Economic Research Service, Foreign Agricultural Research Report No. 166, Washington, D.C., August 1981).
5. _____, *The World Food Situation and Prospects to 1985* (Economic Research Service, Foreign Agricultural Economic Report No. 98, Washington, D.C., December 1974).
6. In discussing the world food situation, the "world" excludes China for which total food production data are lacking or very preliminary. "Developed countries" here includes the Soviet Union and Eastern Europe. "Developing countries" excludes China. Many of the data reported in this article on world food represent an update of information contained in (5).
7. A study by Winrock International (8) indicates that in its most likely scenario, world use of grain for livestock feed is expected to reach 47 percent (excluding rice) compared to the 40 to 44 percent share over the past 10 years. Further, total grain used by livestock is projected to exceed that used for direct human consumption by about 10 million metric tons in 1985.
8. Winrock International Livestock Research and Training Center, *The World Livestock Product, Feedstuff, and Food Grain System: An Analysis and Evaluation of System Interactions Throughout the World, with Projections to 1985* (Winrock, Ark., 1981).
9. The coefficient of variation around a simple trend analysis of world food production for the periods 1951–1960, 1961–1970, and 1971–1980 is, respectively, 0.7, 1.2, and 1.8 percent.
10. Food and Agricultural Organization of the United Nations, *Food Balance Sheets and Per Capita Food Supplies 1977* (FAO, Rome, 1980).
11. Total grains include wheat, coarse grains, and rice. The total grains analysis includes China as part of the "developing countries."
12. National Defense University, jointly with U.S. Department of Agriculture, Defense Advanced Research Projects Agency, National Oceanic and Atmospheric Administration, and the Institute for the Future, *Crop Yields and Climate Change to the Year 2000, 1980.*
13. United Nations, *Selected Demographic Indicators by Country, 1950–2000: Demographic Estimates and Projections as Assessed in 1978* (United Nations, New York, 1980).
14. International Food Policy Research Institute, *Estimates of Soviet Grain Imports in 1980–1985: Alternative Approaches* (IFPRI Research Report No. 22, Washington, D.C., February 1981).
15. U.S. Department of Agriculture, *Agricultural Food Policy Review: Perspectives for the 1980's* (Economics and Statistics Service, Washington, D.C., April 1981).
16. International Food Policy Research Institute, *Food Production in the People's Republic of China* (IFPRI Research Report No. 15, Washington, D.C., May 1980).
17. _____, *Investment and Input Requirements for Accelerating Food Production in Low-Income Countries by 1990* (IFPRI Research Report No. 10, Washington, D.C., September 1979).
18. U.S. Department of Agriculture, *World Food Aid Needs and Availabilities as of March 15, 1981* (USDA Economics and Statistics Service, Washington, D.C., 15 March 1981).
19. Food and Agricultural Organization of the United Nations, *Trade Yearbook* (FAO, Rome, various years).
20. U.S. Department of Agriculture, *World Indices of Agricultural and Food Production* (USDA Economic Research Service, Statistical Bulletin No. 669, Washington, D.C., July 1981).

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