The World Outlook for Conventional Agriculture

More emphasis is needed on farm price policy and plant research if future world food needs are to be met.

Lester R. Brown

The problem of obtaining enough food has plagued man since his beginnings. Despite the innumerable scientific advances of the 20th century, the problem becomes increasingly serious. Accelerating rates of population growth, on the one hand, and the continuing reduction in the area of new land that can be put under the plow, on the other, are postponing a satisfactory solution to this problem for at least another decade and perhaps much longer.

Conventional agriculture now provides an adequate and assured supply of food for one-third of the human race. But assuring an adequate supply of food for the remaining two-thirds, in parts of the world where population is increasing at the rate of 1 million weekly, poses one of the most nearly insoluble problems confronting man.

Dimensions of the Problem

Two major forces are responsible for expanding food needs: population growth and rising per capita incomes.

Populations in many developing countries are increasing at the rate of 3 percent or more per year. In some instances the rate of increase appears to be approaching the biological maximum. Populations growing by 3 percent per year double within a generation and multiply 18-fold in a century.

According to projections, world population, now just over 3 billion, will increase by another 3 billion over the remaining one-third of this century (Fig. 1). Even with the most optimistic assumptions concerning the effect of newly initiated family-planning programs in developing countries, we must still plan to feed an additional 1 billion people by 1980. The world has never before added 1 billion people in 15 years. More significantly, four-fifths of these will be added to the less-developed countries, where food is already in short supply.

Rising income levels throughout the world are generating additional demand on the world's food-producing resources. Virtually every country in the world today has plans for raising income levels among its people. In some of the more advanced countries the rise in incomes generates far more demand for food than the growth of population does.

Japan illustrates this well. There, population is increasing by only 1 percent per year but per capita incomes are rising by 7 percent per year. Most of the rapid increase in the demand for food now being experienced in Japan is due to rising incomes. The same may be true for several countries in western Europe, such as West Germany and Italy, where population growth is slow and economic growth is rapid.

Comparisons between population growth and increases in food production, seemingly in vogue today, often completely ignore the effect of rapidly rising incomes, in some instances an even more important demand-creating force than population growth.

The relationships between increases in per capita income and the consumption of grain are illustrated in Fig. 2. The direct consumption of grain, as food, rises with income per person throughout the low-income brackets; at higher incomes it declines, eventually leveling off at about 150 pounds per year.

The more significant relationship, however, is that between total grain use and income. Historically, as incomes have risen, the use of grain, both that consumed directly and that consumed indirectly in the form of meat, milk, and eggs, has risen also. The upper curve in Fig. 2 indicates that every $2 gain in annual per capita income requires one pound of additional grain.

The rapid increases in both population and income are recent phenomena, in historical terms. Both have occurred since the war, and both are gaining momentum on a worldwide scale.

The effect of the resulting explosive increase in the demand for food is greater pressure on the world's food supplies. This rapid expansion of demand, together with the reduction of surplus grain stocks in North America, contributed to a rapid decline in world grain stocks during the 1960's (see Fig. 3).

Between 1953 and 1961, world grain "carryover" stocks increased each year. The size of the annual buildup varied from a few million tons to nearly 20 million tons. After 1961, however, stocks began to decline, with the reduction or "drawdown" averaging 14 million tons per year.

A stock buildup, by definition, means that production is exceeding consumption; the converse is also true. The trend in grain stocks indicates clearly that 1961 marked a worldwide turning point; as population and income increases gained momentum, food consumption moved ahead of production. Since 1961, the ever-widening excess of consumption over production has been compensated by "drawing down" stocks. But there is little opportunity for further reductions.

This means that the two lines in Fig. 4 cannot remain apart much longer. The question is: How will the lines be brought together? Will the production line go up, or will the consumption line come down? What are the implications of recent trends for world food price levels? Rising prices, a possible result, would act both to reduce consumption, particularly among the world's low-income peoples, and to stimulate production. At a time when hunger and, in some cases, severe malnutrition are commonplace in much of the world, reducing consumption is obviously not a desirable alternative. The effect would be to widen the food gap between the world's "haves" and "have-nots."

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Meeting future food needs will require immense increases in output. The expected increase of 1 billion in world population over the next 15 years will require expansion of world grain production, now totaling about 1 billion tons, by about one-third, or 335 million tons. Additional demand generated by rising per capita incomes, even if only half as large as the population-generated component, could push the total needed increase toward 500 million tons.

What are the prospects of meeting these future increases in world food needs through conventional agriculture? There are two methods of increasing food production: expanding the cultivated area or raising the productivity (output per unit) of land already under cultivation. Throughout most of history, increases in food production have come largely from expanding the area under cultivation. Only quite recently, in historical terms, have some regions begun to rely on raising output per acre for most of the increases in their food supply (*1*).

Over the past 30 years, all of the increases in agricultural production in North America and western Europe have come from raising the productivity of land. Food output has about doubled in both regions, while the area cultivated has actually declined somewhat. Available technology has made it more profitable to raise output per acre than to increase the area under cultivation.

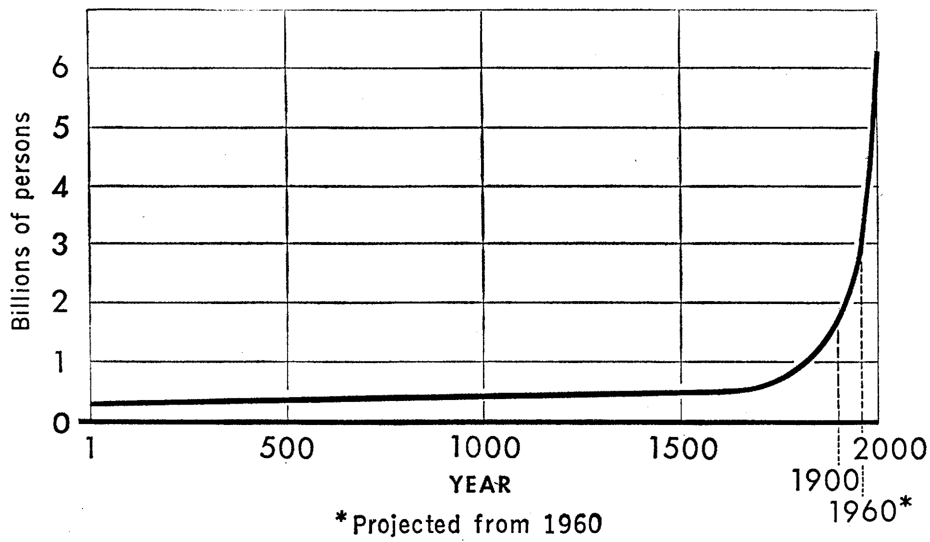


Fig. 1. Twenty centuries of world population growth. [U.S. Department of Agriculture]

Expanding the Cropland Area

The world's present cultivated land area totals some 3 billion acres (1.2 billion hectares). Estimates of the possibilities for expanding this area vary from a few hundred million acres to several billion. However, any such estimate of the area of new land likely to be brought under cultivation must, to be meaningful, specify at what cost this is to be accomplished.

Some land which was farmed a few decades ago has now been abandoned because it is no longer profitable. Much of the abandoned farmland in New England and Appalachia in the United States, or in other countries, such as portions of the Anatolian Plateau in Turkey, falls into this category.

In several countries of the world the area of cultivated land is actually declining. Japan, where the area of cultivated land reached a peak in 1920 and has declined substantially since, is a prominent example. Other countries in this category are Ireland, Sweden, and Switzerland.

Most of the world's larger countries are finding it difficult to further expand the area under cultivation. India plans to expand the cultivated-land area by less than 2 percent over its Fourth Plan period, from 1966 to 1971; yet the demand for food is expected to expand by some 20 percent over this 5-year span. Mainland China, which has been suffering from severe

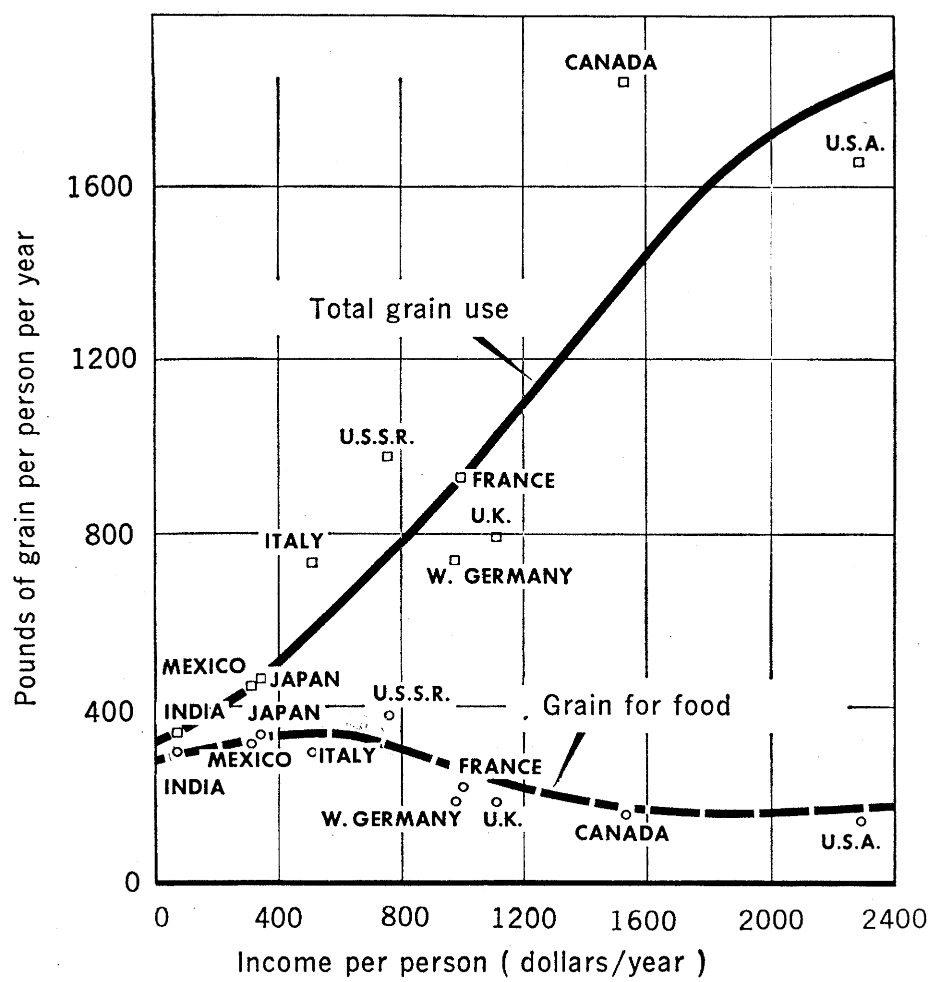


Fig. 2. Income and per-capita grain consumption, total and for food (data for 1959–61). [U.S. Department of Agriculture]

population pressure for several decades, has plowed nearly all of its readily cultivable land.

Most of the countries in the Middle East and North Africa, which depend on irrigation or on dry-land farming, cannot significantly expand the area under cultivation without developing new sources of water for irrigation. The Soviet Union is reportedly abandoning some of the land brought under cultivation during the expansion into the "virgin-lands" area in the late 1950's.

The only two major regions where there are prospects for further significant expansion of the cultivated area in the near future are sub-Saharan Africa and the Amazon Basin of Brazil. Any substantial expansion in these two areas awaits further improvements in our ability to manage tropical soils—to maintain their fertility once the lush natural vegetation is removed.

Aside from this possibility, no further opportunities are likely to arise until the cost of desalinization is reduced to the point where it is profitable to use seawater for large-scale irrigation. This will probably not occur before the late 1970's or early 1980's at best.

The only country in the world which in recent years has had a ready reserve of idled cropland has been the United States. As recently as 1966, some 50 million acres were idled, as compared with a harvested acreage of 300 million acres. The growing need for imported food and feed in western Europe, the Communist countries, Japan, and particularly India is bringing much of this land back into production. Decisions made in 1966 and early 1967 to expand the acreage of wheat, feed grains, and soybeans brought some one-third of the idled U.S. cropland back into production in 1967.

Even while idled cropland is being returned to production in the United States and efforts are being made to expand the area of cultivated land in other parts of the world, farmland is being lost because of expanding urban areas, the construction of highways, and other developments. On balance, it appears that increases in world food production over the next 15 years or so will, because of technical and economic factors, depend heavily on our ability to raise the productivity of land already under cultivation.

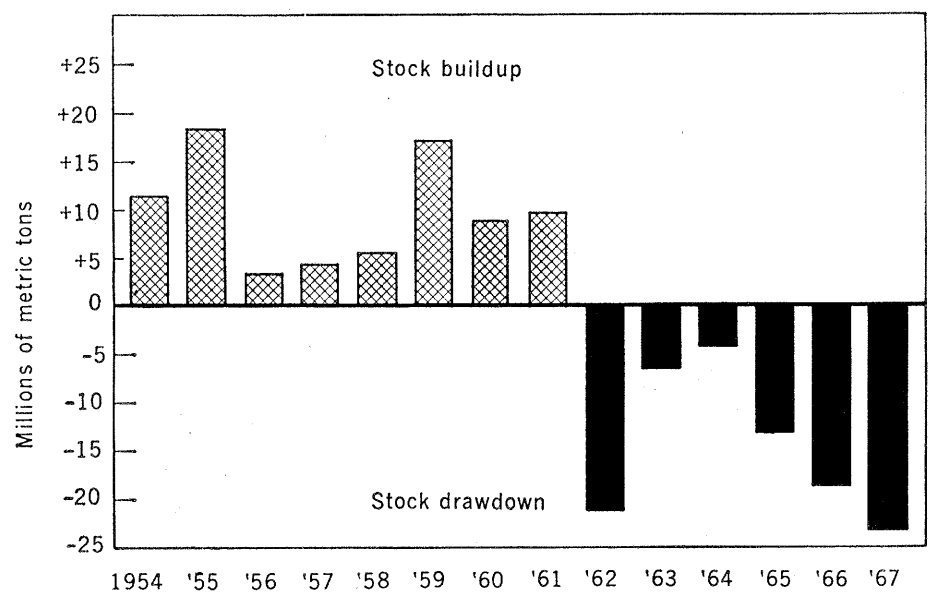


Fig. 3. Changes in world grain stocks. [U.S. Department of Agriculture]

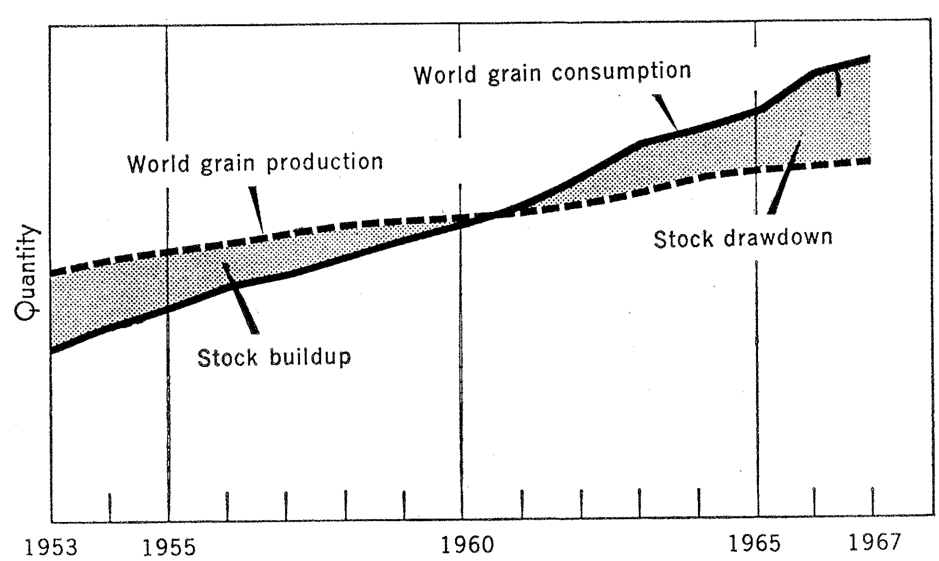


Fig. 4. World grain production now lagging behind consumption. (Schematic representation is not drawn to scale.) [U.S. Department of Agriculture]

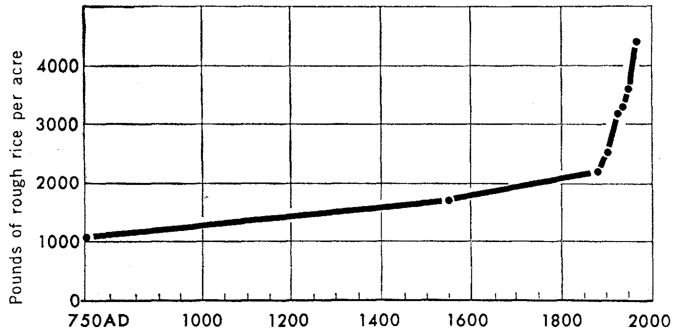
Increasing Land Productivity

Crop yield per acre in much of the world has changed little over the centuries. Rates of increase in output per acre have, in historical terms, been so low as to be scarcely perceptible within any given generation. Only quite recently—that is, during the 20th century—have certain countries succeeded in achieving rapid, continuing increases in output per acre—a yield "takeoff." Most of the economically advanced countries—particularly those in North America, western Europe, and Japan—have achieved this yield-per-acre takeoff (*2*).

The first yield-per-acre takeoff, at least the first documented by available data, occurred for rice in Japan during the early years of this century (see Fig. 5). Yield takeoffs occurred at about the same time, or shortly thereafter, in several countries in northwestern Europe, such as Denmark, the Netherlands, and Sweden. Several other countries, such as the United Kingdom and the United States, achieved yield-per-acre takeoffs in the late 1930's and early 1940's.

Increasing food output per acre of land requires either a change in cultural practices or an increase in inputs, or both. Nearly all increases in inputs or improvements in cultural practices involve the use of more capital (*3*). Many (mechanization itself is an exception) require more labor as well (*4*).

A review of the yield trends shown in Figs. 5 and 6, or of any of several



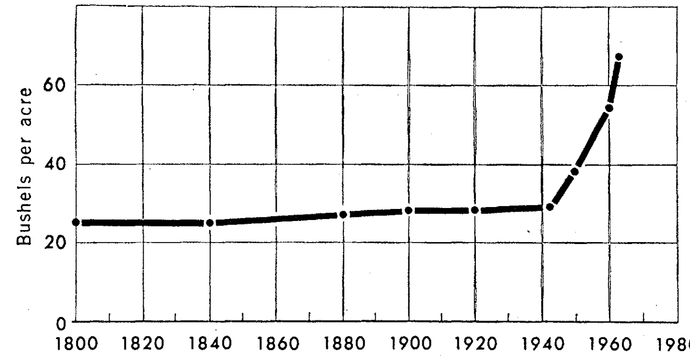


Fig. 5 (left). Rice yields in Japan from A.D. 750 to 1960. Historical estimates from Japanese ministry of agriculture. [U.S. Department of Agriculture] Fig. 6 (right). Corn yields in the United States. [U.S. Department of Agriculture]

others for the agriculturally advanced countries, raises the obvious question of how long upward trends may be expected to continue. Will there come a time when the rate of increase will slow down or cease altogether? Hopefully, technological considerations, resulting from new research breakthroughs, will continue to postpone that date.

Differing sources of productivity. One way of evaluating future prospects for continuing expansion in yields is to divide the known sources of increased productivity into two broad categories: "nonrecurring" and "recurring" sources of increased productivity (5). Nonrecurring inputs are essentially of a one-shot nature; once they are fully adopted, further increases in yields are limited. Recurring inputs, even when fully adopted, offer further annual increases in output through more intensive application.

Corn provides a good illustration. Yields have expanded sharply in the United States (see Fig. 6). Total production now exceeds 100 million tons of grain annually, or about half the total U.S. grain crop. Much of the increase in corn yields, however, was due to two nonrecurring sources of productivity: the replacement of open-pollinated or traditional varieties with hybrids and, to a lesser extent, the use of herbicides.

Hybrid corn has now replaced open-pollinated varieties on more than 97 percent of the corn acreage in the United States (see Fig. 7). Further improvements in hybrid varieties are to be expected. (Hybrids in use today are superior to hybrids developed in the mid-1930's.) The big spurt in yields, however, is usually associated with the initial transition from open-pollinated or traditional varieties to hybrids. Consequently, the big thrust in corn yields in the United States resulting from the adoption of hybrids is probably a thing of the past. Likewise, once herbicides are widely used and virtually all weeds are controlled, there is little, if any, prospect of future gains in productivity from this source.

Some sources of increased yields are of a recurring nature. Among these, there is still ample opportunity for further yield increases as a result of the use of additional fertilizer. As plant populations increase, provided moisture is not a limiting factor, corn yields will rise further as more fertilizer is used.

Just how far the yield increase will go in the United States, however, is not clear. Paul Mangelsdorf of Harvard University, speaking recently at the National Academy of Sciences, asked this vital question (*6*):

> With more than 95 percent of the corn acreage already planted to hybrid corn, with the genetic potentials of the hybrids having reached a plateau, with 87 percent of the acreage in the Corn Belt and Lake States already using fertilizer, and with many farmers already employing herbicides, from where will come the future improvements that will allow us to continue our present rate of improvement?

The same question may be asked of other crops in some of the other agriculturally advanced countries.

The S-shaped yield curve. As the nonrecurring sources of productivity are exhausted, the sources of increased productivity are reduced until eventually the rate of increase in yield per acre begins to slow. This might be depicted by that familiar biologic function the S-shaped growth curve (Fig. 8). John R. Platt of the University of Chicago recently explained the curve this way (*7*):

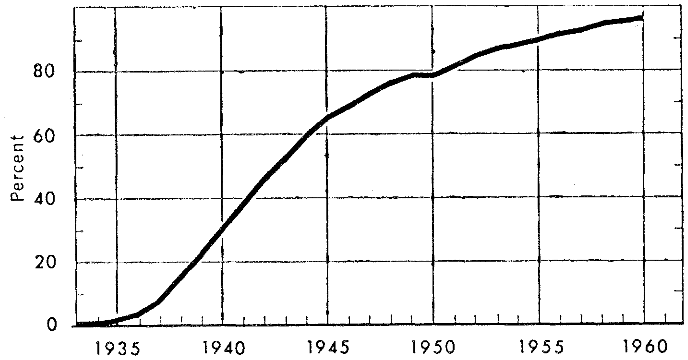
> Many of our important indices of technical achievement have been shooting up exponentially for many years, very much like the numbers in the biologists' colonies of bacteria, that double in every generation as each cell divides into two again. But such a curve of growth obviously cannot continue indefinitely in any field. The growth of the bacterial colony slows up as it begins to exhaust its nutrient. The exponential curve bends over and flattens out into the more general "S-curve" or "logistic curve" of growth.

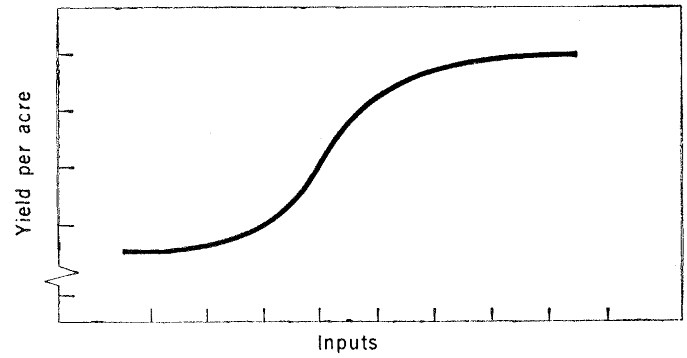
We do not know with any certainty when the rate of yield increase for the major food crops on which man depends for sustenance will begin to slow, but we do know that ultimately it will.

The key questions are: Is the slowdown near for some of the major food crops in some of the agriculturally advanced countries? Will the slowdown come gradually, or will it occur abruptly and with little warning? Finally, to what extent can the level at which the final turn of the S-shaped yield curve occurs be influenced? Can the level be raised by increasing the prices received by farmers, by adopting technological innovations, and by stepping up investment in crop research?

Most of those countries which have achieved takeoffs in yield per acre are continuing to raise yields at a rapid rate. But there are indications that the rate of gain may be slowing for some crops in some of the more agriculturally advanced countries.

Projected per-acre yield levels for the major grains in the United States show a substantial slowing of the rate of yield increase over the next 15 years as compared with the last 15. The rate of yield increase for wheat, averaging 3.5 percent yearly from 1950 to 1965, is projected to drop to less than 2 percent per year between 1965 and 1980 (Fig. 9). Sorghum yields, recently increasing at a rate of nearly 6 percent annually, are projected to increase at just over 2 percent per year between now and 1980 (Fig. 10). For corn, the projected slowdown is less dramatic, with yield increases dropping from





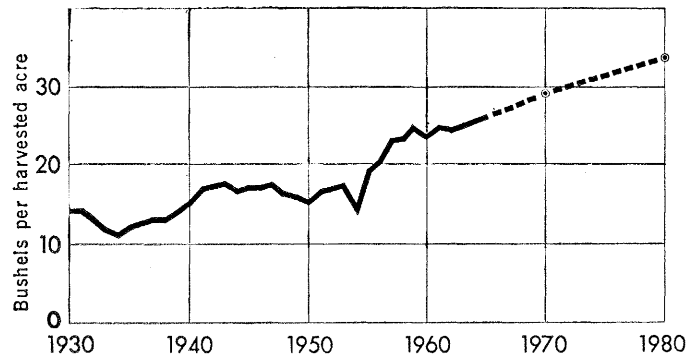


Fig. 7 (top left). Share of U.S. corn acreage planted with hybrid seed. [U.S. Department of Agriculture]

Fig. 8 (top right). S-shaped yield curve (schematic representation). [U.S. Department of Agriculture]

Fig. 9 (left). Wheat yields in the United States, with projections. Plotted as a 3-year sliding average. [U.S. Department of Agriculture]

about 4 percent to 3 percent. Per-acre yields of wheat and grain sorghum have apparently achieved their more rapid gains as the use of nonrecurring technologies becomes almost universal. In Platt's words (*7*), they may already be "past the middle of the S-curve."

The rate of increase could also be slowing down for certain crops elsewhere in the world. Rice yields in Japan may be a case in point. Yields were relatively static before 1900 but began to rise steadily shortly after the turn of the century. This rise continued until about 1959 (except for a brief period around World War II, and a period from 1949 to 1953, when production was disrupted by land reform). Since 1959, U.S. Department of Agriculture estimates (*8*) indicate, the rate of increase has slowed appreciably and, in fact, has recently nearly leveled off (Fig. 11). Whether or not this is a temporary plateau or a more permanent one remains to be seen. Interestingly, projections of per-acre rice yields made by the Japanese Institute of Agricultural Economic Research, using a 1958–1960 base period (*9*), did not anticipate the recent slowdown in the rate of increase in rice yields.

This recent leveling off of yields, however, may be caused by economic as well as technological factors. One key factor contributing to the very high yields obtained in Japan has been the intensive use of what was once low-cost labor. In recent years there has been a withdrawal of labor from rice production as rural workers have found more remunerative urban jobs. If economic development continues, it is unlikely that recent trends in labor costs will ever be reversed. Thus, it may well be that per-acre rice yields in Japan are approaching what is, in the immediately foreseeable future at least, a plateau.

A slowdown in the rate of yield increase seems also to be occurring for some of the grain crops in the Netherlands. This is not particularly surprising since yields there are already among the highest in the world. Further yield responses of some grains to the use of additional inputs, such as fertilizer, now seem limited by genetic constraints—the inherent ability of the plant to effectively use additional plant nutrients.

There are, on the other hand, some crops in the agriculturally developed countries which have not yet begun their upward advance on the growth curve. One of the major U.S. crops, the soybean, has thus far stubbornly resisted efforts to generate a yield-per-acre takeoff (*10*). The combination of near-static yields, on the one hand, and the very rapid growth in demand for soybeans, on the other, means that the necessary increases in the soybean supply are obtainable only through a rapid continuing expansion in the area planted to soybeans—an expansion which is steadily reducing the area available for other crops.

During the two decades since World War II, projections of increases in per-acre yields in the United States have invariably underestimated the increases actually achieved. This may be due in part to the yield-raising effect of idling large areas of marginal cropland during this period. There is now a risk that our faith in technology will cause us to overestimate future increases in yields if, in fact, the rate of yield increase ultimately slows as the sources of further gains in productivity diminish.

It is significant that the major sources of increased agricultural productivity—the use of chemical fertilizer; the use of improved varieties, including hybrids; the use of pesticides and irrigation—have all been known for decades, if not longer. The key question now is: Are there any sources of increased productivity in existence or in the process of development comparable to the traditional ones listed above?

The concept of the S-shaped curve is not new, but its implications for future agricultural production have not been fully explored. Although the S-shaped yield curve for crops is, at this point, still an untested hypothesis, it is, in Platt's words (*7*), "at least as plausible as the uncritical assumption that changes like those of the twentieth-century will go on forever."

Photosynthetic efficiency and research. The ultimate factor limiting crop output per acre is the crop's photosynthetic efficiency (*11*). Defined as the percentage of solar energy used relative to that which is available on a given area occupied by a particular crop, photosynthetic efficiency is always quite low, usually less than 3 percent. Density of plant population, actual position of the leaves on the plant, and temperature are key factors accounting for variations within this range.

In 1962, James Bonner of the California Institute of Technology stated (*11*):

> . . . the upper limit of crop yield, as determined by the factors that regulate photosynthetic efficiency, is already being approached today in those regions with the highest level of agricultural practice—in parts of Japan, of Western Europe, and of the United States.

Obviously, research into ways of increasing the upper limit of yield is needed. This increase could be achieved by developing plants which have greater photosynthetic efficiency or by improving present cultural practices so as to increase efficiency per acre, or by both means. The development of smaller and more efficient corn plants, along with reduction in the need for cultivation during the growing season, makes it possible to reduce the width between corn rows—a width that was initially determined by the width of a horse, in the age of the horse-drawn cultivator. The result is a dramatic gain in the number of corn plants per acre, and increased output.

More productive hybrid wheats have been developed, but they are still in the experimental stage and are not yet being grown commercially. Work on breeding new varieties with higher nutritive value—a potentially promising activity—is also under way. The adoption of a new technology takes time, even in an agriculturally advanced country. It took a quarter of a century for U.S. farmers to adopt hybrid corn (see Fig. 7). Hybrid grain sorghum, introduced in the early 1950's, required about a decade to become widely disseminated.

Both corn and wheat have been the subject of many years of research in the United States and other developed nations. Much less work has been done in rice. To help rectify this situation, the Rockefeller and Ford foundations established the International Rice Institute in the Philippines several years ago. The Institute devotes its efforts not only to the development of new varieties but to the whole range of cultural practices as well.

The need for such research is further emphasized by a recent statement by Harvey Brooks, chairman of the Committee on Science and Public Policy of the National Academy of Sciences (*12*):

> Future food production, even for domestic purposes, will be strongly dependent on the quality and direction of both the basic and applied research undertaken within the next few years. Most of the potential of past basic research has already been realized, and new knowledge will be needed even to maintain present levels of productivity.

Clearly, much more research is essential if we are to (i) get the underdeveloped nations to the yield takeoff point, and (ii) maintain the upward thrust of yields in the developed countries by postponing the final turn on the S-shaped curve (*13*).

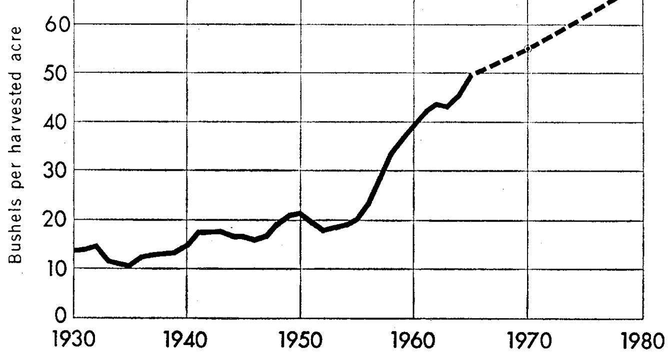
Research and Reality

Two groups of factors should be kept in mind in evaluating the real potential of research results for significantly increasing food output on a worldwide basis. The first group centers about the pronounced variations in natural resources and managerial abilities, which can lead to wide differences between record yields and average national yields obtained by individual farmers under localized conditions. The second group concerns the matter of costs and returns, which spells the difference between technical potential and economic reality.

Record yields versus average yields. It is often assumed that record yields attained on experimental plots can be easily and quickly translated into national average yields. Such is not, however, the case. Maximum yields obtained on experimental plots under closely controlled conditions usually far exceed those generally obtained in practice. Average yields of wheat in this country, for example, are far below those attained on experimental plots during the latter part of the last century. The same is true for many other crops.

Equally common and equally unwarranted is the assumption that all countries will eventually attain the average yield prevailing in the nation which now has the highest yield. Potential yield levels attainable by individual countries vary widely with variations in rainfall, temperature, soil types and topography, production costs, managerial abilities of farmers, and other factors.

Wheat yields in the United Kingdom now average about 60 bushels per acre (52 hectoliters per hectare) as contrasted with only 18 bushels per acre in Australia. This does not mean that wheat-production technology is less ad-



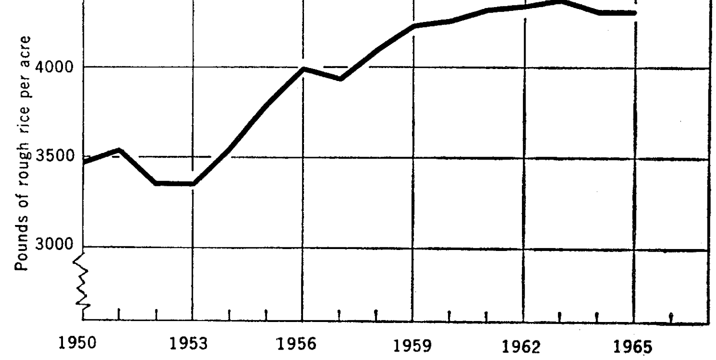


Fig. 10 (left). Grain sorghum yields in the United States, with projections. Plotted as a 3-year sliding average. [U.S. Department of Agriculture] Fig. 11 (right). Rice yields in Japan, 1950–1965. Plotted as a 3-year sliding average. [U.S. Department of Agriculture]

vanced in Australia than in the United Kingdom. The yield differences do reflect the difference between growing conditions in Australia, where rainfall in the wheat-growing regions averages 12 to 15 inches (30 to 38 centimeters) annually, and those in the United Kingdom, where rainfall may average 40 to 50 inches. Although wheat yields in both the United Kingdom and Australia may continue to rise, there is no reason to assume that the differences in yields between the two countries will narrow appreciably in the foreseeable future.

The average national rice yield in Japan is nearly four times that in India. A large part of this difference is accounted for by a much greater volume of inputs, including labor as well as modern practices and management. Not to be overlooked, however, is the fact that virtually all of the rice crop produced in Japan is irrigated, whereas only part of India's rice crop is irrigated. A large share of India's rice fields are rainfed, thus the yield levels attained depend greatly on the vagaries of the monsoon.

There are also very wide variations in yield within individual countries. Variations in corn yields within various corn-producing states in the United States are almost as pronounced as variations in corn yields between the various corn-producing countries of the world. Average yields in principal U.S. corn-producing states in 1965, for instance, varied from more than 90 bushels per acre in some states in the Midwest to less than 40 bushels in some states in the southern Mississippi Valley.

It is significant that the leveling off of rice yields in Japan has occurred at a time when average rice yields in the more productive and the less productive prefectures vary widely. Some individual villages in Japan obtain rice yields at least double the national average.

Per-acre yields obtained by individual farmers in the same area may vary even more than do those for various states or prefectures. It is often assumed that the performance of the best farmers can be emulated by all. There are and will continue to be some very basic differences in the innate capacities or motivations of farmers. There is no more reason for assuming that all farmers can or really want to attain a record yield of corn or wheat than to assume that all students can or want to become Harvard Phi Beta Kappas. The distribution of talent and motivation is probably at least as wide within the world's rural communities as in any other area.

Technical potential versus economic reality. The failure to distinguish between the technical potential for expanding food production and the economically profitable possibilities for doing so has resulted in confusing variations in estimates of future food production. The difference between estimates based on these two criteria is often very great. The earlier discussion of the experience in Japan—where rice yields seem to have leveled off in recent years—suggests the importance of economic relationships.

A recent reduction in milk production in the United States closely parallels the Japanese experience with rice yields. Through the early months of 1966, milk production in the United States was 3 to 5 percent below production in comparable months of the preceding year. At prevailing prices it was not profitable for dairy farmers to use some of the existing resources. During 1966, dairy farmers in New York State received scarcely 40 cents an hour for their labor (when allowance is made for interest on their investment), and farmers in Wisconsin received only 50 cents an hour. At a time when slaughter prices were high and there were many job opportunities to choose from—with a 5-day, 40-hour week in industry and a minimum wage of $1.25 per hour (*14*)—it comes as no surprise to learn that many dairy farmers liquidated their holdings and took other jobs. In order to help increase returns to farmers and expand milk production, the Department of Agriculture raised milk support prices twice during 1966, for a total increase of 23 percent.

Both prices received by farmers and costs of production must be taken into consideration in assessing potential increases in production. As farmers move up the per-acre yield curve, the point of diminishing returns is eventually reached. Additional costs begin to exceed additional returns. Thus it is unrealistic to expect farmers to produce up to the full technical potential.

Therefore, while many farmers can produce much more under a given technology, it is sometimes uneconomic, at existing prices and costs, for them to do so. If society is willing to pay higher prices—and it may have to some day—much greater production may be expected.

Conclusions

1) The worldwide demand for food will continue to be strong in the coming decades. Two forces—rapidly growing population and, in much of the world, rapidly rising incomes—are expected to result in increases in the demand for food even more rapid than those that have occurred during the past.

2) Conventional agriculture has assured an adequate food supply for the economically advanced one-third of the world. The challenge now is to assure an adequate food supply for the remaining two-thirds, where population is now increasing at the rate of 1 million people per week and where malnutrition is already widespread.

3) Economically feasible prospects for significantly expanding the world's area of cultivated land in the 1960's and 1970's are limited and largely confined to sub-Saharan Africa and the Amazon Basin. Even here, agronomic problems will limit the rate of expansion. When the cost of desalting seawater is substantially reduced—probably not before the late 1970's or early 1980's at best—it may become feasible to irrigate large areas of desert.

4) Given the limited possibilities for expanding the area of land under cultivation, most of the increases in world food needs must be met, for the foreseeable future, by raising the productivity of land already under cultivation. Food output per acre, rather static throughout most of history, has begun to increase rapidly in some of the more advanced countries in recent decades. All of the increases in food production over the past quarter century in North America, western Europe, and Japan have come from increasing the productivity of land already under cultivation. The area under cultivation has actually declined.

5) Achieving dramatic gains in land productivity requires a massive investment of capital and the widespread adoption of new technology. A similar effort must now be made in the less-developed nations if these nations are to feed their people. The most important single factor influencing this rate of investment is food prices, more particularly the relationship between the price farmers receive for their food products and the cost of modern inputs such as fertilizer.

6) In some of the more-developed countries where per-acre yields have been rising for a long time, there is

now evidence that the rate of yield increase may be slowing. Nonrecurring inputs may have made their maximum contribution to output in the case of some crops, pushing yield levels past the middle of the S-shaped logistic curve. Although this cannot be determined with any certainty, the possibility that the middle of the curve has been passed in some instances should be taken into account in viewing the long-term future.

7) If the rate of increase in yield per acre does in fact begin to slow in some of the agriculturally advanced countries, additional pressure will be put on the less-developed countries—which have much of the world's unrealized food-production potential—to meet the continuing future increases in world food needs.

8) Man has not yet been able to bypass the process of photosynthesis in the production of food. This dependence on photosynthesis plays a significant role in determining the upper levels of the S-shaped yield curve. Additional research is urgently needed to increase the photosynthetic efficiency of crops and to raise the upper levels of economically feasible yields.

References and Notes

1. I have previously examined these matters in some detail in "Man, Land and Food," *U.S. Dept. Agr. Foreign Agr. Econ. Rep. No. 11* (1963).
2. I have discussed this concept at length in "Increasing World Food Output," *U.S. Dept. Agr. Foreign Agr. Econ. Rep. No. 25* (1965).
3. For further discussion of this point, and the role that may be played by private industry, see L. R. Brown, *Columbia J. World Business* **2**, No. 1, 15 (1967).
4. As one leading agricultural economist recently stated, there is considerable evidence that in most low-income countries "technological advance requires a complementary input of labor" [J. Mellor, *The Economics of Agricultural Development* (Cornell Univ. Press, Ithaca, N.Y., 1966), p. 157].
5. The "nonrecurring" concept was introduced by Paul C. Mangelsdorf; (see 6).
6. P. C. Mangelsdorf, *Proc. Nat. Acad. Sci. U.S.* **56**, 370 (1966).
7. J. R. Platt, *The Road to Man* (Wiley, New York, 1966) [originally published in *Science* **149**, 607 (1965)].
8. Estimates published by the Food and Agriculture Organization show a continued increase in rice yields up until 1963–64, followed by successive declines in each of the three following seasons; see annual issues of *Production Yearbook* (Rome) and *Monthly Bull. Agr. Economics Statistics* **15**, No. 12, 26 (1966).
9. *Japanese Import Requirement: Projections of Agricultural Supply and Demand for 1965, 1970 and 1975* (Institute of Agricultural Economic Research, University of Tokyo, 1964), p. 84.
10. Soybeans cannot be commercially hybridized and show only limited response to nitrogen; see *The World Food Problem* (Government Printing Office, Washington, D.C., 1967), vol. 2, p. 197.
11. J. Bonner, *Science* **137**, 11 (1962).
12. *The Plant Sciences Now and in the Coming Decade* (National Academy of Sciences, Washington, D.C., 1966), p. iv.
13. A detailed discussion of the technical problems and issues faced in intensifying plant production in the developing nations is presented in *The World Food Problem* (Superintendent of Documents, Government Printing Office, Washington, D.C., 1967), pp. 215-233.
14. The minimum wage was recently raised to $1.40 per hour.
15. I am indebted to Dana G. Dalrymple of the U.S. Department of Agriculture for his suggestions and assistance.

NEWS AND COMMENT

NIH: Fountain Committee Issues Bitter Attack on Programs

In one of the bitterest critiques a congressional group has ever directed at a federal research agency, the House Government Operations Committee has charged the National Institutes of Health with a thick catalog of failures, ranging from "weak and ineffective central management" to administrative procedures that are "irresponsible, unscientific and contrary to the best interests of the academic community and the government." It has questioned the quality of research supported by NIH, has accused the agency of favoritism in the distribution of money, and has revived the charge that NIH is single-mindedly overfeeding research to the detriment of teaching and medical services.

These allegations were made on 22 October by the Committee's intergovernmental relations subcommittee, chaired by Representative L. H. Fountain (D–N.C.), who, since 1959, has been scrutinizing the affairs of NIH with a constancy, intensity, and, at times, hostility that are unique in congressional dealings with scientific affairs.

Despite nearly a decade of Fountain's surveillance, NIH has, in a sense, flourished, its budget having risen from $430 million in 1960 to over $1.1 billion this year. But, though the effects of Fountain's criticisms cannot be precisely measured, there is no doubt that the congressman has contributed significantly to effecting (i) a decline in NIH's financial rate of growth and (ii) the burgeoning of a paperwork thicket between the agency and its grantees. For, since Fountain started riding herd on NIH, the main consequence of his diligent diggings has been twofold: to help persuade his congressional colleagues that NIH has grown much too fast, and to persuade NIH that, in trying to reconcile science's free-form administrative ways with government's insistence upon precise accountability, it had better come out on the side of government.

In his dealings with NIH, Fountain has evolved a relatively simple and highly effective technique. With the threat of subpoena power giving his subcommittee access to virtually every bit of paper in NIH's files, his formidable staffman, Delphis C. Goldberg, who holds a Harvard Ph.D. in political economy and government, untiringly pores over the records; departures from prescribed form are carefully culled, and then a case—well documented and often damaging—is put together to support the contention that NIH is functioning as something of an extra-legal rogue in the federal hierarchy. Easily lost in the shouting and the ensuing shock is NIH's defense that Fountain is ascribing universality to a few departures from the rule book, and that, in any event, the scientific and medical success of NIH's billion-dollar operation should be the measure of performance, rather than NIH's score in abiding by every curlicue of administrative procedure.

Fountain's latest product, titled "The Administration of Research Grants in the Public Health Service,"* is far and away the most damaging of the three reports he has issued on NIH since 1961. And, in the absence so far of any formal response or explanation from NIH, it appears that Fountain and Goldberg have dredged up at least one

* Available without charge from the House Government Operations Committee, Rayburn Building, Washington, D.C.