

Food Production, People, and the Future

Sylvan H. Wittwer

Solutions to the world food problem seem more common today than the problems themselves. The issue is not one of agricultural production capability. There was never a greater opportunity for food abundance. The exploitation of that opportunity, however, was never more vulnerable to the uncertain responses of human political institutions. There must be the political will to produce food. The USA and the world are becoming increasingly susceptible to this constraint.¹

Assuring our food supply is also more than production. It involves post-harvest handling, processing, storage, and consumer use and acceptance. There is enough food now produced to feed the world's hungry. Today we have more food per capita than twenty years ago. That people are malnourished or starving is a question of food distribution, resources and economics, not agricultural limits. The problem is delivery. It's putting the food where the people are, and providing an income so they can buy it.

Currently, hysterical campaigns are being waged against population growth. An expanding population is declared the greatest threat to mankind.² Americans have been persuading themselves, but not the world, that man is overrunning the earth. Little can be done in the immediate future to reduce population growth, short of

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Sylvan H. Wittwer is director of the Michigan State University Agricultural Experiment Station, assistant dean of the College of Agriculture and Natural Resources and professor of horticulture at Michigan State University, and chairman of the Board on Agriculture and Renewable Resources, Commission on Natural Resources/National Research Council/ National Academy of Sciences.

¹D. W. Hopper, "To Conquer Hunger: Opportunity and Political Will," Second Annual Address, John A. Hannah Lecture Series in International Development, Michigan State University, 16 May 1975.

²Russell W. Peterson, "The Quest for Quality of Life," *BioScience* 25 (1975):166-71.

catastrophic events such as earthquakes, famine, pestilence or war. These are either uncontrollable or undesirable alternatives.

I am optimistic about man's capability of feeding himself, now and in the foreseeable future. How many of the 1.5 billion people at the beginning of this century would have believed the earth could have now absorbed 4 billion?

We often speak and write as if malnutrition, famine, and starvation are new afflictions besetting the human race. They've always been with us, and more acutely so in the past than at present. A worldwide communications network of visuals and words, now brings home to us daily the reality and at times the unreality of it all.

I totally reject the concept of "triage" or the "lifeboat ethic."³ This philosophy states that we cannot possibly save all mankind from starvation, and we have to decide now who is expendable. It is morally unacceptable, politically unrealistic, economically unsound, ethically unthinkable, and realistically unnecessary if one gives any recognition to human creativity and the management of resources.⁴

The immediate solution lies in all-out food production, improved nutrition, and education. The victory has to be an agricultural one. It will take a Herculean effort. "We will have to find in the next 25 years, food for as many people again as we have been able to produce in the whole history of man till now."⁵

There are four good reasons for increased emphasis on food production in the United States. First, the humanitarian—assist starving peoples overseas. This has become a tradition and legacy of America. Secondly, it will help reduce current worldwide unrest, anxiety, and tensions. Thirdly, it will help keep food prices reasonable for everyone. Finally, it is good business to maintain a favorable balance of payments in international trade. During 1975, the USA produced 92 percent of the world's surplus food and had an agricultural export return of over \$23 billion (Table I). The prospects are that food dependence on North America will continue.⁶

FOOD PRODUCING TECHNOLOGIES — AT HOME AND ABROAD

U. S. research and technology have developed an agriculture which is capital-management-and-energy intensive. There is emphasis on

³Garrett Hardin, "Living on a Lifeboat," *BioScience* 24 (1974):561-68.

⁴D. E. Hathaway, "The World Crisis—Periodic or Perpetual?" Paper presented at the Twenty-fifth National Public Policy Conference, Clymer, New York, 11 September 1975.

⁵J. Mayer, *Proceedings of the International Crop Productivity Conference Research Imperatives*. Harbor Springs, Michigan, October 20-24, 1976. Michigan State University Agricultural Experiment Station and C. F. Kettering Foundation.

laborsaving technology. This may not be what the rest of the world wants. It may not continue to be the best for us. Unemployment, inflation, and food needs are global issues. Partial resolution of these problems may come from food-producing technologies that are labor intensive with production maintained at high levels, and with minimal input of capital, management, and the nonrenewable resources of land, water and energy. Such technologies must also be nonpolitical.

Thus far we have given little attention to research and development in these areas, but they do exist. A good example is the production of hybrid cotton in India where tens of thousands of workers are required to hand pollinate the flowers, but yields are doubled.⁷ Ultralow-volume knapsack sprayers for pest control in agriculturally developing countries; the production of short statured wheat varieties in Pakistan and the Punjab of India; multiple cropping systems in the tropics; and reduced tillage and surface interseeding of crops in temperate zones are other accomplishments.

A prime example of a food producing system that is labor intensive, high producing and with a minimum of resource, capital and management input is the home food garden.⁸ Vegetable and fruit crops are seldom included in world food statistics. Yet they can, and do, contribute significantly to food supplies. The science and art of food production in home gardens should be exploited. Production is at the site of use. Wastes and by-products can be utilized as fertilizer. Energy expenditures from fossil fuels are minimized. Marketing, packaging, and transport problems are eliminated. High production and top quality are possible. Home gardening can be the most intensive food production system on earth. Vegetables (beans, peas, potatoes, cucurbits, root crops, tomatoes, onions, crucifers, and sweet corn) are principle sources of calories, proteins, vitamins, and minerals for hundreds of millions of people.

FOOD SOURCES

A consideration of the world food problem must include thought as to what food is to be provided for whom. If the world's population is to be fed, what will it be fed with? It will likely be that which people are familiar with.

⁷S. C. Sharma, "Impact of Cultivation of Hybrid Cotton on the Economy of Indian Farmers," Synopsis of a Seminar, 25 October 1975, Division of Agronomy, Indian Agricultural Research Institute, New Delhi.

⁸Michigan Agricultural Experiment Station, "Science and the Home Garden," *Science in Action*, series no. 28, 1975.

When it comes to human nutrition there are issues of flavor, appearance, and acceptability. Someone is going to have to eat what is produced. Dietary habits of people are not changed easily or quickly. The primary effort in food production for the immediate future must be directed toward conventional food crops, not the unconventional.⁹ Conventional food and feed crops serve as the primary food sources for both people and the livestock products consumed by man.¹⁰ Chief among the food crops are rice, wheat, maize, soybeans, millet, barley, oats, rye, sorghum, field beans, chick peas, pigeon peas, peanuts, cassava, potatoes, sweet potatoes, sugar beets, sugarcane, coconuts and bananas. Fruits and vegetables, processed and fresh, add personal enrichment and joy in eating and provide essential dietary nutrients. Hay and pastures provide most of the feed units for cattle and sheep.¹¹

There is now the strong suggestion that the world's food problem is not one of protein deficiency but caloric adequacy. If sufficient calories are provided through conventional food crops, and the biological values of the proteins of these same crops are genetically upgraded, there should be no protein problem.¹² Eighty percent of the people in India are vegetarians—they don't eat meat. The dietary merits of a vegetarian diet based on new improved cereal grains and legumes should be experimentally evaluated. Cereal grains alone account for 60 percent of the calories and 50 percent of the protein now consumed by the human race.

STABILITY OF PRODUCTION

Variabilities in the yields of food crops and in livestock production from year to year and area to area are principle causes of food shortages and surpluses. Weather is the most determinant factor in food crop productivity. Production stability at high levels can be achieved only as environmental stresses are minimized. Season to season weather variations are of much greater significance than any identifiable long-term climatic changes.¹³

The year 1975 was a classic example. India, with favorable climate and rainfall produced an all-time record crop of 115 million tons of

⁹University of Wisconsin. Papers from a Workshop on Unconventional Sources of Protein, Madison, Wisconsin, 22 April 1975.

¹⁰National Science Foundation—Research Applications Directorate, *Protein Resources and Technology—Status and Research Needs*, NSF RA-T. 75-037, 1975.

¹¹Harlow J. Hodgson, "Forage Crops," *Scientific American* 234 (February 1976): 61-75.

¹²University of Wisconsin, Papers on Unconventional Sources of Protein; R. G. Hansen, "An Index of Food Quality," *Nutritional Reviews* 31 (1973):1-7.

¹³The Rockefeller Foundation, *Food Production, Climate Change, and Interstate Conflict*. Report of an International Conference, Bellagio, Italy, 9-13 June 1975.

food grains. The USSR by contrast, had a dismal failure with an estimated 135 million tons of grain compared with a projected hope of 210. Not since the days of Khrushchev have the Soviets had such an agricultural disaster. Meanwhile, the USA produced a record corn and wheat crop in 1975. A drought in the U.S. corn belt during 1974 resulted in production that was more than 20 percent off in yields per acre of corn, wheat, soybeans, and sorghum.

Decreased vulnerability of crops to weather uncertainties must be sought. Stability of food production at high levels should be a global research imperative. It could be improved by nitrogen self-sufficiency; identification of aspects of photosynthesis which limit CO₂ input; innovative water management; an understanding of the mechanisms of senescence; improved pest management systems; and for both crops and livestock the ability to predict extreme weather events at crucial times.

Little research has been done to optimize the use of limited water resources in crop production. Over one half billion people live in the semiarid tropics. These are areas frequented by violent and unpredictable storms. The goals are the development of improved water management practices, and crop varieties less vulnerable to the weather. An international agricultural research center has been established for this purpose.¹⁴

There are current anxieties as to the price of food and its adequacy. The impact of weather, and a rising population of increasing affluency coupled by a depletion of world stocks of grain have precipitated an instability, volatility, unpredictability, in the price of corn, wheat, soybeans, rice, sugar, beans, potatoes, beef and pork never before experienced.

Only farmers produce food. They will do it only if there are economic and other incentives. Farmers in the United States and throughout the world now face numerous and ever mounting numbers of economic, social, political, and environmental constraints and disincentives to food production.

The principle of free enterprise must prevail in American agriculture. The family farm is the most efficient food producing system the world has ever known. Corporate agriculture, in spite of the great visibility recently attached to it, has not met with resounding success in the USA, nor has it worked abroad. The Soviets with their state and collective agricultural enterprises have tried for 40 years to

¹⁴International Crops Research Institute for the Semi-Arid Tropics, *Annual Report 1973-74*, Hyderabad, India, 1975.

develop an efficient food producing system. Free enterprise with opportunity for profit is nonexistent in the USSR. Producing food is more than a factory operation. In addition, the Soviet Union has vast agricultural areas that are marginally too cold or too dry for stable crop production at high levels. The Soviets cannot consistently feed themselves.

FOOD PRODUCTION RESEARCH

If food production is important, it's not reflected by current investments in research. The 1977 projected federal research and development budget assigned to the United States Department of Agriculture is approximately \$0.5 billion. This is not on par or even close to that currently projected for defense (\$9.5 billion), energy (\$3 billion), space (\$3.5 billion), or health, education, and welfare (\$2.5 billion).

A recent National Research Council report states that crop surpluses, political pressures from commodity groups, budgetary reductions, and emphasis on immediately applicable information have resulted in a formerly substantial basic research effort in the USDA-Agricultural Research Service and the State Agricultural Experiment Stations, to virtually disappear. "Fundamental research undergirding food production has languished for two decades."¹⁵

As a nation and as an agricultural food and nutritional research community, we have been guilty of gross neglect in the very areas that hold the keys to crop and livestock productivity. The United States is no longer the leader in fundamental research on some of the biological processes that control the productivity of renewable resources.

Our agricultural technology system has been designed to support research at both ends of the applied-basic research spectrum, but not in the middle. This was the stimulus for the Michigan State University Agricultural Experiment Station with its applied-mission oriented background to join forces with the basic research scientists of the Charles F. Kettering Foundation in sponsoring an International Conference on Food Crop Productivity, October 20-24, 1975 at Harbor Springs, Michigan. The *Proceedings* of this conference relate to six biological process areas that control and limit food crop production.¹⁶

¹⁵National Academy of Sciences, *World Food and Nutrition Study, Enhancement of Food Production for the United States*. Board on Agriculture and Renewable Resources of the Commission of Natural Resources of the National Research Council.

¹⁶Michigan State University Agricultural Experiment Station and the C. F. Kettering Foundation, *Proceedings of an International Conference on Crop Productivity Research*

The focus for many new technologies should be mission oriented basic research.

NEW TECHNOLOGIES - CROP PRODUCTION

The resource base can change with time and new technology. Expanded efforts for greater photosynthetic efficiency, biological nitrogen fixation and unconventional approaches to plant breeding would literally add to the resources of the earth. Photosynthetic carbon dioxide fixation and biological nitrogen fixation are the two most important biochemical processes on earth. Photosynthesis is the source of all carbohydrates and calories consumed by man and the fossil fuels he is now exploiting. Biological nitrogen fixation provides the raw products for protein synthesis. These processes are nonpolluting. They are renewable. No limits can be ascribed as to what might be accomplished. Acquired technologies would be global in their impact and nonpolitical. These three mission oriented basic research areas are interrelated. Photosynthesis and nitrogen fixation are interdependent processes. Research on one complements the other. More carbon flow is essential if biological nitrogen fixation is to be enhanced. Moreover, since new techniques for genetic manipulation have worldwide application in the development of new and improved plants, research in all three areas should be coordinated. Results of such research investment have global interest and application and are nonpolitical. Details concerning most promising approaches in each of these three areas have been described.¹⁷

Photosynthesis. Food production involves effective utilization of land and water. But it is more than that. It's a series of strategies in crop management and design to most effectively farm the sun. Plants differ dramatically in their photosynthetic efficiencies. Most crops capture only one percent or less of the energy from the sunlight that illuminates their leaves. The most efficient producers are sugarcane, corn, sorghum, and pearl millet. Other crops such as rice, wheat, soybeans, field beans, peas, potatoes and cotton respire twice as fast when exposed to sunlight and burn up to half the carbohydrates they produce. Not so with sugarcane, corn, sorghum and millet. They have

Imperatives, 1976. Free copies available from the Michigan State University Agricultural Experiment Station, East Lansing, Michigan, and the Charles F. Kettering Foundation Research Laboratories, Yellow Springs, Ohio.

¹⁷National Academy of Sciences, *World Food and Nutrition Study - Interim Report*. Report of the Steering Committee of the Commission on International Relations of the National Research Council; National Academy of Sciences, *Enhancement of Food Production*; Michigan State University, *Conference on Crop Productivity*.

little if any photorespiration. Ribulose diphosphate carboxylase controls photorespiration. A key to feeding the world resides with the control or regulation of a single enzyme. Biochemists and plant scientists are working feverishly, both genetically and chemically, to accomplish the task. Meanwhile, better light receiving systems for many crops are being created. Plant architecture can be changed. Repositioning of the flag leaf above the panicle of new rice varieties is a classical example of achievement. New plant shapes can be quickly created.

The atmospheric concentration of carbon dioxide remains the most important variable determining the rate of photosynthesis in food crops. All respond. Remarkable effects occur when the normal level of 300 ppm is raised to 1000. A six-fold increase in biological nitrogen fixation for soybeans has been achieved.¹⁸ While CO₂ enrichment is now commonplace with greenhouse-grown crops, its use has not been actively pursued as a means of maximizing the production of food crops in the field. Massive quantities of CO₂ are now being flared into the atmosphere, and large geological reserves are being discovered in current explorations for natural gas and oil.

Biological Nitrogen Fixation. The focus has been on legumes. They are major food crops and include soybeans, field beans, broad beans, mung beans, peanuts, chick peas and pigeon peas. Agricultural legumes in the United States annually fix about 12 million tons of atmospheric nitrogen per year.¹⁹ This is greater than the amount applied as fertilizer. Worldwide, biological nitrogen fixation by agricultural and nonagricultural species fix over 200 million tons of nitrogen for crop production. This contrasts with a world supply of approximately 40 million tons of nitrogen fertilizer, fixed chemically. The magnitude of biological nitrogen fixation under field conditions can be measured by the acetylene reduction technique. The stimulus for research on biological nitrogen fixation is the rising cost of nitrogen fertilizer (Table I), its low recovery by plants, and the massive fossil fuel (natural gas) input required for chemical fixation.

Opportunities for optimization lie in improvement of nitrogen fixation by legumes, the extension of this capability to additional plants, the discovery and use of new nitrogen-fixing organisms, and finding new chemical mechanisms of nitrogen fixation.²⁰ There are

¹⁸Harold J. Evans, ed., *Enhancing Biological Nitrogen Fixation* (Washington, D. C.: National Science Foundation, Division of Biological and Medical Sciences, 1975).

¹⁹Ibid.

²⁰National Academy of Sciences, *Enhancement of Food Production*.

three known sources of biologically fixed nitrogen in the rice paddies of Southeast Asia—bacteria that are rhizosphere associated, the free-living azotobacter, and the blue-green algae. Cropping systems involving interplantings of legumes and cereal grains are emerging in Southeast Asia and elsewhere as new labor intensive, high-producing food systems with a minimum of resource input and the potential for year around production.

New Techniques in Plant Breeding. Many remarkable achievements have been made in the creation of new plants. These include hybrid corn, sorghum, and millet. The development of hybrid corn is the most spectacular of all scientific achievements in American agriculture. Increases in productivity have been truly remarkable. The creation and introduction of short statured, nonlodging, photoperiodically day neutral, high yielding rice²¹ and wheat varieties have resulted in a Green Revolution.²² Hybrid wheat is becoming a reality.²³ Most all commercial hybrids until now are hard, red winter types adapted to the winter wheat regions of Texas, Oklahoma, and Kansas. There has also been great progress with fruits and vegetables. This includes dwarf and spur-type apples, hybrid coconuts, hybrid onions, carrots, cabbage, spinach, melons, and parthenocarpic seedless cucumbers.

We are now moving beyond the horizons of conventional plant breeding. Included are the *in vitro* techniques for asexual approaches and broad crosses between crop species. Vegetative cells can now be crossed. The fused cells are then cultured for organ differentiation. New plants are then created from crosses that otherwise would be incompatible. Haploids can be produced by culturing pollen grains or anthers.

Wide or Broad Hybridization is listed under the heading of "radical research" in the report of the International Maize and Wheat Improvement Center (CIMMYT) in Mexico.²⁴ Quantum leaps in crop productivity will require some form of radical research. Wide hybridization is one of them. The production of specific, generic and even hybrids between plants of different families may be possible. Barriers to wide crossing appear to be biochemical. The use of

²¹P. R. Jennings, "Rice Breeding and World Food Production," *Science* 186 (1974):1085-1088.

²²D. G. Dalrymple, *Measuring the Green Revolution: The Impact of Research on Wheat and Rice Production*. USDA-Foreign Agricultural Economic Report No. 106.

²³DeKalb AgResearch, Inc., *Hybrid Wheat, A Special Report—History, Economics, Opportunities* (DeKalb Ill.: Dekalb AgResearch, 1975).

²⁴International Wheat and Maize Improvement Center, "Radical Research and CIMMYT'S Role," *CIMMYT Review*, 1974, 1975, pp. 73-83.

immunosuppressant chemicals to possibly circumvent this limitation is an emerging technology.²⁵ Chemical control of genetic processes, particularly barriers to crossability between species and genera may be a key to rearranging genes and the synthesis and building of new crop species. The development of triticale, a synthetic species derived from a cross of wheat and rye is one success story. Triticale is superior to either parent in productivity, adaptability, and nutritional value. A much wider range of genetic variability, with less genetic vulnerability, than presently exists in food crop species will be necessary to allow plant breeders to continue crop improvement programs for the next 25-30 years. Species can be "endangered" by man but they can also be created.

Chemical Regulators. Interest for the first time in history has moved beyond the parameters of horticulture. Chemical regulation of rooting of cuttings; setting of fruit and control of flowering; flower sex expression; vegetative growth; senescence; and fruit shape, size, color, and ripening has thus far been confined largely to ornamentals, fruits and vegetables. The focus now is on the agronomic and major food crops. Leading agricultural chemical industries are interested.

There now appear to be breakthroughs for enhancement of yields of two important crops—sugarcane and corn. Seven thousand hectares of sugarcane were treated with a variety of chemical ripeners in Hawaii in 1975. Sugarcane ripeners are herbicides used at low doses. They are applied several weeks before harvest. Vegetative growth is slowed and carbohydrates (sucrose) accumulate. The resultant increase in productivity of sugar from sugarcane approximates 2 tons per hectare per year.²⁶

Related to the chemical ripeners for sugarcane is 4,6 dinitro-o-sec-butyl phenol (DNBP) for corn.²⁷ It, along with a wetting agent, is applied as a foliar spray when the unemerged tassels are about ½-inch in length. Again, as with sugarcane ripeners, the vegetative growth of corn is slightly interrupted and metabolites are shifted earlier to the reproductive parts. The results are earlier pollination, more ears per plant, larger ears, and a 5-10 percent increase in grain yield. Some hybrids are very responsive. Again, DNBP is an herbicide applied as

²⁵L. S. Bates, A. Campos, R. Rodriguez, and R. G. Anderson, "Progress Toward Novel Cereal Grains," *Cereal Science Today* 19 (1974):283-85.

²⁶M. L. Pulido, *A New Sugarcane Ripener*, Buckman Laboratories, Reprint No. SYA-7406, Memphis, Tennessee; L. G. Nickell, *Bulletin—Plant Growth Regulators* 2 (1974):51-54. Hawaiian Sugar Planter's Association, Honolulu.

²⁷E. Hatley, K. Herrman, K. Collins, and A. J. Ohlrogge, "Foliar Applications of Pre-Emerge Increases in Corn-Grain Yields," *Down to Earth* (in press), Dow Chemical Company, Midland, Michigan.

plant sprays at low dosages and at critical stages in crop development.

Crop Protection and Pest Management. Annual losses from pests (insects, weeds, diseases, nematodes, rodents, etc.) in the United States are enormous. They approach $\frac{1}{4}$ – $\frac{1}{3}$ of the total harvest.²⁸

Approximately one billion pounds of chemical pesticides are used annually. They still provide the foundation (over 90 percent) of contemporary pest control practice.²⁹ New strategies for pest management offer promise. These include insect viruses and bacteria and chemicals (juvenile hormones) that interfere with reproductive cycles. Egg and larvae parasites, pheromones, and resistant varieties may be alternatives. The hope is for reductions in cost with fewer environmental and health hazards.

Heretofore, biological methods for control of weeds have been successful only on individual species. Allelopathy is an emerging technology.³⁰ It is defined as mutual harm, where chemicals released by one plant species inhibit the growth of another. Allelopathy provides the opportunity to control weeds by genetically incorporating such chemical factors into desirable food crops. It has been documented for the cucumber, rye, and oats.³¹

Nutrient Absorption and Fertilizer Utilization. There is inadequate knowledge concerning nutrient absorption and its control of crop productivity. Improved efficiency in fertilizer uptake is a major challenge ahead. Only 50 percent of the applied nitrogen and less than 35 percent of the phosphorus and potassium are recovered by the crop. Losses of nitrogen are even greater in the tropics with recovery averaging only 25–35 percent.³² Several new and high priority technologies are emerging to reduce these enormous losses. Greater efficiency in fertilizer uptake can be achieved through the use of improved cultivars with enhanced capacities of ion uptake. Modulation of nitrification and denitrification also offer promise. Recovery and efficiency for nitrogen fertilizer can be improved by sulfur-coated urea and treating with nitrification inhibitors.³³ One such inhibitor is

²⁸National Academy of Sciences, *Enhancement of Food Production*; Michigan State University, *Conference on Crop Productivity*.

²⁹National Academy of Sciences, *Pest Control: An Assessment of Present and Alternative Technologies*. Report of the Executive Committee and Summary and Recommendations, Volume 1. Environmental Studies Board of the Commission on Natural Resources of the National Research Council.

³⁰Elroy L. Rice, *Allelopathy* (New York: Academic Press, 1974).

³¹Alan R. Putnam and William B. Duke, "Biological Suppression of Weeds: Evidence for Allelopathy in Accessions of Cucumber," *Science* 185 (1974):370–72.

³²National Academy of Sciences, *Enhancement of Food Production*.

³³D. M. Huber, H. L. Warren, and D. W. Nelson, "Nitrification Inhibitors: Powerful Tools to Conserve Fertilizer Nitrogen," Manuscript, Department of Botany and Plant Pathology, Purdue University.

known as "nitropyrin" [2-chloro-6-(trichloromethyl) pyridine]. Nitropyrin is a highly specific bactericide which is toxic to *Nitrosomonas* bacteria.³⁴ It reduces but does not eliminate the population of this organism. The reduction of nitrification lasts from six weeks up to three months. This nitrification inhibitor is under extensive trial in the tropics and for rice production in Southeast Asia.³⁵

Another promising means of improving nitrogen uptake efficiency in India is use of a product of the Neem tree. This tree produces a seed, the pulp of which is used, after the oil is extracted. It is mixed with the nitrogen fertilizer. There are identifiable bacteriocidal properties in the Neem tree product. Most nitrogen fertilizer for crops in India and Southeast Asia is in the form of urea.

Foliar absorption of nutrients, with both beneficial and harmful aspects, has taken on new significance. Little credence, however, has been heretofore attached to the process by authorities on nutrient uptake, although the author and his colleagues have published extensively on the potential role of non-root absorption in meeting the mineral nutrient requirements of food crops.³⁶ The role of plant foliage in absorption of carbon dioxide has already been emphasized. The gradual lowering of the pH in atmospheric precipitation in the eastern part of the United States is having an effect on the soil as well as what is absorbed by the leaves of plants.³⁷ Sulfur is seldom applied to the soil as a fertilizer because adequate quantities are absorbed directly from the atmosphere by aerial plant parts. Many other gaseous liquid and particulate materials are removed by plant foliage from the atmosphere. Some are beneficial, but more often they are air pollutants and harmful. Air quality standards in the United States have given little attention to the effects on renewable resource productivity.

There is a remarkable report on foliar fertilization of soybeans.³⁸ Yields have been increased by 10 to 20 bushels per acre. The results are

³⁴D. A. Laskowski, F. C. O'Melia, J. D. Griffith, A. J. Regoli, C. R. Youngson, and C. A. I. Goring, "Effect of 2-Chloro-6-(Trichloromethyl) Pyridine and Its Hydrolysis Product 6-Chloro-Picolonic Acid on Soil Microorganisms," *Journal of Environmental Quality* 4 (1975):412-17.

³⁵G. B. Rajale, and R. Prasad, "Relative Efficiency of Urea, Nitrification Inhibitor Treated Urea and Slow Release of Nitrogen Fertilizers for Rice (*Oryza sativa* L.)," *Journal of Agricultural Science* 83 (1974):303-07.

³⁶Sylvan H. Wittwer, and M. J. Bukovac, "The Uptake of Nutrients Through Leaf Surfaces," in Karl Scharrer and Hans Linser, eds., *Handbuch der Pflanzenernahrung und Dungung* (New York: Springer-Verlag, 1969).

³⁷Ohio State University and United States Department of Agriculture, "Acid Precipitation and the Forest Ecosystem, International Symposium," Ohio State University, 12-15 May 1975.

³⁸R. L. Garcia and J. J. Hanway, "Foliar Fertilization of Soybeans (*Glycine Max* [L.] Merrill) During the Seed Filling Period," Paper presented at the 28th Annual Fertilizer and Agricultural Chemical Dealer's Conference, Des Moines, Iowa, 13 January 1976; *Agronomy Journal* (in press).

all the more remarkable because the yield increases were obtained from a production base that was already high and derived from the best in conventional practices. The gain was in harvestable seeds, not an increase in seed size. The ratios of nitrogen, phosphorus, potassium and sulfur in the foliar spray are the same as in the seed. Phosphate is applied as polyphosphate, and nitrogen as urea. The first spray is applied when beans can be felt in the pods of the upper four nodes. Two to three sprays are then applied 10-14 days apart. The leaves must be active and green. Nineteen gallons of solution containing 25 pounds of nitrogen, 6 pounds of P_2O_5 , 9 pounds of K_2O and 1.5 pounds of sulfur are applied either by ground or air equipment in each of three applications. These results with a major crop, confirm the long reported added efficiency of uptake associated with foliar applications of nutrients to many horticultural crops, sugarcane and pineapple; and micronutrients for major food crops. Foliar applications have been declared the most efficient method of fertilizer placement.³⁹ Future yield barriers may well be broken by utilizing the absorptive capacities of leaves at crucial stages of plant development. The rising costs of nonrenewable fertilizers should be an added stimulus for the further development of this technology.

NEW TECHNOLOGIES - RESOURCE UTILIZATION

Land Resources and Utilization. Food production capacity reserves are delineated by land, water, energy, fertilizer, chemicals, capital, credit, machinery, management and technology. Food production is a renewable resource but requires nonrenewable resource inputs.

Land comes first. The productivity of land may be improved as well as depleted by cropping. To meet domestic and world food needs we have brought into production during the past three years approximately 12 million new hectares—at a cost. What cost resources would it take to bring an additional 12 million hectares into crop production? Agricultural research directors ought to be as concerned about preservation of the land base crop and livestock production as for new yield or productivity practices. A 10 percent increase in the yield of corn or wheat, or preservation of the land base by an equal percentage for its production at the same level, gives an identical result in the amount of grain produced. The resource input and flexibility in the use of the land resource, however, is quite different. Also, as we drive our land resource base harder, different kinds of problems

³⁹Wittwer and Bukovac, "The Uptake of Nutrients."

emerge. We need to review the options in food security, prices, world trade, energy, and employment for society at different levels (quantity and quality) of a land base.⁴⁰

Irreversibility of land use for food production is becoming a national disaster. During the past 20 years, 11 million hectares have been converted into urban areas and highways. At the same time, the quality of our arable land is being slowly degraded by excess tillage and soil erosion. Losses in the United States are about 3.6 billion metric tons of top soil annually, equivalent to 31 metric tons per hectare.⁴¹ These soil losses are accompanied by degraded water quality, fertilizer and organic matter losses, and the silting of rivers and harbors.

No more than 25 percent of our farm lands are under approved conservation practices. It is not now profitable and there is little incentive for individual farmers to apply conservation practices. This must be changed.

There is one exception—reduced tillage. The no-till systems of soil management conserve soil, water, organic matter, fuel, labor, machinery and fertilizer. One of the secrets of the no-till economy is a seed drill that disturbs only enough soil in the stubble or sod from one crop to make an opening for the seed of the next crop. A still newer innovation is interseeding—sowing the seed of a second crop such as soybeans before the first one such as wheat is harvested. The concept involves complete elimination of tillage. Competing weeds are controlled with herbicides, not cultivation.

For the U. S. corn belt, no-till has proven the most effective management practice ever developed for the control of wind and water erosion. Zero tillage can be seen throughout the United States for corn, soybeans and sugar beets. It is effective for asparagus. No-tillage farming has spread to more than three million hectares in the United States. Minimum tillage technologies now embrace more than 18 million hectares in the U. S. It is projected that more than half of America's cropland will be farmed without plowing in thirty years. Much additional land can now be used for crop production formerly not considered suitable. It is now used for small grains in Britain, rice in Southeast Asia, and provides an improved system of land management for highly erodible and difficult-to-manage tropical soils. Entire issues of professional and trade journals are devoted to the

⁴⁰D. Pimental, W. Dritschilo, J. Krummel, and J. Kutzman, "Energy and Land Constraints in Food Protein Production," *Science* 190 (1975):754-61; R. D. Vlasin, *Conservation, Use and Retention of Agricultural Lands for All-Out Food Production*, American Society of Agronomy, Special Publication, No. 22, pp. 35-53.

⁴¹Pimental, et. al., "Energy and Land Constraints."

topic.⁴² The advantages of reduced tillage which come through most clearly to the producer are the (a) saving of time, (b) reduction of costs, (c) greater land utilization, (d) quick turn around time from one crop to the next, and (e) taking advantage of short spells of good planting weather.

Water Resources and Utilization. It is estimated that in the United States 90 percent of all water that is withdrawn from streams and ground water storage for use, is consumed in irrigated agriculture.⁴³ Eighty-one percent of the sugar beets, 70 percent of the fruits and vegetables, 40 percent of the cotton and sorghum, 30 percent of the alfalfa, 25 percent of the barley and 10 percent of the corn and wheat produced in the United States is from land that is irrigated. In view of the predominate use of water in food producing systems it is somewhat ironical that the 1975 Staff Draft Report of the National Commission on Water Quality does not address itself to water quality for agriculture. All other aspects of water quality ("fishability," "swimability," leisure, human health, etc.) are, however, given thorough treatment.

Irrigated land generally is the most productive. Up to 30 percent of the food for mankind is produced on about 15 percent of the irrigated cultivated land of the globe. Irrigated acreages in the Peoples' Republic of China, the USSR and India exceed those in the U. S. Agriculture, other than dryland grazing and dryland farming, would be nonexistent in the western USA without irrigation.

Agriculture suffers from some degree of water deficiency over the entire globe. Drought is one of the major factors contributing to food shortages and instability of supplies. While billions of dollars have been expended for development of new land resources through irrigation, little attention has been directed toward increasing efficiency of water usage by crops and new technologies for water management. Efficiency in usage of irrigation water varies from a low of 30-40 percent in the United States to more than 80 percent in Israel. The amount of water required to produce a unit of food is also a variable. In the Hawaiian Islands only 18-20 inches of rainfall is required annually for pineapple but for sugarcane it is 90-100 inches per year.

An improved system of water management is trickle or drip irrigation. It had its origin 25 years ago in the greenhouses of western

⁴²Imperial Chemicals Industries; Plant Protection Division, 1973, 1975. *Outlook on Agriculture*, 7:4 and 8:special number.

⁴³Michigan State University, *Conference on Crop Production*.

Europe. Only in the 1970s, however, has it been introduced for production of high value crops in the field. It is irrigating the crop not the soil. Quantities of water required to start young orchards in the desert may be reduced to 1/20th of conventional sprinkling systems. For sugarcane, corn and sorghum, nutrients may be added through the system and the lines may be buried 12-18 inches deep to discourage weed growth.

Drip irrigation is being installed in the sugarcane plantations of Hawaii at the rate of 5,000 hectares per year. All new plantings are equipped with the drip system. The total estimated cost of \$1,500 per hectare is amortized in one year as a result of savings in labor. Drip irrigation will eventually be installed in all sugar plantations of Hawaii (50,000 hectares) that are currently irrigated. This water conserving-labor saving technology needs careful evaluation for other major food crops as well as high value fruits and vegetables.

Energy Resources and Product Utilization. The importance of energy options with land, water, and labor in food systems has been emphasized.⁴⁴ While food production is more than energy and protein, the two are closely related. Use of agricultural by-products and hydrolysis of waste cellulose could add enormously to our food and fuel sources.⁴⁵ Economic viability will determine the rapidity with which such technologies are developed.

Meanwhile, studies of energy inputs into alternative agricultural production techniques and total food systems are crucial. Low energy production and handling techniques for the major food crops and their products, should be pursued on a national and global scale. Improved food processing efficiency could reduce energy use by 35 percent, waste and effluent by 80 percent, and increase processing yields by 5-20 percent. Total losses between harvest and consumption could be reduced by 30-50 percent.⁴⁶

NEW TECHNOLOGIES - LIVESTOCK PRODUCTION

Domestic animals produce meat, milk, and eggs from nutrients derived from crops, forages, and by-products that have less value elsewhere. The magnitude of the current contribution of animal products to the U. S. food supply is significant. They produce 2/3 of the

⁴⁴Pimental, et. al., "Energy and Land Constraints."

⁴⁵Ibid.; G. H. Heichel, "Agricultural Production and Energy Resources," *American Scientist* 64 (1976):64-72.

⁴⁶National Science Foundation, Office of Science and Technology Policy, *Food Science Research Needs for Improving the Utilization, Processing and Nutritive Value of Food Production - Special Report*, 1975.

protein, 1/3 of the energy, 1/2 of the fat, 4/5 of the calcium and 2/3 of the phosphorus consumed by man.⁴⁷

Make Ruminants Less Competitive With Man for Protein and Energy. Cattle (beef and dairy), sheep and goats can grow and produce primarily from plant foods that cannot be consumed by man, but are converted to useful products (meat, milk, hides, wool). The rumen stomach is essentially a fermentation vat. Nonprotein nitrogen sources (anhydrous ammonia, ammonia solutions, urea) can be added to whole chopped corn plants and other forages in the field or at the silo. If done at the proper stage of maturity sufficient energy and nitrogen is provided for finishing beef cattle and all but the very high producing dairy cows. Only 12-15 percent of the nation's corn crop is currently harvested as silage. A vast new energy resource could be put to use. Forages now constitute about 3/4 of the feed units consumed by ruminants (beef cattle, dairy cows, sheep, goats). This could be raised to an even higher level with an effort directed toward improved management of range lands and pastures coupled with the development of superior grasses and legumes, and improved harvest technologies. Targets of opportunity in these areas have been outlined.⁴⁸

Ruminant livestock do not have to compete with man for energy or for protein. Large quantities of grain have been fed to livestock in the past only because it was in surplus and it was economically feasible to do so. Forages can be produced on vast areas of land that globally exceed by two-fold that suitable for cultivated crops. Only ruminant animals can convert these forages to human food. One of the greatest research challenges is to increase the efficiency of this conversion. The ultimate goal may be control of rumen fermentation to optimize the production of desirable end products.⁴⁹

Improved Animal Health. Prenatal immunization of the unborn dairy calf is now a reality.⁵⁰ This is an insurance against calfhood diseases. A worldwide record for speed of adoption of a new technology was recently achieved in the history of agricultural science. A vaccine for Marek's disease was first introduced by a team of four

⁴⁷National Academy of Sciences, *Enhancement of Food Production*.

⁴⁸Hodgson, "Forage Crops"; National Academy of Sciences, *Enhancement of Food Production*.

⁴⁹Kenneth L. Blaxter, "The Nutrition of Ruminant Animals in Relation to Intensive Methods of Agriculture," *Proceedings of the Royal Society of London* 183 (1973):321-26.

⁵⁰Joseph P. O. Wamukoya, and Gabel H. Conner, "Local Immune Responses in the Bovine Fetus Vaccinated *in utero* with *Escherichia coli* Antigen," *American Journal of Veterinary Research* 37 (1976):159-63.

scientists in 1971.⁵¹ It is a vaccine that will control a type of cancer in chickens. This contribution for the health of laying hens and broilers is now being studied for possible adaptation to human health problems relating to the control of cancer.

Improved Fertility. Closely allied to disease control is high reproductive performance. A new frontier is emerging for fertility control in dairy and beef cattle and for horses. Prostaglandin F_{2α} controls estrus and greatly improves efficiency of artificial insemination.⁵² An approved commercial use has already been introduced for horses and final clinical tests are underway for dairy and beef cattle. Ovulation control with prostaglandin F_{2α} will permit artificial insemination in herds where detection of estrus is now difficult or impossible. The potentials lie in rapid genetic improvement and for greater reproductive efficiency. The implications of this discovery are global. This may be the long awaited technological breakthrough for improving the notoriously low fertility of the water buffalo in Southeast Asia, and in other parts of the world.

CONCLUSIONS

Modern food systems must be viewed in their total context. The production of a commodity begins with the seed, land, water, fertilizer and pesticides. It requires machinery, capital, labor and often credit. This assemblage on the farm demands superb management. The natural resources, some nonrenewable (land, water, energy, fertilizer), some renewable (sunlight) are utilized. The vagaries of weather and climate must be dealt with. The farmer must put it all together and make it work. Raw agricultural products (corn, wheat, soybeans, beef, pork, milk, poultry, eggs, fruits, vegetables, cotton, etc.) are produced. They must be harvested. They then move beyond the farm to processing, packaging, transportation, storage, and distribution to consumers everywhere.

There are many technological solutions to the world food problem. One is impressed by the number of potentially important and viable alternatives. We have emphasized the development of new agricultural technologies for enhancement of food production as our best hope for the future. These advances, however, will be of little value without the free enterprise system, the family farm, and

⁵¹H. G. Purchase, W. Okazaki, and B. R. Burmester, "Long Term Field Trials with the Herpesvirus of Turkeys Vaccine against Marek's Disease," *Avian Diseases* 16 (1972):57-71.

⁵²H. D. Hafs, J. G. Manus, and Bridget Drew, "Onset of Estrus and Fertility of Dairy Heifers and Suckled Beef Cows Treated with Prostaglandin F_{2α}" *Animal Production* 21 (1975):13-20.

economic and social incentives to produce food. There must also be the political will.

Agricultural productivity as a renewable resource, the adequacy of our food supply, and improved nutrition will assume an increasingly greater importance and visibility. Never in the history of mankind has one nation had such a monopoly on food. Never has a single nation exported so much food. This nation has never experienced a famine. Today's generation has never known hardship or witnessed a shortage of food, shelter or clothing. Never before in history has there been such an interest in agriculture, food, and nutrition. College and university enrollments in agriculture and renewable resources have doubled in five years.

Recent records of accomplishments in food production have never been equalled by any nation in the history of mankind. Agricultural, food and nutrition education must be expanded rapidly to meet current demands and an escalating interest. Otherwise, those with nonagricultural backgrounds will be prone to take over. There is already the perception that the present agricultural establishment is obsolete and incapable of meeting today's problems in the food area. Never was there a greater need and opportunity for qualified and trained people. To meet the food requirements of an expanding population, quantum jumps even greater than we have thus far witnessed must be achieved in agricultural productivity during the next 25 years. I am confident that we can meet these challenges.