Food Production: Technology and the Resource Base

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This article is a plea for instituting a massive program in agricultural science and technology. Such a program will be an investment and not an expenditure. Improved technology is the world's only hope of substantially increasing food production. Food can become an instrument for peace in international diplomacy. The emphasis should be on the enhancement of renewable resource productivity (food, feed, fiber, timber, fish, and wildlife). We can thereby add to, rather than subtract from, the resources of the earth. Enhancement of renewable resource productivity for food, feed, recreation, and industry must become a national commitment of top priority. The research challenge will be to minimize the nonrenewable resource inputs (land, water, energy, fertilizer, pesticides, time) and maximize the outputs.

Many authorities have recently addressed the issues of agriculture, population, and food supply (*1, 2*). Projections for agricultural productivity have appeared (*3, 4*). What are our production capacity reserves? Will there be enough food? Is food production of sufficient priority to warrant a doubling of agricultural research investment commensurate with that in other areas such as the biomedical? What technology reserves are left, and what can yet be created? To what extent can we change the resource base for food production with time and technology? Do we have sufficient nonrenewable resources (land water, energy, fertilizer) for all-out production? If so, what will be the cost-benefit and risk-benefit trade-offs? What will be the environmental impacts?

The need for a greater national commitment has been voiced by several members of Congress. A broad and objective review of the organization of agricultural research has been suggested (*5*). It is hoped that this would speed a needed reorientation essential for future food supplies. President Ford has requested an assessment of the problems of food production and malnutrition, and specific recommendations on how our research and development capabilities can best be applied to meet the challenge of our food supply. Currently the Environmental Protection Agency has a \$5-million contract with the National Academy of Sciences to review the extent to which regulatory decisions are based on input from science and technology. This appraisal is focused, in part, on the many social and political constraints recently imposed upon food-producing systems. An interest in food production and agriculturally oriented research on energy conservation and production has emanated from the National Science Foundation. There is also interest in renewable resource availability. The possible impacts of changing climatic and weather patterns and their effects on agricultural and renewable resource productivity are deemed sufficiently important for major review (*6*).

Projections made 3 to 4 years ago for food prices, agricultural income, productivity, food demands, and agricultural imports have been invalidated by a crisis in energy, fertilizer, and food precipitated by a fourfold increase in the price of imported oil, unprecedented demand from abroad, and adverse weather. The current pressing demand for food and other renewable resources—coupled with our lack of national commitment or of a program for food production with greater research input in a nation that supplies 86 percent of the world's surplus food—is a travesty of the times.

If food production is to be a national priority, it is not reflected by current and projected federal inputs into research and development. Five times as much is currently expended for research by the Department of Health, Education, and Welfare. R & D budgets for the Department of the Interior and the Environmental Protection Agency have risen more than 50 percent in the past year, accompanied by a modest increase of only 11 percent for the Department of Agriculture.

Scientific Frontiers: Crops

These frontiers have been emphasized recently (*7–9*). They will be repeated here only to underscore potentials. Average yields of major commodities are well below the records in productivity (Table 1). Gains in productivity of 100 percent are reasonable for all food crops in the tropics (*10*). New levels are achieved annually for some crops. Biological limits for productivity have not yet been realized nor delineated. New frontiers and research targets lie in achieving greater photosynthetic efficiency and inhibition of photorespiration. Genetic, physical, and chemical approaches all show promise. We need a commitment for a major investment in bioconversions of solar energy through the photosynthetic process. Most food crops capture only 1 percent, and usually less, of the sunlight that illuminates their leaves.

Enhancement of biological nitrogen fixation should first focus on fixation by legumes. A fivefold increase for soybeans following atmospheric enrichment with carbon dioxide has been recorded (*11*). Extension of natural or synthetic symbiosis to cereals and its domestication in such crops as wheat, rice, corn, and sorghum is a second research target of promise. A major discovery is the recent report (*12*) of a number of tropical grasses having a primitive kind of intracellular root symbiosis that will fix up to 1.7 kilograms of nitrogen per hectare per day. A third frontier in nitrogen fixation would be utilization of new catalysts that are effective in abiotic chemical fixation at ambient temperatures and atmospheres. This would greatly reduce costs and energy resource inputs.

Other promising targets for enhancement of crop productivity and reduction of resources input reside in improved water and fertilizer management. These include trickle or drip irrigation, leaking pipes, nonvariable root environments, foliar applications, and timely application of nutrients, often in combination with irrigation. The rapid spread and worldwide in-

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← *Triticale, first man-made grain* [*Courtesy Rockefeller Foundation, New York*]

Table 1. Average and record yields (1 bushel = 0.036 m^3; 1 acre = 0.405 ha; 1 pound = 0.45 kg).

Food	Average, 1974	Record	Record/ average
Corn (bushel per acre)	72	307	4.3
Wheat (bushel per acre)	28	216	7.7
Soybeans (bushel per acre)	24	110	4.6
Sorghum (bushel per acre)	45	320	7.1
Oats (bushel per acre)	48	296	6.2
Barley (bushel per acre)	38	212	5.6
Potatoes (bushel per acre)	420	1400	3.3
Sugar Beets (ton per acre)	19	54	2.8
Milk production per cow (10^3 pounds)	10.3	50	4.9
Eggs per hen	230	365	1.6

terest in trickle irrigation for high-value crops may be designated as a "blue revolution" (*13*). Predictable incremental increases of precipitation and snowpack in mountains from cloud seeding by aircraft now seem likely. The prospects are for as much as 2.5 centimeters of additional rainfall during the growing season in some drought areas (*14*).

New strategies for pest control continue to offer hope for reduction in costs, more effective pest management, and lessened use of chemical pesticides and consequent impact on the environment. Total pest management will include more resistant plant varieties, use of pheromones and juvenile hormone analogs, and environmental monitoring networks. All of these strategies are in their infancy.

Heretofore, biological methods for control of weeds have only been successful on individual weed species. The inhibition of growth of one species by chemicals released from another, known as allelopathy, offers the opportunity to control many weed species by incorporating such factors into crop species. Allelopathy has recently been demonstrated in cucumber, rye, and oats (*15*).

Additional possibilities for boosting crop productivity reside in protected cultivation, carbon dioxide enrichment, multiple and intensive relay cropping, reduced tillage, and chemical growth regulants (*8*). Mulch or no-till systems of agriculture continue to gain in prominence. The technique now appears to be especially applicable for conservation of difficult to manage, highly erodible tropical soils (*16*). Many studies now recognize the soundness of reduced tillage for enhancement of yield as well as for the conservation of soil, organic matter, water, and energy. Sugarcane ripeners (*17*) continue to show promise for substantial increasing of sugar yields per acre.

New crops and improvements in existing types offer immediate promise for increasing food production (*8*). Possibilities include the extension of heterosis to all cereal grains and legumes; breeding for specific yield components, processing constituents, plant architecture, and physiological processes related to yield (*18*); the creation of new industrial food and feed crops; and improvement of tree and other long-lived perennials in the tropics. The building of new food crop species, including their creation without recourse to sexual reproduction, is a possibility. Included is the production of haploid plants from tissue cultures of anthers or pollen grains. This would provide a source of true-breeding individuals (*19*). These techniques are designated by some as the new botany or test tube breeding.

Currently, progress with new crops includes that with triticale, a synthetic species derived from the cross of wheat and rye, which has been developed with great success (*20*). It now seems certain that triticale will compete successfully with other cereal grains (*21*). Possibilities of new crop species from crosses of wheat and barley and of barley and rye are being explored (*22*). A sorghum mutant that produces high-lysine grain with normal head and plant phenotypes has been achieved by treatment of seed with diethylsulfate, a chemical mutagen (*23*).

A concerted effort toward improvement of nutritive values of seed proteins —both for cereal grains and legumes— would have an immediate payoff in improved health, nutrition, and capacity to meet world food needs (*24*). There is now substantial evidence (*25*) that if adequate calories are provided through conventional food sources, particularly the cereal grains, and if the proteins of these food sources are improved, there will be no major food protein problem. Emphasis should be on the major food crops (*26*): rice, wheat, maize, barley, millet, potato, root crops (sweet potato, cassava, and taro), and the edible legumes (common bean, soybean, cowpea, mung bean, pigeon pea, chick pea, and peanut). The aim would be to improve the biological value of the protein (Table 2).

Genetic, climatic, and chemical vulnerabilities of major crop varieties persist and are often precipitated by modern efforts to build otherwise superior cultivars. The ever-increasing demands for productivity often work at cross-purposes with the need for variability in the genetic base. Genetic vulnerability to disease epidemics has received national attention (*27*). Some efforts are under way for its correction. Many horticultural crops, having the most vulnerable of all cultivars, need special attention.

Of equal concern is climatic vulnerability. It is exemplified by winter injury of wheat, widespread destruction from drought, root rots of beans, injuries from frosts in late spring and early fall, and weather-induced susceptibilities to insects and diseases. The impact of changing climatic patterns points to the priority of selecting crop varieties having a broad adaptive base to wide differences in moisture and temperature. Improved usage of favorable growing areas could also increase the food supply (*28*).

Scientific Frontiers: Livestock

Animals cannot be ignored if one is to consider seriously the food-population-environment issue. They may be providers for the human population or directly competitive with it, as in the case of pets (cats, dogs, and horses) (*29*).

There are an estimated 100 million cats and dogs in the United States. They compete directly with people for food. The birth rate is 3000 per hour compared with 450 human babies. The annual pet food bill is $2.5 billion— six times that spent on baby food. Of the total, $1.5 billion is spent on dog food alone (*30*). In addition to the urban problems caused by dog feces and urine and dog bites, wild dogs cause a $5-million cattle loss each year. The cost of pet health care approaches $5 billion and is directly competitive with veterinarian services for farm animals. There is little interest among the new crop of veterinarians to serve cattle, swine, and chickens when cat, dog, and horse hospitals are far more remunerative (*31*).

Horses for recreation are the most rapidly expanding group of large animals in the United States. The estimated increase is 10 to 15 percent per year. No accurate inventory is available. There are now at least 8 million. They are nonruminant herbivores, and while they consume much roughage, they, along with cats and dogs, compete directly with man for grain.

Domestic and global demands for grain have raised serious questions as to whether we can continue the massive diversion of resources to pets, beef and dairy cattle, chickens, and pigs. We will have to feed them differently. The rumen of ruminants is essentially a fermentation vat. High grain rations are not necessary in beef and dairy production. Also, much of the grain, particularly corn, sorghum, and barley, fed to livestock is not acceptable for human food.

Nonprotein nitrogen sources (ammonium solutions, anhydrous ammonia, and urea) can be added to the whole chopped corn plant and other forages at the proper stage of maturity (that is, when they contain 30 to 37 percent dry matter). This provides a ration of energy and protein that is completely adequate for finishing beef cattle (*32*) and all dairy cows except very high producers (*33*). Latest estimates are that up to 500,000 tons of urea and ammonia solutions are added annually to corn silage and other roughages as protein supplements. This represents a replacement for several million tons of soybean meal.

Only 10 to 15 percent of the nation's corn crop is currently harvested as silage. Vast energy resources of the nation's number one crop—40 percent of the total crop—are dissipated annually. Under some conditions, animals as well as grain can represent storage mechanisms for food.

A ruminant livestock industry will continue to flourish. These animals, however, must become increasingly greater converters of plant resources (protein and energy) not usable directly to man. It is also only through ruminants that a substantial segment of our renewable resources can be converted to food for man (*34*). One of the greatest of research challenges is to increase the efficiency of this conversion. Control of rumen fermentation of the cow to optimize the end products may be an ultimate goal (*35*).

Increasing allocations of feed grains for human food pose problems for swine and poultry. Here, also, alternative sources of protein and energy must be sought. Serious consideration should be given to technology for upgrading the protein content of forages and agricultural wastes, including their processing or fermentation by bacteria, protozoa, fungi, nematodes, and arthropods. Nonconventional foods or feedstuffs such as single cell protein, leaf protein, fish protein concentrates, and sterilized, dehydrated excreta of poultry should first be evaluated as poultry and swine feed supplement rather than as human food. Recycling of poultry excreta (anaphage), which contain significant energy and protein, can help solve a pollution problem, alleviate the economics of a crucial feed grain supply, and aid in the survival of a viable animal agricultural industry (*36*).

Table 2. Food grains, ranges of protein and lysine. The assistance of F. C. Elliott with this table is gratefully acknowledged.

Crop	Protein (%)	Lysine (% in protein)
Corn	8–15	1.6–4.8
Wheat	8–20	1.7–4.1
Rice	6–15	1.9–4.4
Triticale	10–19	2.4–5.5
Sorghum	8–20	0.9–3.3
Barley	9–27	2.0–5.3
Oats	13–26	3.0–5.0

There are at least four frontiers of technology for improvement of crops for livestock: higher-yielding types, increased nutritive values, improved harvest techniques, and the merger of production and utilization systems. Forages provide more than two-thirds of the feed units consumed by ruminants (*37*), that is, 75 percent for beef cattle, 65 percent for dairy cows, and 90 percent for sheep. Improvement of corn and sorghum for forage as well as for grain should be an immediate goal.

Both urgency and opportunity exist for developing new types of forage crops suitable for range and pasture on erosive landscapes in arid and semiarid areas of the world (*38*). Such forage crops and shrubs must produce large quantities of material during the short growing (rainfall) seasons and then remain as a palatable hay which could be harvested by grazing animals over an extended harvest season. Deep-rooted legumes would have merit. There are also weedlike plants, such as *Amaranthus edulus,* which have high photosynthetic efficiency, are a good source of leaf protein, and make rapid growth even under drought stress.

Current harvest technology with alfalfa results in a respiratory loss of up to 500 pounds of digestible protein and 350 pounds of sugar per acre during the drying process. Highly valuable food nutrients already fixed by photosynthesis and nitrogen fixation are lost back to the atmosphere. Development of improved processing is feasible, and the payoff would be great (*39*).

There are other frontiers for advancements of productivity with livestock (*7, 40*). A new high of 50,759 pounds of milk in 365 days was achieved in 1974 by Mowrey Prince Corinne, a Holstein cow in Pennsylvania. The lifetime production record of 335,000 pounds is held by OR-WIN Masterpiece Riva of Adrian, Michigan. Increased rates of gain are being registered for crossbred beef cattle. Litter size in swine can be substantially increased (84 percent above the national average) by alterations in the natural hormone balance at the time of implantation. Swine have broken the "2 pounds of feed per 1 pound of gain" barrier. The number of lambs and frequency of lambing in Finnish Landrace sheep and in crosses between this breed and domestic ones are two to three times higher than average performance heretofore. Twinning in beef cattle could be a reality in 10 years.

A vaccine for Marek's disease, first introduced in 1971, achieved a record for speed of adoption of a new technology in the history of agricultural science. The treatment was so effective in reducing losses of laying hens that within a few months after its introduction, there was a resultant all-time low in egg prices.

A new frontier has emerged for fertility control in cattle and horses (*41*). Prostaglandin $F_{2\alpha}$ effectively controls estrus and greatly improves efficiency of artificial insemination. Possible ovulation control with prostaglandin $F_{2\alpha}$ may permit commercial artificial insemination in some herds where detection of estrus is difficult or impossible.

There are also opportunities for improved animal health through new technology. Prenatal immunization has tremendous potential. There could be no greater impact on the production of disease-free cattle than to have them immunized at the time of birth. Such a concept is well within the realm of possibility (*42*).

The Resource Base

Time and technology can change the resource base. For food-producing systems this base consists of land, water, energy, fertilizer, pesticides, capital, credit, machinery, and technology. One could also add climate or weather as the most determinant factors of all (*6*). Solar energy and atmospheric nitrogen are considered renewable resources and essentially unlimited. Production capacity reserves are delineated by these resources. The ultimate objective is enhancement of production of renewable resources with the least expenditure of nonrenewable. This ushers in a new era for the biological sciences and for agriculture (*43*). There is, however, a concern for the availability of the nonrenewable resource inputs required as well as for the costs of these resources.

Land comes first. There had been a declining dependency on land until the past 2 years, during which government set-aside acreage has disappeared (Table 3). However, one should not assume or conclude that there is no additional acreage to cultivate. Best estimates indicate that there is at least twice as much land (7.8 billion acres) physically available worldwide for crop production as the 3.4 billion acres presently used (*3*). Most of the available land, however, lies outside densely populated areas. Alaska's potential agricultural land, for example, exceeds the state of Iowa in area. Bringing new land into production requires expenditures of resources and labor. That of greatest utility is already being cropped.

Land productivity may be improved as well as depleted by cropping. The original croplands of western Europe and Japan were vastly inferior to what they are today. With incentives to invest to improve land, the productive capacity of this resource could be greatly increased in most parts of the world.

The food-producing potential, the production capacity reserves, of the land and water resources can be achieved only by commitments of energy fertilizers and technology (*2*). India has almost the same acreage (350 million) under cultivation as the United States. With a comparable soil and water potential, its crop is only two-fifths as much. Fertilizer, technology, water, pesticides, and incentives make the difference. Preferential use and preservation of land for food production has been given little mention or priority by the annual reports of the Council on Environmental Quality. The latest (*44*) is no exception.

Water is a second important resource. It is usually inseparable from that of land, and for purposes of irrigation may be a renewable or nonrenewable resource. Irrigated cropland constitutes about 15 percent of the total cultivated land on a global basis (*3*). This irrigated land, however, produces up to 30 percent of the food for mankind. As a resource for increasing production, it has become increasingly important with the advent of new high-yielding varieties (the Green Revolution), and with the introduction of any other technologies, including fertilizer usage, that enhance yield. Five nations—People's Republic of China, India, United States, Pakistan, and the Soviet Union—have more than 70 percent of world's irrigated area, with 40 percent in China alone.

Trickle or drip irrigation, the one significant development in water management during the past 10 years, is still confined largely to high-value crops in arid regions. Its growth, however, has been phenomenal (*13*). All systems for irrigation require an energy input. Most of them have a direct fossil fuel requirement. The energy needed for the low-pressure drip system is the least.

Technology to improve efficiency in water utilization by plants is of high priority. There would be a quick payoff in crop productivity and conservation of a valuable and limited resource. Development and adoption of new irrigation procedures with soil and water management should be sought. Water movement is a continuum from the soil through the plant to the atmosphere. The plant's expenditure of energy in water uptake and the water requirement itself are variables that can be altered. Reduced tillage and the use of chemical regulants that control water loss and modify requirements should be evaluated. Monitoring of water application to crops should become essential along with new technologies to reduce losses from deep percolation and surface runoff (*9*).

The carrying capacities of range and pasture involve a consideration of both land and water resources and type of forage available. Current livestock grazing capacity in the United States is 213 million animal unit months (AUM's). One AUM is sufficient dry forage to maintain one 1000-pound cow and a calf or five sheep for 1 month. It is considered economically feasible to double the carrying capacity to 426 million AUM's. Maximum productivity could raise this figure to 1700 million AUM's (*45*).

Food production research strategy of the past has been to grow two blades of grass where one grew before, irrespective of resource input. Today we have a problem—the cost of food, which has increased precipitously. If costs of all inputs into food production had not changed, there would be no problem. This, however, has not been the case. A dramatic change in cost and availability of energy and all of its inputs (fertilizers, pesticides), has occurred (Table 3). The problem we now face is not only to increase the absolute levels of food, feed and fiber, but do it with the most efficient utilization of resources, especially those that are nonrenewable. This magnifies the complexity of research strategy and management (*9*).

Energy is now the focal point. Contrary to many popular reports, production of the major food crops—cereals and legumes—resulted in 3 to 5 calories of food and feed energy for each calorie consumed. Most food-producing systems, even with modern technology, give a positive energy return. This is because plants are the primary harvesters of free solar energy (*7*). However, vast amounts of energy are expended in food processing, handling, storage, transportation, and food preparation. It is estimated that our present total food system expends at least five units of fossil energy for each unit of food energy made available (*46*). One study suggests that 6 to 7 calories of fuel energy are expended for each calorie of food energy produced (*47*). Farming itself, however, collects more energy than it consumes and could, as well, provides some of our primary fuel needs (*46*). Hydrolysis of waste cellulose could add enormously to our food and fuel resources (*48*). Man has, through the ages, evolved a strategy for manipulating the plant and its environment to maximize solar energy conversion into food, feed, and fiber. It is called agriculture. The farmer was the first "ecological engineer." The challenge now is to reduce energy inputs into food production systems without jeopardizing productivity or energy output. Some promising agricultural technology approaches are itemized in Table 4.

Studies of energy inputs into alternative agricultural production techniques are crucial. Calculations should be made of the actual food energy of crop output per unit of actual energy input. Low energy production techniques for the major food crops should be pursued on a national and global scale (*49*). These crops include rice, wheat, maize, sorghum, millet, rye, barley, cassava, sweet potato, potato, coconut, banana, common mung bean, soybean, cowpea, chick and pigeon pea, peanut, sugar beet, and sugarcane. These crops furnish more than 90 percent of the food consumed and occupy three-fourths of the earth's cultivated land.

There is an urgent need for a "Manhattan Project" on the bioconversion of solar energy. It is renewable. It is unlimited. It is nonpolluting. A major research investment for enhancement of photosynthetic efficiency in carbon dioxide fixation by conventional agricultural crops would provide ample food, feed, and fiber for an ever-growing and affluent society

Fertilizer as a resource in crop productivity is no longer a luxury item for high-value crops. Thirty to 40 percent of the increased agricultural productivity in the United States in recent years is directly attributable to increased fertilizer usage (*50*). For developing nations it may be 50 percent (*51*). A fourfold increase in the cost of imported oil has precipitated a threefold jump in the price of nitrogen fertilizer. Increased food and feed prices are partially compensating for the additional cost of fertilizer. Recent shortages of fertilizer, arising from a rapidly rising demand (which could be a good sign), have intensified difficulties of expanding crop production, especially in developing countries. Existing food shortages will be compounded since there is neither oil nor fertilizer. Limited supplies and high prices for both have slowed food production in both Bangladesh and India (*3*). New high-yielding grain varieties have brought new demands for fertilizer, pesticides, and water. As fertilizer is added, the new types give a much higher grain response per increment of fertilizer at all comparable dosage levels (*10*). The rapid acceptance and high performance of the "new seeds" is conditional upon added resource input, of which fertilizer and water are the most significant (*52*). A tragedy of our time, with fertilizer shortages and high prices, is that developed nations with generally adequate food and distribution systems can bid fertilizer away from developing nations where food supplies are marginal if not critical (*3*). Also, the greatest return per increment of fertilizer input would probably be achieved in the most deficient areas (*51*). Currently 86 percent of the world's fertilizer is used in developed countries with only 39 percent of the world's population.

Table 3. Some major agricultural and food data, United States 1971 to 1974; Est., estimated. The assistance of J. N. Ferris in the preparation of this table is gratefully acknowledged.

Data	1971	1972	1973	1974 (Est.)
Idle land (10^6 acres)	37	62	20	0
Grain stocks (10^6 tons)	55	74	46	30
Agricultural exports (10^9 dollars)	8.5	13	21	22
Cost of NH_3 fertilizer (cents per pound)	11	14	30	33
Yields of corn (bushels per acre)	88	97	91	72
Milk production per cow (10^3 pounds)	10	10.3	10.1	10.3
Price of corn (dollars per bushel)	1.08	1.57	2.55	3.20
Price of wheat (dollars per bushel)	1.60	1.76	4.00	4.25
Price of soybeans (dollars per bushel)	3.00	4.37	5.70	7.25
Price of sugar (cents per pound)	12	16	17	60
Wholesale price index of fuels and related products and power (1967 = 100)	114	119	134	225
Income for food (percent)	15.7	15.4	15.9	16.7
Enrollments, colleges of agriculture (10^3 students)	60	65	73	82
Hatch payments to states for agricultural research (10^6 dollars)	60	63	67	68
Gross agricultural income (10^9 dollars)	61	70	97	102

Table 4. Some agricultural technology approaches to energy production and conservation.

- Production of energy
  - Enhancement of photosynthetic efficiency
    - Improved plant architecture for better light reception
    - Genetic selection for greater efficiency
    - Chemical inhibition of photorespiration
  - Conversion of crop and animal wastes and by-products
    - Microbiological degradation of cellulose to glucose
    - Generation of methane
    - Use as feed supplements for livestock
- Conservation of energy
  - Enhancement of biological N_2 fixation
  - Reduced tillage
  - Greater utilization of forages in the nutrition of ruminants
  - Integrated control of pests
    - Resistant varieties
    - Biological controls
    - Allelopathy
    - Aerial application of pesticides
  - Reducing energy input into food processing
    - Aseptic processing and storage
    - Compressed foods
    - Canning versus freezing
  - Improved grain drying
  - Development of crop cultivars less dependent on water and fertilizer
  - Development of crop cultivars more efficient in uptake and utilization of fertilizer
  - Development of animals more efficient in conversion of feed to food
  - Reduction of amount of fat in animal carcasses used for food

Table 5. Time for adoption of new technology (95 percent acceptance).

Examples	Interval	Time (years)
Vaccine for Marek's disease	1971–1973	2
Mechanical harvesting of grapes	1968–1971	3
High-yielding rice, Colombia	1967–1974	7
Hybrid corn, Iowa	1933–1940	7
Monogerm sugar beet seed	1956–1965	9
Mechanical harvesting of cherries	1961–1973	12
Hybrid sorghum	1955–1970	15
Hybrid corn, United States	1933–1969	36
High-yielding wheat, India (50 percent adoption)	1967–1973	6
High-yielding rice, Philippines (50 percent adoption)	1967–1973	6

Two problems are posed. Recovery of applied fertilizer nutrients by plants is only about 50 percent for nitrogen and 30 percent for phosphate (*50*). This is notoriously low for a resource so important. Second, a major research investment is needed, comparable to that suggested for enhancing photosynthetic bioconversion of solar energy. Maximization of biological nitrogen input—on site—into food-producing systems must be pursued as an alternative to the use of chemically fixed nitrogen requiring an enormous fossil fuel input.

Conclusions

Despite a growing population and increasing demands of that population for improved diets, it appears that the world is not close to universal famine (*3, 53*). There is enough food now produced to feed the world's hungry (*54*). That people are malnourished or starving is a question of distribution, delivery, and economics, not agricultural limits. The problem is putting the food where the people are and providing an income so that they can buy it.

As to the future, there are clouds on the far horizon. Only increased scientific and technological innovation, coupled with a change in human behavior and in national policy with regard to increased investments in agricultural research, can avert a growing food and population crisis. Only scientists develop new technology. Only farmers produce food. Motivation and incentives are important both for scientific discovery and food production.

Agricultural research is also a process. There is no finite beginning or end. It is a continuing search to unravel mysteries.

We must force the pace of agricultural development, but technology must be tailored to local conditions. This can be done by scientists who also know how to farm. Individual dedication and sustained government commitments are important.

Rapidity of information transfer and of acceptance of technology is also crucial (*55*). There is a wide gap between progress in research and the point of application for human benefit (Table 5). What accounts for the vast time differences in rapidity of technology acceptance? The current avalanche of new knowledge coupled with problems of food, feed, and fiber supplies, and issues of availability, preservation, protection, renewability, and costs of resources should bring to the front the urgency of rapid information transfer and reassessment of information systems for agricultural and other renewable resources.

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