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Food for the Future

The Philadelphia Society for Promoting Agriculture Bicentennial Forum Proceedings

1785 - 1985

The Philadelphia Society for Promoting Agriculture
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"No measure, in my opinion, will be more conducive to the public weal than the establishment of this Society . . . Much is it to be wished that each State would institute similar ones; and that these Societies when formed would correspond regularly and freely with each other."

George Washington to Samuel Powell, July 19, 1785. History of the Philadelphia Society for Promoting Agriculture. pg iii, 1985.

PREFACE

Two hundred years ago a group of 23 influencial farmers, merchants, and professional people organized the Philadelphia Society for Promoting Agriculture. The purpose of the new organization was to create a communication link among the members and with similar societies organized elsewhere in America and Europe. The Society met frequently and helped to keep agricultural leaders in the Delaware River Valley informed of new technology and economic developments affecting agriculture.

From the beginning the Society served the nation and attracted individuals interested in the broadest aspects of agriculture. Four of the charter members were later signers of the Declaration of Independence. George Washington and Benjamin Franklin were among the early members.

Formation of the Philadelphia Society for Promoting Agriculture preceded the signing of the Declaration of Independence. America was a developing country. Agriculture was concerned with the task of providing food for the families of those that tilled the soil. Essentially everyone was closely involved with the production of food. In this respect the conditions that confronted early American farmers were not greatly different than conditions confronting farmers in many of the developing nations today.

During the 200 years that the Society has been in existence, American agriculture has undergone dramatic change. Farms have been established from border to border. The productivity of our land has increased until it greatly exceeds the needs of the few that live and work on farms. The vast majority of the people in our country are no longer involved with farming and yet we meet all of our domestic food needs and are able to export huge quantities of farm product to other countries.

The Society celebrated its 200th anniversary by sponsoring a Bicentennial Forum which was held in Philadelphia on November 6, 1985. The topic for the Forum was "Food for the Future." The objective of the meeting was to provide an opportunity for a select group of national and international agricultural leaders to discuss several aspects of the enormously complex problem of producing enough food to adequately feed the world's steadily increasing population. The seven addresses presented at the Forum have been reproduced in these proceedings.

During the Forum numerous contributions were made to a clearer understanding of the problem of producing the world's food supply. Perhaps the most significant contribution was the conviction of all speakers that the world has the required physical, economic, technical, and human resources it will need to produce food for the immediate future. The production of adequate supplies of food for the longer term pivots on our ability to (a) curb population growth rates, (b) create stable political environments, (c) provide appropriate economic incentives for farmers, (d) continuously improve agricultural technology, and (e) adequate finance these undertakings.

The remarkable achievements of Southeast Asia during the past 20 years and of the People's Republic of China during the past 10 years provides a sound basis for optimism that similar agricultural developments can be attained in Africa.

As the Philadelphia Society for Promoting Agriculture moves into its third century, it does so with confidence that agriculture will succeed in the future just as it has in the past.

W. BEVERLY MURPHY
President

ACKNOWLEDGMENTS

Conception, development, and completion of the Bicentennial Forum required the dedicated efforts of a number of individuals, as well as funds generously contributed by several donors. Without the interest and involvement of this group, the Forum and these Proceedings would not have been possible.

I am deeply indebted to the members of the Philadelphia Society for Promoting Agriculture for their help, encouragement, and support throughout this anniversary project. Specifically, I want to thank Dr. Mark A. Allam, Mr. Alfred M. Campbell, III, Mr. William Beverly Murphy, and Mr. Frank R. Wallace, Jr.

I am particularly indebted to the Advisory Committee members who contributed so capably toward development of the program and the selection of the speakers: Dr. Alva A. App, Director Agricultural Sciences, The Rockefeller Foundation; Dr. Orville G. Bentley, Assistant Secretary, Science and Education, U. S. Department of Agriculture; Dr. Nyle C. Brady, Senior Assistant Administrator, Science and Technology, U. S. Agency for International Development; Dr. Edwin A. Crosby, Director, Agricultural Research Institute; Dr. W. David Hopper, Vice President, South Asia Division, World Bank; Dr. J. B. Kendrick, Jr., Vice President for Agriculture and University Service, University of California; Dr. Samuel H. Smith, President, Washington State University; Dr. Sylvan H. Wittwer, Director Emeritus, College of Agriculture, Michigan State University.

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NEW TECHNOLOGY NEEDED TO SUSTAIN INCREASED FOOD PRODUCTION

Sylvan H. Wittwer

INTRODUCTION

Food is our most important renewable resource, and food production is the world's oldest science. It is the model science upon which our lives depend, and continues as our most important industry (136). Our greatest global challenge, for the decades ahead, will be to produce and deliver adequate and safe food supplies of high nutritional value, from traditional land, water, energy and genetic resources, to meet the demands for improved diets and the increasing purchasing power of an ever expanding population (252).

Agriculture has been and remains the paradigm of modern science. During this latter part of the 20th century, food production is demanding, requiring and is adopting the highest of technologies. Perceived as an integrated system, and at one time simply defined as farm management, farming systems research may now be looked upon as science of the highest order. The science of food production demands the inputs and coordination of all sciences, from physics and genetic engineering to sociology and anthropology. Modern day farmers, to be successful, must put together, in a systems approach, all that emerges from scientific laboratories to field trials, the management of natural resources, new technologies, labor supplies, changes in demand, marketing skills, and credit options. This is the challenge of contemporary agriculture.

THE WORLD FOOD DILEMMA

The world food situation is currently beset with contrasting dilemmas and disturbing contradictions (251). At one end is widespread hunger, disease, and brutal deaths in a number of subSaharan countries, as Africa's worst drought in

this century continues. At the other end is over production, particularly of grain in the USA, Canada, Brazil, Argentina, and Australia; and more recently in China, India, England. France, and Thailand (99). Surplus rice now plagues the markets in Taiwan, Japan, and Indonesia, and mountains of surplus dairy products have accumulated in the USA and the European Community. These countries are in an over production trap. China and Indonesia are witnessing some of the most impressive gains in food production in history. For the first time in several decades, China is concerned with marketing, handling, and storing of food surpluses. As of 1985, it is the world's leading producer of rice, wheat, and cotton and is now an exporter of corn (219). Within four years, Indonesia has moved from the world's largest importer of rice to a country not only self-sufficient but with the world's largest rice reserves (245). Many countries in the European community are moving in as strong exporters of both grain and animal products. The only areas now on earth with endemic food insufficiencies are the Soviet block, some elements of the Middle East and South Saharan Africa. Who, ten years ago, would have predicted the present state of affairs?

Global food production problems have shifted from Asia to Africa, where the need for food is now most critical (137). Concurrent with the major improvements in food production, is the continued existence of extensive malnutrition, poverty, and starvation, especially in Africa. There is more famine now than a decade ago.

The spectacle of world impotence toward too much food in some places and too little in others is especially shocking since it is man-made. It has been said that while half the people in the world are starving, the other half are dieting. Hundreds of millions of people suffer for want of food and from malnutrition in a world that has, in total, more than enough to feed everyone.

Meanwhile, there was never a greater avalanche of reports from conferences, workshops, commissions, symposia, and individually written books and articles on issues of the adequacy, the security, the sustainability, the safety, the health aspects, the strategic values, and the dependability of our food supplies and agricultural productivity (20, 25, 26, 30, 31, 56, 85, 108, 130, 164, 202, 221, 238). A new series of buzzwords and phrases, relating to resource conservation and management—"sustainable," "regenerative," "alternative," "agro-

ecological," "biological farming," ecologically healthy systems," "holistic," "closed system agriculture," and "stewardship" have found place in our vocabularies. All of this may seem a little ironical when agriculture is currently beset with global surpluses and record crop yields that exceed those of any time in recent, and perhaps in all history.

The determinants for future food production are new technologies, economic incentives and resource inputs (237). Many uncertainties reign as to our capacity to provide and maintain the agricultural output necessary to meet the food needs of future generations. New constraints are also emerging. Uncertainties relate, in large part, to the current inadequacies for preservation, management, protection, diversion, and utilization of our natural resources of air, soil, land, water, energy and the earth's plant and animal genetic resources. There is a declining ratio—harvested solar energy/energy equivalent of inputs (mainly fossil-carbon based), growing pressures on agricultural land, indirect constraints on water use from ground and surface pollutions and losses of native soil. One of our future challenges will be to provide food for people at the same time protecting our natural resources (233, 234). Alternative production systems must be vigorously explored.

While the European Community as a whole has achieved surpluses of wheat grain and dairy products and Indonesia, Japan, Thailand, and Taiwan a surplus of rice, they are far from self-sufficient in terms of the full range of food products and especially soybeans, cotton, and timber. Even the U. S. in the full context is a major net importer of many key food and agricultural products.

Finally, it should not be forgotten that the present world population of 4.8 billion is sustained by the modern intensive agricultural practices of a relatively few nations. There is now evidence that new technologies for increasing food production, if coupled with the social and economic changes required for increased food production and better health, are conducive to reduced birth rates (41, 44). Nevertheless, it is projected by the year 2000 there may well be a world population of over six billion. The world is not now over populated as far as the food production capacity is concerned. By the second half of the 21st century, however, when the projected world population would be 60% larger than today, the carrying capacity of the earth may become critical if there are no influxes of new technology (74).

THE CAPACITY TO PRODUCE FOOD

In face of the above dilemmas of uncertainty and instability an increased production capacity, whether or not that capacity is actually used, must be called for. All projections indicate that because of international competition in commodity markets, coupled with increasing constraints for limited energy, water, and land resources; frequency of occurrences of natural hazards such as droughts and floods; threats of international conflicts; concerns for food security; higher costs of labor; increasing demands for improved diets; and accelerations in population growth; that more science and technology must be put into agriculture to double food production in the next half century (108, 250). This must be accompanied by improved institutions and policies, an expanded capital base and greater entrepreneurial and managerial skills. The capacity to produce food through an adequate resource base, and the use of such capacity are two different things but the capacity must be at hand. New technologies, such as genetic engineering and the use of computers and sensors, may or may not expand production in periods of food shortages, and their use should not be suppressed in periods of food surpluses. A well-managed resource base of soil, water, energy and air, with preservation of plant and animal genetic resources and the devleopment of human capital, must accompany either an expansion or a suppression of agricultural production for the decades ahead. Continuing support of agriculture research for the development of new technological advances in crop and livestock productivity and improvements in food utilization technologies, both in times of plenty and shortages, is essential, but a message seldom understood by those in decision making processes.

FORCES IMPACTING FOOD PRODUCTION

Many forces, some of which have not heretofore been experienced, are impacting agriculture. They include government programs; genetic engineering and other biotechnologies; mechanization and automation; on-farm personal computers and an accompanying communication revolution changing patterns for agricultural exports and imports; continued focus of research and educational programs on bigness, an increasing number of part-time farmers and those with secondary incomes. and the transition of farming from a way of life to a business (108).

Societal and Demographic Trends. Societal and demographic trends impacting agriculture include an increase in spending power—people can buy more expensive things and be more wasteful. There is rising interest in physical fitness and increasing expenditures for "health," "natural," and "organic" foods. A "grazing society" is emerging with demands for "fast foods" and "eating on the run." Populations are aging and households are becoming smaller, with more single parents and single or no-child families. We now have a new audience of consumers with solitary eating habits and two-income households. Dietary changes, based on health considerations and cost, are having major impacts on some agricultural sectors. There is an ever increasing concern of a consuming public as to human health, food safety, and pesticide residues. An example is the significant reduction in the number of beef cattle in the U. S. and in per capita consumption of beef with parallel increases in marketing of broilers, turkeys, and fish. This transition is having a major impact on beef cattle producers with cattle numbers in the U. S. dropping by six percent during the past two years (252).

THE NATURAL RESOURCE BASE

The importance of an overall view of the life supporting resources of the earth and to inventory these changes, has been manifested by a new mission of the National Aeronautics and Space Administration designated as "global habitability," or "mission to planet earth" (59). There is the recognition that in some ways we know more about our neighboring planets than we do about our earth. Changes in the global hydrologic cycle; biogeochemical cycles in the water, soil, and air; productivity of crops and livestock, and changes in the land surface characteristics affect the global environment and future earth habitability (76, 151). Human activities, fueled by increasing numbers of people and their demands for goods and services, and their rising consuming powers, are affecting the biosphere. There are changes in land cover, in biological productivity, the distribution and preservation of genetic resources, soil moisture and ground water reserves, soil erosion, desertification, biogeochemical cycles, atmospheric CO_2 and other so-called "greenhouse gases," trace compounds, including pollutants, and toxic substances in the environment. Some of these world environment trends have been of great concern during the past decade (27, 171, 172, 202).

Global problems relating to the sustainability and productivity of agriculture, along with the adequacy and dependability of our food supplies, are associated with changes in the gaseous and particulate composition of the atmosphere, the nature of land surfaces, the abundance, availability, distribution and quality of our water resources, our fossil fuel reserves and the increasing rate of extinction of plant and animal genetic resources.

Air or Atmosphere. As to air or atmospheric resources, ozone (O_2) alone, or in combination with sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), account for 90% of the crop losses in the U.S.A. caused by air pollution. Annual crop losses usually range between 2 and 4% (84) and may go as high as 50% for ozone alone (182). The legumes are particularly susceptible to air pollutants and food crops more so than tree species. No one can yet accurately predict the effects of acid deposition (rainfall) on agricultural productivity (100). The effects of a build-up of CO_2 along with other "greenhouse gases' such as methane (113), carbon monoxide, and chloro-fluoro carbon trace gases may not be so much as the widely publicized warming per se but a large scale disruption of the global weather machine (202). This may have profound effects on the productivity of the U.S.A. breadbasket, Italy's Po Valley, the Soviet Ukraine, China's Yangtze river basin and all other major food producing areas. With the man-made rising levels of atmospheric CO_2 and other gases we are inadvertently conducting a great biological and physical experiment of global proportions, the outcome of which is not now known, but has been predicted to markedly affect both directly and indirectly the total biological and agricultural productivity of the earth (53, 121, 145, 223, 236, 243, 249). Four points are important with respect to agricultural productivity and air pollutants. The effects are regional, they are subtle in magnitude, they are multiple and they interact with man-made and environmental constraints and stresses. No major food-producing area on earth is immune from the effects of air pollution. The problem could become critical in most all of the U.S.A., the Yangtze river basin (the rice bowl) of China, in western Europe, Japan, Korea, Taiwan, much of India and Thailand.

Land. Several global problems are associated with ongoing changes in the global land surface. These include deforestation (estimated to range from 11 to 20 million hectares per year), desertification, soil erosion, excess tillage, salinization, a lack of drainage, aluminum toxicity and accumulation of heavy

metals and other toxic materials (202). Included are changes in tillage practices, marginal soils, conversion of non-cropland, and management of rangeland resources. Neither the magnitude nor the rate of these changes are known; yet volumes have been published on the future hazards of some of the above practices and phenomena on life supporting systems for global habitability (151). Estimates of annual losses from soil erosion range from 4 billion tons annually in the U.S.A. (mostly from row cropped land) to 25 billion tons globally (120, 202). During the past two decades, there has been a major shift in the grain belt of the U.S.A. from mixed crop-livestock systems to cash or row cropping, prompted by future hopes of an ever expanding export market. The rise of corn (maize) production during the past two decades in Western Europe, is even more striking.

Meanwhile, no soil management technology has moved more rapidly for conservation of the nation's soil, water, energy, and organic matter, than reduced or conservation tillage, which now stands at approximately 50 million hectares or 1/3 of the total cultivated crop area of the United States (26). Combined with allelopathic properties of plant residues (174, 175, 176, 177), conservation tillage or no-till (82, 173, 213) and/or alley cropping (110), may provide the long sought-after means for continuous cropping of many of the shallow, fragile, and easily erodible soils in the lowland humid tropics (102, 114, 117, 157). Globally, it is estimated that we are annually losing 8 million hectares of land from non-agricultural conversions, 3 million to soil erosion and 2 million hectares each to desertification and toxification (202).

Seldom has such a totally new set of competitive forces been unleased on global land resources as is now occurring. Yet, this is coupled with a marvelous opportunity to take corrective measures to conserve our soil. With a surplus of almost everything agriculturally and a declining public support for farm subsidies, there is an ever increasing support for resource conservation. It is time we began to devote highly erosive, fragile, and shallow crop land to other uses such as grazing, wood fuel production, and reserves for wildlife and for recreation. Such measures would simultaneously conserve our soil, land, and water resources and bring agricultural production down to a level where prices will be profitable to the farmer and acceptable to the consumer. Can world leadership merge the two problems and does leadership to do so now exist?

Water. What agriculture needs more than anything else is water. The management of water resources, as to both availability and quality, will be particularly critical for the sustainability, productivity and dependability of food production in the decades ahead (156, 185). It is estimated that agriculture consumes, mostly through irrigation, the majority of the globe's fresh water resources. In the U.S.A., it is 80 to 85% of the total. This is far greater than the energy budget for agriculture. The current overdraft of ground water resources, again, mostly for crop irrigation in the U.S.A., is estimated at 20 to 25 million acre feet per year. Land subsidence from these overdrafts is becoming serious in some of the valleys of the western U.S.A. and in many other areas throughout the world. One-third of the world's food supply is now grown on 18 percent of the cropland that is irrigated (180).

The amount of irrigated crop land both in the United States and globally is increasing. Since 1950, irrigated land has almost tripled and now totals nearly 270 million hectares. An estimated three-fourths of the potentially arable land in the tropics has limited production capacity because of insufficient moisture. Irrigation is the one option that nations have for increasing agricultural output and assuring dependability of supplies. Water for irrigation requires energy for lifting, transporting and pressurizing (48, 164). Most of the orchard and vegetable land on earth is now under irrigation and the irrigated areas are increasing yearly. There are now approximately 1 million acres of drip irrigation in the United States, Israel, and Australia. Of all the major food crops, rice is the most intensive user of water. Because of its high water requirement, one may expect a shift in the decades ahead to a greater proportion of wheat, sorghum, millet, corn, and other cereal grains that have only half or less than half the water requirement of rice. Even further shifts may occur in going from corn to sorghum and millet.

Water is currently the limiting resource input for agricultural production in each of the five most populous countries on earth—China, India, the U.S.S.R., the U.S.A., and Indonesia. It is recognized as the most critical natural resource for future agricultural development in all of the Middle East, southern Europe, Egypt, the Sudan, all of sub-Saharan Africa, Taiwan, Pakistan, Australia, Argentina, Brazil, most all Canada, and most all of Central and South America. Much of the relative stability as well as the magnitude of agricultural production

in China, the most populous country on earth, relates to the fact that almost 50 percent of the cultivated crop land is irrigated.

New irrigation technologies for improved water use efficiency in the production of food are called for. Computer programming for automation of irrigation and customized water management will be the technology waves for the future (93). The recently developed "surge" technology in west Texas shows great promise for improving the efficiency of gravity flow irrigation systems (172).

Genetic Resources. There are an estimated 5 to 10 million plant and animal species now on the earth. The extinction rate is high (perhaps 1,000 per year) and rising (140, 202). By the end of the century, we could lose 1 million of the 5 to 10 million species. Five thousand plant species historically have fed the human race. Today, about 150 plant species, with a quarter of a million of local races, meet most all the calorie needs of people. Plant products derived from fewer than 30 species provide more than 90 percent of the human diet (140, 167, 228, 230).

Only 5 to 10% of the 250,000 to 750,000 existing species of higher plants have been surveyed for biologically active compounds. The plant kingdom has received little attention as a resource of potentially bioactive materials (11). Gene banks in developing countries may soon outnumber those in industrialized nations since 70% of the earth's species are in the developing countries of the tropics. China is particularly rich in rare and exotic plant and animal genetic resources. The center of origin of most all the food crops grown in the U.S. is in the Third World (24). Ethiopia with endemic food shortages is particularly endowed with genetic resources (124).

Our earth has 3.8 million square miles of soils too salty to grow conventional crops. Yet there are many crops that tolerate salt, including relatives of commercial barley, wheat, sorghum, rice, millet, sugarbeets, tomato, date palm, and pistachio. Also there are many equally salt-tolerant forage plants for livestock feeding, such as alfalfa, Lidino clover, creeping bent grass, Bermuda grass, and various reeds and rushes. Most of our so-called world collections of crops (genetic resources) are sadly deficient in wild races (140).

While there is an International Board for Plant Genetic Resources and hundreds of thousands of accessions are now found in various parts of the world, particularly in the U.S.A. (228), the U.S.S.R. (55), China, and the international agricultural research centers, there is, however, no organized program, either in the United States or internationally, to sample, evaluate, preserve, and utilize exotic and endangered species (or sources) of chicken, turkey, swine, sheep, goat, and cattle germplasm. Existing research and service organizations do not have the financial resources to undertake this expensive long-term program, which is of vital importance to the entire world (46).

NEW TECHNOLOGIES—FOOD CROPS

New technologies, along with resource inputs and economic incentives are the determinants that will control food production for the future. Some 20 to 30 crops stand between people and starvation (252). As past trends and future prospects are reviewed, increasing crop yield is the key to greater agricultural production. There is little evidence of yields plateauing except when constrained by Socio-economic politico factors. One of the most remarkable features of American agriculture is a two- to four-fold increase in productivity of major food commodities during the past 40 years. This has been achieved without an increase in cropland. Near comparable increases in production of some food commodities have been witnessed during the past 5 years in Indonesia and China with significant gains in Japan, Thailand, Taiwan, India, and several countries in the European Community.

There are two general types of food producing technologies for the future (250). The first is a highly mechanized and land, water, and energy resource intensive. It has produced the greatest output per farm worker the world has ever known. The second is biologically based and sparing of land, water, and energy resources. The future will see a worldwide shift from less of a resource-based to a more science—and biologically based agriculture. The emphasis will be to raise output per unit natural resource input and release the constraints imposed by relatively inelastic supplies of land, water, fertilizer, pesticides, and energy and human labor. Hopefully the output per farm worker will be maintained. It is projected that future increases in food production will come primarily from increases in yield

and from growing additional crops during a given year on the same land. This underscores in a dramatic way the importance of science and new technologies for meeting future world food needs. Automation and mechanization will continue in an important role (132, 133, 181). New high payoff food producing technologies for the future, to meet the needs of hungry and poor people, will be those which result in more dependable production coupled with higher yields, and are more labor than capital intensive, are crop intensive, and are sparing of natural resources. They must also be non-polluting. They will be the ones which offer solutions to global food problems and inadequacies in human nutrition, increase the demand for under-utilized labor resources and put people to work more days per year and more productively. There are many projections as to where the new frontiers in food research lie and what agricultural technologies will be like in the 21st century (3, 4, 7, 9, 10, 14, 15, 22, 49, 60, 66, 67, 68, 71, 72, 77, 78, 81, 90, 104, 105, 106, 107, 108, 109, 112, 123, 125, 126, 141, 146, 147, 148, 160, 183, 186, 187, 188, 189, 193, 199, 199, 200, 205, 207, 208, 210, 212, 218, 232, 233, 235, 237, 240, 242, 246, 248, 250, 253). A resume of some such technologies follows.

Genetic Improvement. Conventional plant breeding, with a focus on agricultural genetics, has contributed more to the increased productivity of food crops than any other technological input, and will likely continue to do so until the end of this century. The contributions have been steady and sizable (33, 65, 83). For the cereal grains, the wheat and rice varieties of the green revolution are legend, along with significant developments for maize, sorghum, millet, barley and triticale (10). Hybrids now cover one-third of the rice acreage in China with increases in yields, ranging from 10 and 25 percent. The first practical hybrids for cotton, alfalfa and rapeseed, are now being field tested. New early maturing maize hybrids cover vast areas in northern and western Europe, in contrast to the almost complete absence of this crop only 25 years ago. Corn production has been moved 500 miles further north in the U.S. in the last 50 years and 250 miles nearer to the earth's poles in the past decade. Winter wheat has moved 200 miles northward in the Soviet Union. About half of the increase in U. S. soybean yields during the past 50 years, has resulted from the contributions of plant breeders. Disease-resistant high-yielding sweet potatoes and cassava, drought tolerant sorghum (23), early maturing pest resistant cowpeas (201), hybrid coconuts, carrots with 3-fold increases

in carotene (198), genetically improved triticale varieties resistant to both cool temperatures and soils (103), and many more are among the contributions of those engaged in genetic improvement by conventional plant breeding technologies.

Elements of crop improvement include increases in yield, changes in plant architecture, leaf orientation and height, improved harvest index and cropping index, greater reistance and tolerance to diseases and insects, and the abiotic stresses of temperature extremes, soil salinity, acidity (aluminum toxicity) (43) heavy metals and drought (18, 21, 70).

The composition of seeds, fruits and vegetables has been manipulated by plant breeders. Seed proteins have been altered to improve the biological value of species proteins. Soviet plant breeders have increased the oil content of sunflowers from 30 to 50 percent and the Chinese have significantly lowered the erucic acid in rape seed. The alkaloid gossypol has essentially been eliminated in some varieties of U.S. cotton.

There are also special genetic traits that indirectly contribute to crop improvement and food supplies. They include cytoplasmic and genetically controlled male sterility essential for producing hybrids of many horticultural and agronomic crops, and genetically tailored plants adapted to mechanical harvesting. New crops enter into many of the projections relating to the adequacies of food supplies for the future (35, 37, 39, 47, 61, 64, 87, 128).

Important for the future in plant breeding programs will be to collect, inventory, preserve, and more extensively utilize the germplasm that is now available and being added to daily (55, 167, 228, 230). Computers, now generally available for research purposes, will aid greatly in the effort to catalog genetic resources, conduct complex experiments, summarize and manipulate data, and communicate the results of research (93).

Biotechnology. Exotic genetic engineering techniques include protoplast fusion (34), various systems of tissue, anther and meristem culture, the use of recombinant DNA, construction of plasmid vectors, the use of cloned DNA fragments and transposable elements. The ability to clone many crops *in vitro* has been achieved, and the crown gall (*Agrobacterium*) T plasmid

system enables the incorporation of potentially useful germplasm into food crop cells. All the above have become almost routine. The biochemical characterization of physiological and agronomic traits, that contribute to the control of such basic biological processes as photosynthesis, the storage of protein stress resistance, and symbiotic nitrogen fixation is still another approach. These techniques have yet to find a place of any significance in food crop production, but complex biotechnology, commonly referred to as genetic engineering, may ultimately add more to our food supplies than any other development (32, 42, 119, 122, 138, 139, 147, 220, 224).

Meanwhile, some significant down-to-earth developments in biotechnology are having, or will soon have, some major impacts for food production and its utilization. First among these are cell, tissue, and haploid culture. Tissue culture will be the pathway by which many genetically engineered and disease resistant plants will ultimately find their way to field production. Chief among the crops which may be clonally propagated by tissue culture technologies to achieve disease-free selections are potatoes, sweet potatoes, cassava, yams, plantains, bananas, the oil palm, strawberry, asparagus, onion, garlic, many forage crops, and forest trees and a great variety of flowers and ornamental plants. Tissue culture is a means of achieving rapid multiplication of the highest yielding individual plants (32, 51, 94, 98).

Another significant potential for culturing plant cells and tissues, is a new means for commercial processing of rare plants and the chemicals they produce. This will greatly enhance the usefulness of plants as producers of renewable resources and in promoting new products for regulating plant growth, and for insect, disease and weed control. A classical example is the clonal propagation by tissue culture of 11 million elite genotypes of pyrethrin plants in Equador, whose flowers contain large amounts of pyrethrin, a naturally occurring insecticide (11). The production of rare alkaloids and other metabolites has also been greatly enhanced by selective cell cultures (11, 256, 257). Biotechnology is making many contributions in food processing as well as for food production (115). The recent announcement of the construction of a recombinant metabolically engineered bacterial strain that will syntheisze a key intermediate in the production of ascorbic acid, is exciting (5).

While it is recognized that the most widely acknowledged

contributions of biotechnology reside in the human medicine and pharmaceutical areas (54) there are widening frontiers for enhancement of food production and resource utilization, both with crops and livestock. The avermectins—novel insecticides, acaracides, and nematicides are products of a species of streptomyces (178). It has been recently discovered that the fungus that causes white-rot decay in wood, and the enzymes from it will break down lignin, the second most abundant organic compound on earth. The enzyme can also be used as a catalyst to degrade environmental pollutants, toxic substances, industrial wastes or for on-farm chemical waste disposal units (29). Hybridoma clones have been identified which secrete specific monoclonal antibodies which are effective against aster yellows, an economically important mycoplasma-like disease that affects many food and ornamental crops (124). Meanwhile, many products of biotechnology of economic value as pharmaceuticals for people, have counterpart uses for food animal production and disease control (54).

There are four areas where biotechnology, for the near term, will play an important role in food crop production. First, there will be improved efficiency in producing new genetically improved disease-resistant crops through the tissue culture cycle. The values of this technique are already being realized with some major food crops and many of the minor ones. Secondly, anther culture will cut the time in half that it takes to produce a new variety of wheat or rice. Results have already been taken to the field in China (96, 97). Thirdly, food crops will be developed that are resistant to herbicides (38, 64, 89). Considerable progress has already been made with maize and sorghum. Finally, plants will be developed that have built-in pesticides, and genetically engineered bacteria may be incorporated into the soil that will control pests.

New Fertilizer Technologies. The most important industrial input into food production is that of nitrogen fertilizer. Almost 50 percent of the fossil energy requirement for crop production resides in this single product. Energy needs and oil prices, however, have not been the constraint on food production that was predicted over a decade ago. Prices of petro-chemical-based fertilizer, particularly nitrogen, did not rise as much as oil because the primary input was natural gas, much of which is still being wastefully flared in oil rich countries. Also, more energy efficient processes for chemical fixation were developed.

Technologies that will result in greater efficiency in fertilizer uptake and utilization will be necessary to sustain future food production. Losses of fertilizer nitrogen in the U.S. approach 50 percent, half of which is used on a single crop, corn. Up to two-thirds of the applied nitrogen may be lost in tropical rice culture. Any technologies that will reduce losses from denitrification, volatilization, surface run-off and soil erosion, from burning, and losses by leaching below the root zone must be sought after (41, 79, 101, 197). The benefits would be greater crop productivity, profitability, less environmental hazards and a sparing of non-renewable resources.

New technologies for improving biological nitrogen fixation under field conditions with economically important food crops, offer a continuing challenge. Biological N_2 fixation research, until now has been outstandingly productive of sophisticated basic information on a better understanding of mechanisms and processes with essentially no significant or practical field applications for increasing crop productivity.

Some significant developments, however, are now in progress, in placing the results of laboratory studies of biologically fixed nitrogen into the field for enhancement of food crop production. One of the most immediate benefits has been with Azolla-Anabaena symbioses for rice culture in China, and as a high protein food source for pigs (127). Major constraints are high labor requirements, the availability of phosphorus and a high sensitivity to herbicides.

There are other developments that show promise of field applications (52, 135, 162, 201, 231). Soybeans have been developed that nodulate prolifically under tropical environments, and thus, supply their own nitrogen (102). Field beans have also been bred for improvements in nodulation and have been matched with more effective strains of Rhizobia. The result is that the biologically fixed nitrogen is now substituting for the previous requirement of nitrogen fertilizer. Finally, the Cooperative Research Support Program sponsored by the United States Agency for International Development has initiated research programs and provided the catalyst for plant breeders and microbiologists to work together in the solution of field production problems with field beans and cowpeas.

The potential of new technologies for enhancement

of food production through modification of mycorrhizal root associations and root colonizing bacteria are great (190, 211). Since mycorrhizae cannot yet be grown in pure culture and do not reproduce sexually, the genetics are not known. The benefits of mycorrhizae on phosphate and micronutrient uptake and drought tolerance are becoming well-known and are exciting areas to pursue (2, 12, 88, 111, 134, 203). Next to nitrogen, potassium and phosphorus are absorbed in the greatest quantities by food crops. Phosphorus, in particular, is often in low supply and a function of the large quantities that are fixed in the soil and unavailable. Potassium, as a plant nutrient, is in short supply in China and is a major constraint in food production especially south of the Yangtze river (143). There is still the unresolved long-standing controversy as to foliar versus ground applications of fertilizer relating to efficiency of uptake, yield responses, costs and conservation of resources (80, 204, 254). Micronutrient needs may be more effectively supplied from foliage application than from the soil.

Biological Constraints and Biologically Active Chemicals. There must be integrated approaches to pest control. Strategies for the future will rely on new technologies for cultural management, host plant resistance, allelopathy, biological controls (1, 44, 95), new pesticide developments and pesticide resistance/biotype adaptation. A major conceptual philosophy of pest control in the U.S.A. and other nations during the past 10-20 years, is integrated pest management (16, 54, 163, 214). The intent is to reduce costs, minimize environmental and human health risks and improve control strategies. A major concern is the rising number of resistant biotypes and the increasing need for pesticide resistance management (58, 149). Viral and bacterial insecticides will become prominent as control agents. The focus for the future should be on the simultaneous management of multiple pests (insects, disease and weeds) as an integral part of crop management. Herbicide resistance at the whole plant, cellular and molecular levels will be pursued (64, 89), and a renewed effort will be directed to allelopathic responses and the identification and characterization of "nature's own herbicides."

A new class of biological active compounds, designated as the next generation of chemical plant regulators, (28, 131, 155, 244) is emerging. Some are inhibitors of sterol and gibberellin synthesis, and have both fungistatic and plant growth regulatory capabilities and a wide spectrum of effects (86, 216).

Included for the induced responses are gametocides for rice and wheat, growth promoters for tissue cultures, partitioners of carbohydrates, regulators of microbial activities, control of lodging in corn and cereals, programmers of plant growth, harvest aid chemicals, seed germination, root growth, nutrient absorption and transplant survival. Triacontanol is stimulating a plant growth regulator revolution in China where it was used on 17 million acres in 1984 to stimulate the productivity of rice, wheat, maize, peanuts, rapeseed, beans, and mushrooms. There are still, however, many uncertainties as to its consistent effectiveness (184). A myriad of possibilities exist in the field of chemical plant growth to modify basic biological processes that control crop productivity (73, 75, 116), and for control of some of the world's worst weeds (6).

Recent progress in chemical weed control has been phenomenal (92). Herbicides now account for 85% of pesticide usage in the U.S. Weed science is a new science with its beginnings in the late 1940's. The backbreaking drudgery of weed control has been greatly reduced in agriculturally developing countries, as well as the developed with significant returns over costs. For corn and soybeans, modern weed control has reduced energy inputs for crop production in addition to increasing the yields by 15 and 9 percent, respectively. The value of chemical weed control for yield enhancements are even greater with solid seeded cereals, and their use has reduced the needs for fallow. Herbicides have also contributed significantly to reduced tillage practices which are now extending far beyond the borders of the U.S.

Weed control technologies for the future will see innovative biological approaches (161), and include the use of highly effective materials at only a few grams per acre. There should be a systems approach to conservation tillage utilizing allelopathic properties of many commonly available plant mulches and residues coupled with the identification and use of natural herbicides derived from them (174, 176). Other technological potentials reside in conventional plant breeding and genetic engineering of cells and chromosomes for developing herbicide resistant food crops. Considerable progress in these areas has already been reported (147). Crop varieties with appropriate built-in resistance to specific chemicals will be developed and sold as complete packages for grower use.

Mixed Cropping. Intercropping or mixed cropping is

the most common system for food production in Africa and many other parts of the third world including South America, parts of China and in southeast Asia. It is now believed that mixed cropping and other traditional food producing systems comprise an involved set of techniques that provide something close to the very best substitute for productivity under the existing environmental conditions and technology. Such systems reduce the crop failure risks of depending on a single crop; they provide a variety of returns from land, water, and labor; they optimize the use of sunlight, moisture, and soil nutrients, particularly nitrogen; reduce the spread and severity of pests, compared to typical monocultures; and may substantially increase food production over that realized in equivalent single crop programs. An opportunity for enhancement of food production in many countries where the most endemic food shortages now exist, would be to address new technologies that would improve the food output from traditional mixed cropping systems. Such a research effort might also aid farmers in the western world to cut economic, energetic, and environmental costs and at the same time enable those in agriculturally developing countries to escape some of the pangs of poverty and food shortages.

Protected Cultivation. Significant developments, coupled with new technologies for the future, are occurring worldwide in what could be termed a "plastic revolution." The approach is highly intensified crop production with computer programmed inputs and controlled top and root environments.

A nutrient film technique, developed in the early 1970's at the Glasshouse Crops Research Institute in England, is now considered by some as the most promising hydroponic or soilless system yet developed. It involves highly sophisticated plant production with prescription types of watering and mineral nutrient controls (45).

Other developments include sensors of environmental variables and computer programmed inputs of temperature, water, photoperiod, mineral nutrients, atmospheric CO_2 and light conditioned for the season of the year, species of plant and stage of plant development. Plastic mulches, row covers, and greenhouses, for the production of basic food crops as well as for high value commodities can now be observed extending from the equator to the arctic circle. Plastic row covers, greenhouses, and soil mulches for crop production were introduced shortly after

World War II into the U.S. by Professor E. M. Emmert, now considered the "father of agricultural plastics" in America (62). Their use has since grown precipitously, with the introduction of new materials, improved structures and increased knowledge of factors controlling plant growth. Slitted row covers have reduced installation labor by 80%, and spun bonded polyester covers are even more easily applied. Their floating characteristics leave sufficient slack to accommodate to the growth of plants. With row covers, both early and total crop yields are improved and there is protection against insect pests and frost with increases in lengths of harvest seasons (206, 227).

Plastics for enhancement of high value crop production and protection are widely used in Israel, the Soviet Union, and other Soviet block countries, Turkey, Italy, Spain, Portugal, France, the Netherlands, England, Germany and Scandinavia, United States, Canada, Australia, New Zealand, South Africa, Kenya, and Nigeria.

The most extensive use of agricultural plastics is now in the orient. With Japan's leadership, plastic greenhouses, row and seedbed covers, and soil mulches have moved into Korea, Taiwan, and most recently and extensively into China. In China, rice seedbeds are covered with plastic for earlier seed germination and growth. Plastic soil mulches are extensively used for cotton, with upwards of 1 million hectares in 1985. Other important uses are for peanuts, sugar beets, vegetables, and watermelons (188, 258). Advantages are increases in crop yields and quality, weed control, greater water use efficiency, prevention of soil erosion, earlier maturity and extending the boundaries of successful crop production. Even in Nigeria, the use of plastic soil mulches is receiving its first field tests on cassava, yams and cocoyams. The values are in weed control, conservation of soil moisture, reduction in soil erosion and compaction, and overall improvement in crop yields.

A related development in the use of plastics in agriculture is the rapid expansion of drip irrigation for increased water and fertilizer use efficiency for high value crops. Plastic tubing and plastic laterals are essential. Other significant technologies for the future in controlled environmental agriculture, will be biodegradable plastics. This will minimize or eliminate what is becoming a "plastic pollution" problem with currently used materials.

Maximum Yield Trials. The need for eventually increasing the earth's capacity for food production and to essentially double that of today has led to estimates of the carrying capacity of the earth, the biological limits of productivity, and the limiting factors in crop and livestock production. The gap between what production is now and what it could be is the great food reserve upon which nations can depend and call upon, if need be, for the support of future generations. The current (1985) world record for maize production is 370 bushels per acre achieved by Herman Warsaw of Illinois. This is the highest record for any cereal grain. A new world record of 10 tons per acre has also been reached for alfalfa grown under non-irrigated conditions (209).

Maximum yield trials should become a major part of current and future agricultural research (75, 101, 153, 168, 209, 222, 255). They should represent the ultimate in use of high technology for food production. They are as important for practice as for theory. Records of production for many food commodities of 25 years ago are the averages of today. Record yields should not be regarded as abnormal occurrences (19). A study of the comparative productivity of previously successful agricultural systems could be most rewarding. Scientists should be encouraged, with the aid of modern computer technologies and crop models, to test the limits of available technologies as well as their ability to put together technology components in a systems approach to achieve maximum production. This is what successful farmers are expected to do. Further major breakthroughs in food production will come only if the total agricultural production system is considered. This is true also of successful research programs and technology innovations. Simulation models depicting growth, development, and yield of major food crops are now being designed. These include maize, wheat, rice, soybeans, field beans, potato, cassava, sugarbeets, and sugarcane.

Pockets of Success. There are some notable and recent examples of successful food producing systems throughout the world (239). These include grain production in India's Punjab which rose threefold from 1965 to 1975. Yields of rice in Colombia went from 1.8 metric tons per hectare in 1965 to 4.4 in 1975. Wheat production in Turkey increased from 7 to 17 million metric tons from 1961 to 1977. The white ("milk") revolution in the Gugarat of India involved over one million farmers with a resul-

tant daily cash income, improved nutrition, and a series of labor-savings technologies. New maize production technologies in Kenya increased yields by 4.8 tons per hectare. In the Yaqui Valley of the State of Sonora in Mexico a fivefold increase in wheat yields was recorded in the 20 years from 1950 to 1969. The introduction of hybrid maize in the U.S. increased yields by fourfold from 1940 to 1985. More recently, through technological inputs and economic incentives, rice yields in Indonesia have been doubled in five years, and that nation within three years has moved from being the largest importer of rice to the one with the most abundant resources. In Africa there is the modern day drama of inadvertent transfer of improved cassava clones now grown on over one million hectares to farms beyond the borders of the International Institute of Tropical Agriculture in Nigeria from whence they had their origin (201). Finally, from a newly established production responsibility system in China, with its economic incentives and influxes of new technologies overall crop production has increased by 45% and livestock by 70% since 1980. Cotton production rose by a phenomenal 175%. All this was accomplished with no increase in cultivated land. The ingredients—technological, social, economic, natural resources—that have gone into these and other pockets of success should be identified. Wider adoption or review of these production system models could give encouraging results elsewhere. Any advocacy group looking for alternative food producing technologies, such as organic gardening or sustainable or regenerative agriculture, or associated appropriate agricultural production systems, will find them in China. Farmers there have been in business for 40 centuries (188).

NEW TECHNOLOGIES-FOOD ANIMALS

Animals are nature's protein factories. They harvest vast food resources (forages, roughages) otherwise of little value and convert them to milk, meat, eggs, and other useful products. They are living storehouses of mobile food (17), and constitute a global food reserve that approaches that of grain but is distributed more evenly and often transported more readily. Per capita meat consumption during the past two decades increased in all nations, with several-fold increases in Japan and Israel (13). Livestock and poultry provide 53% of all foods consumed in the United States, including two-thirds of the protein, one-third of the energy, one-half of the fat and significant quantities of

the essential minerals, micronutrients and vitamins (170). Worldwide, animal products contribute over 56 million tons of edible protein and over one billion megacalories of energy annually. With its high biological value, animal protein is equivalent to more than 50% of the protein produced from all cereals. As global populations grow, purchasing powers increase, and demands for improved diets develop, there will be dramatic increases for food animal products. Despite the food shortages in the early 1970's, it is now clear that the world can produce sufficient forage for food animals and enough grain for livestock as well as for humans. Technologies for greater food animal productivity include genetic improvement and diversity, reproductive efficiency, better feeding, environmental control and greater resistance to environmental stresses and disease control, health and animal welfare (247).

Genetic Improvement, Diversity, and Reproductive Efficiency. The Best Linear Unbiased Procedure (BLUP) for computerization of performance of individual dairy cows is now widely used, nationally and internationally. Artificial insemination is essentially a worldwide practice for dairy cattle and turkeys. Crossbreeding of beef cattle and swine is widely practiced and brings together desirable characteristics from more than one breed. With greater reproductive efficiency, high quality breeding animals will be better utilized. There are now and will be marvelous opportunities for rapid genetic improvements through chemical induction of super-ovulation and control of the reproductive cycle. This is true also for semen preservation, pregnancy detection, multiple births, and non-surgical embryo transfer and implantation. These are now realities. All can increase, and dramatically so, the number of offspring from genetically superior parents. These techniques are now revolutionizing genetic improvement, resulting in resource conservation and improved productivity of all farm animals (152, 194, 225).

It is now possible to non-surgically recover embryos from super-ovulated cows, divide each embryo in half and routinely obtain pregnancy rates of more than 50% per half embryo after non-surgical transfer. This is greater than 100% per original embryo. It is also now possible to freeze and sex embryos (195, 196).

Swine reproduction technologies will emphasize breeding at earlier ages (six to seven months), first farrowing at 10 to

11 months, increased ova-fertilization, implantation and placentation with greater embryo survival. More piglets (10 to 12) will be farrowed per litter. They will be weaned after a three-week lactation, and sows rebred on first estris (five to seven days after weaning). This will allow up to 2.5 litters per sow per year and up to 25 pigs marketed per sow per year.

A means of overcoming genetic vulnerability of livestock in agriculturally developing countries is through genetic manipulation within the native breeds. An example is the Criollo of Central America, which has been crossed with the Zebu. The resultant F_1 cattle shows excellent performance, though rapid degradation occurs in subsequent generations. One remarkable achievement has been with Jamaica-Hope, a cross of the Jersey and Sahiwal. This new, high-performing breed is well adapted to tropical environments.

Genetic material may also be introduced through game animals such as the eland, an antelope adapted to very arid areas, which could be a meat animal of some potential. The problem is that game animals are, or have the potential to be, propagators and carriers of disease. Thus, veterinary officials tend to refuse consideration of anything other than cattle, sheep, goats, and pigs. Nevertheless, game or wild species, with their great genetic diversity, should be considered in the decades ahead as alternative meat animals. Another objective would be to breed toward more effective utilization of given feedstuffs, including by-products and wastes. This will be particularly true with short generation species such as swine and chickens.

A significant effort for all farm animals will be directed toward the development of new genetic types that will respond to harsher environments, economic constraints and restricted feed supplies (50). Costs are too high to modify the environment in agriculturally developing countries. Efforts, however, will be continued in modifying the environments for livestock in the United States and other industrialized nations. Other objectives will be to breed toward more effective utilization of a given feedstuff, including by-products and wastes. These will be particularly useful for short generation species such as chickens, turkeys, ducks, swine, and even beef cattle.

There is definite genetic vulnerability in livestock with response to harsh environments. In developing countries, resources

are not sufficient to let the genetic capabilities show forth where many production inputs are limiting. Under such conditions, any shortages of feed supply, prevalance of disease, or adverse environments will reflect on the productivity of genetically superior animals (192). The United States, Japan, and many European countries are in admirable positions to modify the environment and provide inputs for livestock to achieve maximum productivity.

Improved Feeding. The manipulation of basic biological processes in livestock for improved productivity is equally as promising as for crops. The first area for beef cattle involves changes in body composition and gain in weight with the objective toward more lean meat. There are possibilities with feeding, management, and genetics to encourage more lean and less deposition of fat for beef animals. Heretofore, for beef cattle, a single option has been the primary choice—larger steers being killed at a younger age resulting in more lean meat. There are now two other options. The first involves the intervention with several hormones or anabolic steroids which are now commercially available. They consist of combinations of progesterone, estrogen, testosterone, and zearolone (of plant origin) as feed additives. A second possibility is with growth hormones, bovine and porcine, which by the year 2000 will be available for regulation of the growth and productivity of food animals, including dairy cattle, beef animals, swine, and possibly fish and poultry (159).

An additional possibility for manipulating a basic biological process is control of rumen nutrition. This would be the use of ionophores, which are antibiotics produced by streptomyces. Ionophores are effective on ruminants and also as coccidiostats on chickens. The best result with ionophores are obtained with beef cattle. There is a problem in their use with dairy cattle because of a reduction in butterfat in the milk. Carboxylic polyether ionophores when fed to growing ruminants, improve the efficiency of production. Ionophores save feed or provide more gain with less feed. Animals on a high roughage ration in the presence of ionophores have the same feed intake but increased rates of gain. With a high rate of gain, feed intake is depressed but with equal rates in gain. Ionophores change the microbial composition of the rumen. Two have been introduced and widely accepted. A 90% market penetration was obtained with "Monesin" in less than one year and along with "Lasalocid," another ionophore, have received Food and Drug Administration approval in the

United States. Still more active ionophores will be identified and their use will be greatly improved over the present.

Isoacids, a new class of feed additives for dairy cows, have been identified (10). They increase bacterial action and protein synthesis in the rumen, thus reducing feed requirements or increasing milk production or both. Zeolits are a new ingredient which may also reduce the calories required to produce poultry and red meat.

For the future, selection of genetic characteristics that control protein synthesis will be a definite possibility, and genetic engineering will play an important role beyond the current possibilities in animal disease control.

There will also be in industrialized countries a partial transition from feed grains (corn, barley, soybean, oats) to more legumes or more specifically from corn to alfalfa. This will be prompted by increasing prices for energy inputs into corn production.

Meanwhile, significant progress has been made in maximizing yields of alfalfa beyond 10 tons per acre per year under non-irrigated conditions. Technological challenges for the future will be minimizing harvesting and handling losses of alfalfa which could come from new harvesting techniques, the use of chemicals (sodium carbonate and potassium carbonate) for hastening field drying and from improved storage facilities.

Pork production is becoming rapidly industrialized in the U.S. and in many other countries (169). Improvements will be made in feeders which will dispense food and water from programmed units eliminating feed wastes and allowing for maximum feed efficiency. Grain (corn, sorghum, barley) in soybean meal diets will predominate, but synthetic lysine and tryptophane will be used extensively to reduce the amount of soybean meal used. Also, the use of fresh dried blood meal and other by-products of food manufacture will occur. Economical means of cellulose and lignin digestion will be accomplished. This, along with the practical production of bacterial and yeast proteins, will allow use of low grade feedstuffs, both for swine and poultry, heretofore only utilized by ruminants. The ultimate goal will be to increase the productivity of swine, other livestock and poultry with consequent improvement in the efficiency with

which forages, by-product feeds, wastes, and grains are converted to milk, meat, and eggs.

Environmental Control and Resistance to Environmental Stresses. Each food animal has a narrow temperature range for optimal performance (8). Modifications in housing, feedlots, pastures, and feeds have great potentials for helping animals adjust to temperature limitations.

Controlled environments constitute a realm of technology scarcely tapped for livestock production. They are widely used now for poultry and swine and are under test for sheep and goats. Programmed lighting (photoperiod) and temperature regulation should be vigorously pursued relative to their effect on dairy cattle productivity, feeding efficiency, rates of gain, hormonal relationships, and reproductive behaviors. A photoperiod extended to 16 hours in mid-winter in Michigan has resulted in a 10% increase in milk production with high producing dairy cattle. This has been achieved with no additional feed inputs (215). The technique also works with horses.

Environmental stresses, especially those of high and low temperatures, have a marked effect on animals. They change the rate at which they grow, reproduce or accomplish their desired functions of meat, milk, or egg production. Temperatures not only impact directly on animal physiology but indirectly on forage production, parasites, diseases, and soils.

Basic research on alleviation of environmental stresses for livestock and poultry through genetic improvement, hormonal regulation, feed intake, and controlled environments will encompass an important part of our food and agricultural systems for the future, as well as the productivity of rangelands and wildlife. The future will see emphasis on basic research relating to optimal environments that are species specific for livestock and poultry. Controlled environments will become the rule rather than the exception. Such environments already exist for chickens and turkeys and to some extent for hog production. Comfort, productivity, and economics must be equated for future advances in environmental control with that of animal welfare advocates.

Improved housing, providing environmental control for animals in the decades ahead, will be promoted by interest, both in animal welfare and comfort, for increasing reproductive

efficiency performance, and disease control and for improved feed utilization in milk and meat production.

Ethology, the science of animal behavior, will be coupled with physiological evaluations of stress (158). This, with sensors for the environmental factors of temperature, light, humidity, and air movement, will set the stage for innovative management and housing methods for animals in the future (248).

Disease Control, Animal Health and Welfare. Diseases of food animals, perforce, are diseases of relatively young animals. This is especially true of chickens, pigs, and beef cattle. Hence, health problems with dairy cows are reproductive problems, mastitis, calf mortality and exposure to toxic substances. For beef cattle, its respiratory diseases (shipping fever), reproductive disorders and calf mortality. For swine, its reproductive disorders, intestine or digestive diseases, respiratory and locomotion problems. In all, disease control is closely linked with genetic resistance, reproductive problems, nutritional deficiencies and environmental constraints.

Genetic engineering involving embryo transfer techniques and immunogenetics will produce livestock that are both productive and disease resistant. Molecular biological techniques such as the cloning of genes by use of DNA manipulation will produce substances such as interferon and lymphokines effective against destructive animal viral diseases and specifically active vaccines to reduce losses from infectious diseases. The first genetically engineered vaccine which is fully safe and effective against hoof and mouth disease has been developed. Monoclonal antibodies (hybridomas) will be used for both disease diagnosis and target treatment of diseases. The mechanism of tumor development will be identified. Reduction of deaths between conception and weaning have great potential for improving the biological productivity of livestock. The predictable benefits from these efforts will be in terms of improved animal health reflected in both human and animal welfare. In summary, recombinant DNA technologies offer remarkable opportunities for restructuring animal phenotypes, producing disease protective vaccines, and for efficient production of hormones, vitamins and antibacterial agents for more efficient animal production.

The discovery of the hybridoma technique in 1975 and its significance in animal disease control deserves special mention.

It is a method for creating pure and uniform antibodies against a specific target. Scientists learned how to fuse myeloma (cancer) cells with antibody-producing cells from an immunized donor. The hybrid cells or "hybridoma" resulting from this fusion have the ability to multiply rapidly and indefinitely in culture and to produce an antibody of predetermined specificity, known as a "monoclonal antibody." This new hybridoma technology for production of standardized reagents (antibodies) of a given class, specificity and affinity has now provided scientists with a tool that permits analysis of virtually any antigenic molecule. Such reagents can be made in virtually unlimited amounts whenever needed, thus making them readily available to all investigators or diagnostic laboratories. The new technology provides a breakthrough in the methods available for analysis of the antigenic composition of microorganisms for rapid disease diagnosis and to aid in the development of vaccines. It affords an opportunity to make important advances in understanding not only the diseases of animals, but plants and humans and with greater specificity and speed, and a reduced cost.

The current widespread use of feed additives, growth hormones, steroids, antibiotics, chemotherapy, and pesticides for food animals will reach a crisis within the next two decades from an objecting public concerned with environmental issues, food safety, human health, and animal welfare (91, 191). Alternatives to the use of the many biologicals and pharmaceuticals for pigs, chickens and cattle will be emphasis on built-in permanent genetic resistance or tolerance to disease coupled with improved management and housing. Such genetic resistance now exists in many of the native animals in certain parts of the world. A specific example is the water buffalo's resistance to environmental stress. It also has greater resistance than other cattle to mastitis, hoof and mouth disease, rabies, and contagious pleuropneumonia anaplasmosis. Cattle of West Africa have also been found that are tolerant of sleeping sickness, and this tolerance is now being bred into susceptible native stock by scientists at two international agricultural research centers in East Africa.

CONCLUSIONS AND OVERVIEW

This report has focused on new biologically oriented technologies and resource inputs needed to sustain global food productivity in the decades ahead. Socio-economic and political

issues have not been adequately addressed nor that of the unequal distribution of human capital, (179, 229), appropriate institutions, infrastructure, diet and health, profitability or international trade. Instabilities in world agriculture are more attributable to human intervention than to nature, although food production continues to be buffeted by both forces.

In short term, solutions to regional food shortages calls for a redistribution from the haves to the have nots through food aid programs (217). The long term answer resides in getting food produced closer to where the people are and providing an income so they can buy it. Only poor people go hungry.

There is currently a remarkable inequality in the incidence of human capital throughout the world. This is the basis for the development and concentration of pockets of poverty, malnutrition and most of the food shortages. Reducing this inequality would provide increased prosperity and well-being for peoples of all nations including the U.S. The United States with its uniquely endowed educational system should assume a major and continuing role in reducing this inequality.

Attempts of forecasters of a decade ago to assess global food futures, population growth, and the adequacies of food supplies were strongly influenced by the then pervasive climate of food pessimism and more broadly technological pessimism that dominated much of the decade of the 1970's. Model builders and future's simulators were then in an intellectual environment that would have regarded more optimistic projections, which have now come to pass, as "out of touch with reality" (69).

The capacity to produce enough food, and more than enough, for a growing world population, with rising purchasing powers and increasing demands has been demonstrated. That capacity, whether it is used or not, should be maintained. This can come only from continuing inputs of new technologies related to both the stability and the enhancement of crop and livestock productivity. Such technologies must be in packages that can be delivered to farmers of varying managerial skills and that have the financial resources to put them to use (142, 166).

An immediate challenge for most of the world in meeting food needs for people—quite different than a decade ago—is to avoid over-production, with the over-commitment and waste

of resources that go with it. A second challenge is better utilization and improvement of the nutritional value of what is produced (66, 115, 125, 193, 198, 226, 241, 252).

In approximately a year and one-half from the date of this forum commemorating the 200th anniversary of the founding of the Philadelphia Society for Promoting Agriculture, the oldest in America, we will be celebrating the bicentennial of the origin of the American Constitution which was formed also in Philadelphia. Science was not a part of the original constitution nor was it prominent in America's agriculture of 200 years ago. Meanwhile, science and technology have become prime movers not only for nations but for modern day food producing systems and for these we project in the decades ahead. All this is a part of the Philadelphia Story (36) that we are commemorating this day.

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EFFECTIVE DEVELOPMENT AND UTILIZATION OF FOOD PRODUCTION RESOURCES

Emery N. Castle

My assignment is a large one. World agriculture is indeed diverse and every nation has unique natural resources. But I am fortunate to share the program with a speaker who has discussed technology as well as one who will address economic incentives. Resource development and utilization is conditioned by technology and influenced greatly by economic conditions.

My approach is straightforward. I will first discuss resource development and utilization of food resources where economic development and the rate of improvement is low relative to other countries of the world. This discussion will focus on generic problems rather than specific geographic regions. I will then turn my attention to problems of resource utilization and development where development has reached a higher level or is proceeding at a rapid pace. In both instances I will focus on group and individual decision making or on what is likely to happen when the government intervenes in particular ways.

WHEN DEVELOPMENT IS AT A LOW LEVEL AND PROGRESS IS SLOW

Study and observation of global agricultural resource use reveals that diverse problems exist in getting development underway. When both the rate and level of economic development are low, population growth usually is high. Many people are poor whether measured according to some absolute standard or compared relatively. Under such conditions agricultural resource use often is not in a long-run equilibrium condition. That is to say, resource use often is getting worse, not better, and is not in a steady condition.

Several conditions must be met if conditions are to improve. We need to classify and diagnose problems if improvement is to occur.

In some instances the technical knowledge necessary for improvement is lacking. Soil types vary greatly around the world and knowledge obtained in one geographic area is not easily transferred to another. When this situation exists, investment in knowledge creating activities clearly is required. But improved natural resource usage may well require improved knowledge in many areas—not just better knowledge about soil or water. It frequently is assumed that a lack of technical knowledge about resources is the cause of resource misuse and the improvement of technical knowledge is both the necessary and sufficient condition for the improvement in resource use and the stimulation of economic growth. However, it is my belief that this set of problems is far more complex in nature.

Dr. Schuh told us that foodstuffs need to be properly valued in both the domestic and international markets. There is a growing appreciation of the importance of such policies but even technical change combined with appropriate agricultural and trade policies are not sufficient for improved resource use in some instances.

New technology will always change the combination of labor, land, and capital which is used to produce food. Typically it is associated with greater investment (more capital) in humans and less labor per unit of land. Even if more people per unit of land are used, the percentage of the population required to produce food will be reduced and some of those engaged in food production on the land will be displaced. This is not necessarily bad if employment is provided elsewhere in the economy but it is exceedingly unrealistic to assume that improvement in agriculture and economic opportunity outside of agriculture will always grow at the same rate.

What happens when they do not grow at a comparable rate? In actuality many adjustments occur but two need to be mentioned here. The one that is discussed the most is rural-urban migration which results in overcrowded cities and urban poverty. The other adjustment of great importance to this discussion is the absorption of excess people in rural areas. When excess labor resources remain in the rural areas, these people must

have some kind of access to natural resources if they are to survive, which usually means increased pressure on marginal lands. Technical change typically occurs on lands where the returns to new knowledge are the greatest but this often results in greater pressure on marginal lands.

Under such circumstances a key question is what kind of access is permitted to the natural resource base? The way this question is answered frequently determines whether people will migrate to urban centers or whether they will go to the marginal lands. One cannot say generally which is preferable but it is important to note that this is a property rights issue. Often it is stated that resource exploitation results from the existence of common property resources. I believe this is incorrect; the issue is one of access. Access can be denied to common property resources just as it can to private property resources.

This brief discussion has made clear the highly complex nature of natural resource utilization under developmental conditions. Technical knowledge about soil and water management is essential and vital, but it is far from sufficient for the avoidance of resource exploitation. Generalizations are hazardous but it can be said that natural resource conservation usually takes a back seat to human poverty. Most societies will not deny people an existence or an opportunity for existence to preserve a natural resource. Resources are fundamental and those concerned with resource policy are, quite appropriately, concerned not only with technical change and economic incentives, but also rural poverty and property rights. Narrowly focused resource and food policies often are not very productive and, if resource exploitation is to be improved, in many instances rural poverty must first be addressed.

WHEN DEVELOPMENT IS AT A HIGH LEVEL OR PROGRESS IS AT A RAPID RATE WITH SPECIAL ATTENTION TO THE UNITED STATES

Two cases of natural resource use will be discussed in this section. One is where erosion is high and soil productivity is not being maintained. The other is the problem of marginal lands in agriculture.

Soil erosion. Earlier in this paper the term resource exploitation was used but not defined. As used here exploitation means use that cannot be sustained if continued in the present way. Examples of such use can be found in both the developing as well as in the more developed societies and, certainly, we have such areas in the United States. In recent years there has been considerable research on the subject and some generalizations can now be offered with considerable confidence.

Some areas in the United States are losing their capacity to produce because of erosion but potential aggregate output is not threatened. But it is clear that the off-farm costs of such erosion are orders of magnitude greater than the value of lost agricultural productivity.

What is the cause of this problem? Or is it really a problem? Is government intervention appropriate? Despite the fact that we have had a major soil conservation program in this country for a half century, we often overlook the fundamentals of the issue.

We have the technical knowledge to reduce erosion on the highly erodible lands that are being farmed. No doubt the people farming such land are very much aware of the productivity effects of their farming practices and know present practices cannot be sustained indefinitely. Many such farmers are behaving quite rationally given the incentives they face. Technology that will further reduce soil loss cannot be justified economically. When this situation exists, the issue is whether society should intervene to create a different set of incentives, to regulate farming practices or even, perhaps, to declare such land unfit for cultivation.

There are no unambiguous answers in science to these questions. If one is willing to accept current market prices and interest rates as being good guides for the future, intervention probably cannot be justified. In such circumstances the mining or the using up of the soil resources is accepted. At some point cultivation, or at least current cultivation practices, will no longer be economical and the land will then be used less intensively or abandoned. But society might quite logically decide that it did not wish to run the risk of the loss of future productivity or that it does not wish to suffer the off-farm costs of soil erosion and decide to intervene. The way intervention is to occur will

have to be addressed as a part of the decision to intervene. Our fifty years of experience with soil conservation programs have taught us some things about what does not work but we are far from comfortable with the methods of intervention that have been advanced and that are being tried.

Marginal lands. As used here marginal lands means marginal to agriculture. That is, land which, over time, either contributes little to the profitability of farming or to net national income by its use in agriculture. On the surface this may seem to be a straightforward statement but it becomes quite complex when applied in practice. Lands may be marginal because of low physical productivity or because of their high value in some nonagricultural use. Examples of the first case may be found in the arid lands of the Western Great Plains—Eastern Colorado, Wyoming, and Montana, and the Western Dakotas, Nebraska, Kansas, Oklahoma, and Texas. Low physical productivity in agriculture also characterizes much of the rural land of New England. However, the social problems resulting from this low physical productivity in agriculture are very different from that of the Plains because there often is a demand for New England land as a rural residence.

But lands may be marginal to agriculture because of their high value in some nonagricultural use. Land near urban areas may have a high alternative use for highways, for urban residential or industrial purposes. In such cases the value of the alternative use is usually reflected in market price of land. But this is not true for all nonagricultural land uses. The contributions of wetlands to wildlife and the need for open space near urban areas are frequently not reflected in market prices. It is necessary to treat the two cases as distinct and separate for policy purposes.

Agriculture typically surrenders human and natural resources to nonagricultural activities as change occurs and the transfer of such resources often is accompanied by social stress. We are all familiar with rural-urban migration, with rural-urban fringe problems, and with the need of some urban areas for water used in agriculture. While such stress often requires special policies there is little evidence that the aggregate productivity of agriculture has been threatened by such transfers. Even though the loss of agricultural land to urban purposes requires many local adjustments, a case cannot be made that urban growth

has threatened agricultural output.

Nevertheless, frequently there are public values associated with agricultural land use. Sometimes these values are positive, sometimes they are negative but they may not be reflected adequately in market transactions. An example of a positive value that may not be reflected by the market is the contribution of agriculture to the need for open space near urban areas. But if certain wetlands are used in agriculture certain desirable species may be lost. It becomes clear that the institutions for permitting these public values to be reflected in land use decisions are indeed quite different. In the first case local government will be able to weight the costs and benefits of alternatives because those costs and benefits are realized largely or completely at the local level. In the case of species loss the value is a more general one and local government may lack the means to reflect the interests of all those who are affected.

Generally speaking we are searching here for a basis of establishing public, as contrasted to private, property rights when private markets do not reflect public values. For those lands which are marginal because their agricultural productivity is low and where the value in alternative use is also low—The Great Plains example—the best social policy would seem to be to constrain its use in agriculture. Otherwise, both human and natural resources are misused as such land goes in and out of agricultural cultivation. When marginal agricultural lands have high opportunity costs, the appropriate policy response clearly is very different. In some cases those opportunity costs are reflected in the market or are local, as contrasted to national, in their incidence. Markets or local government can be delegated to allocate the resource. But this will not be the case for those public values whose incidence is more general as is the case for the loss of desirable species; there are at least three methods for having these public values reflected in decision making. Public ownership is one; constraints on private use is another. Still another is the establishment of a price to be paid by the public for the production of public goods on private lands.[1] The evidence suggests present policies are far from ideal and that alternative institutional arrangements for improving the present situation should be investigated.

CONCLUSIONS

Little has been said explicitly in this paper about water use in agriculture; the primary focus has been on land. But much of the reasoning which has been applied to land also can be used for water if allowance is made for the unique nature of that resource.

The development of water in agriculture, especially for irrigation purposes, often requires a group decision and may involve a large investment which may come from nonagricultural sources. Such an investment may be made as a means of raising the productivity of other inputs in agriculture—better seeds and fertilizers, for example. Such investments often have unanticipated results, not all of which are necessarily desirable. Salinization and water logging may reduce soil productivity over time. Initially, more people may be settled on the land under irrigation than when agriculture is rain fed. But technical change often occurs rapidly on irrigation projects and many farmers are displaced after having made personal investments in irrigated agriculture. In the United States investments in reclamation have continued far longer than justified by their contribution to national income. Our reclamation program is a prime example of an inconsistent government policy—we subsidize agricultural production even as we suffer from excess production and depressed prices. In some cases, of course, ground water has been developed by individual initiative but as ground water levels decline, agricultural adjustments become necessary. Often there is pressure to alleviate these adjustments by massive water importation schemes. Such plans often make little economic sense and have been resisted. Rather than subsidizing water use in agriculture there is a greater need for water institutions to reflect the nonagricultural value of water which will encourage the more efficient use of water in agriculture.

This brief treatment of land and water resource use in agriculture demonstrates that while it is difficult to generalize with respect to problems and policies, general principles are useful as we classify and diagnose. Human resource development and economic policies affect land use and in some instances may be more important than resource specific policies. The major difference in land use problems that exists when development is rapid from those that exist when development is slow or stagnant, is that opportunity costs of the land resource in

agriculture often rises when development is rapid. These rising alternative values of agricultural land and water resources may represent opportunities that sometimes are mistaken for problems.

NOTE

[1]To the extent that the services produced by such lands are true "public goods" as defined in the economics literature, it is not possible to achieve efficiency in production and use by charging users for such goods. However, government could pay private landowners to manage their land in such a way that "public goods" are either preserved or created.

INCENTIVES NEEDED TO ACHIEVE FOOD PRODUCTION GOALS: SOME THOUGHTS ON AGRICULTURAL POLICY REFORM

G. Edward Schuh

Agricultural policy reform is currently high on the agenda of the World Bank and other international development agencies as they seek to help individual countries strengthen their agricultural sectors. The issue is critical on the African continent since agricultural performance there is generally weak and per capita production of food for the continent as a whole continues the decline that started around 1970.

Policy reform has emerged at or near the top of the agenda because it is believed to be an important reason for poor agricultural performance in many countries. Persistent and sizeable overvaluations of national currencies in many countries, together with high protection of the manufacturing sector, has shifted the domestic terms of trade seriously against agriculture. In the case of Africa this problem is complicated by marketing boards and other parastatal organizations which return to farmers only a fraction of what their product is sold for to consumers, either at home or abroad. More generally, there are other government interventions which discriminate against agriculture, including explicit export taxes, barriers against exports, protection of domestic industries that produce modern inputs for agriculture, direct price fixing to keep agricultural prices low, and investment policy.

I would like to discuss with you six aspects of these attempts to induce policy reform: (1) the precise content of that now-familiar slogan "getting the prices right"; (2) the importance of dealing with the adjustment problems associated with the reforms; (3) the need to deal with the income redistribution problems associated with such reforms; (4) the need for a modern fiscal system if the proposed reforms are both to come off and then to stick; (5) the nature of the response that might be expected from such changes in policy; and (6) the need for inter-

national adjustment to complement the changes in policies in the developing countries. The first issue has to do with getting the prices right in a rather broad context. If the next three issues are not taken into account in designing policy reform packages, either little reform will actually take place or it will be slow and give disappointing results. On the other hand, if the nature of the expected response is not well understood, frustration, disappointment, and loss of creditability in the advice and recommendations from outsiders is likely to emerge in three to five years, even if there is success in dealing with the other three issues. Similarly, if the developed countries do not practice burden sharing, there is very little likelihood that policy changes in the developing countries can be successful.

GETTING THE PRICES RIGHT

The general prescription for determining the proper prices for farmers or any other producer groups in society is that they should be paid no more or no less than what society would pay producers in other countries. These are called border prices—what the commodity could be imported for or exported for. Eliminating the basic discrimination against agriculture in most developing countries, however, involves more than getting domestic agricultural prices up to their border-price levels, important as that may be. The relative social profitability of the sector involves the price of agricultural output relative to the prices in other sectors. In most low-income or developing countries, high levels of protection are provided to the manufacturing sector at the same time that price discrimination is practiced against agriculture. The protection of the manufacturing sector will need to be reduced at the same time that prices are liberated in agriculture if the social profitability of agriculture is to be restored so that some share of the capital generated in agriculture will remain in the sector and the rate of labor outmigration reduced.

As we noted, of course, efficiency prices require that commodities and services be priced at their border price levels. For exports, that is the FOB price at the port of export. For imports, it is the CIF price at point of entry. In both cases, the efficiency price for the currency is equally as important. Hence, CIF and FOB prices must be evaluated at the equilibrium or market-clearing price of foreign exchange.

An important issue that arises in making such evaluations is how to proceed if protection of the manufacturing sector is not reduced to a level consistent with border price levels. Is it then proper to go ahead and fix agricultural prices at levels consistent with their border price equivalents? The answer to that question is "no." If policy makers accept a certain amount of protection for the manufacturing sector, then efficiency demands that the same level of protection be provided the agricultural sector.

The issue then becomes "What form should this protection take?" For both exportables and importables, the level of protection should be the same as that for the rest of the economy. In the case of exportables, the ideal mechanism is a producer-based deficiency payment which provides the equivalent degree of protection as received in other sectors. With a deficiency payment, the government makes up the difference between the market price and the target price as determined by policy-makers.

The main points of this section have been (1) to emphasize the need to take a broad approach - beyond agriculture alone - assessing relative price levels, and (2) to emphasize that a blind application of border price pricing criteria can be misleading. In the latter case, resource efficiency will be obtained when the same level of protection is provided to all sectors, not just when agricultural prices are put at their border price equivalents.

DEALING WITH THE ADJUSTMENTS ASSOCIATED WITH POLICY REFORM

Shifting the domestic terms of trade more in favor of agriculture, and getting the prices right more generally, will lead to significant reallocations of resources. In some economies these adjustments will take place with relative ease and the response will be fairly rapid. That will be the case when the economy has a diversified agriculture made up primarily of annual crops that can be substituted one for the other with relative ease.

In other economies the adjustment will not be all that easy. For example, getting the prices right might induce a shift of resources into tree crops which have a long gestation period

of from two to five years or more. Shifts into these commodities will require a great deal of capital and it will be tied up for a number of years before it becomes productive. Although a certain amount of intercropping of annual crops can take place in these new plantations, policy makers will be reluctant to make commitments to such crops when the adjustment period is so long, especially if the markets are unstable.

This problem is not characteristic of tree crops alone. Many countries either have monocultures or a fairly limited range of commodities which they produce. New activities will have to be introduced, a great deal of learning-by-doing will be required, and alternative complements of capital and marketing infrastructure may be needed. Moreover, there may be little locally adapted modern technology available; hence the output response may be meager.

The World Bank's structural adjustment loans have been of a quick-dispersing nature, and designed to support the introduction of new activities such as these. That provides a means of dealing with some of the problems outlined above. But it is important that the analysis of the adjustment problems to be faced be done in detail and with care, and that loan funds be directed to specific adjustment problems. In the case of adjustments to tree crops, sizeable commitments of capital may be needed to bridge the production gap. More generally, intensive extension efforts may be needed to transmit available knowledge on new production alternatives, as well as an intensive program of on-the-farm trials and adaptive research to provide knowledge needed to facilitate this adjustment. In many respects this should be treated as a classic adjustment problem in that it should aid in facilitating resource mobility.

THE INCOME REDISTRIBUTION PROBLEMS ASSOCIATED WITH POLICY REFORMS

Policy reforms that involve price realignments of the kind needed in many developing countries will involve significant shifts in the distribution of income within the country. These shifts in income distribution are a major barrier to policy reform. My perception is that most international agencies have not been very sensitive to this set of issues, have done little to deal with it, and thus are being frustrated in their attempts at policy reform.

Consider some of the specifics. Currencies often are over-valued with the express purpose of keeping the cost of living low to urban consumers. An over-valued currency is an export tax and thus keeps the price of export commodities lower than they would otherwise be. It is also an implicit import subsidy and keeps either the domestic cost of the imports or the price of import-competing commodities lower than they would otherwise be. Either or both of these commodities may be important wage goods. With no changes in the nominal wage, the consequence of a devaluation would be a decline in the real wage. More generally, a rise in food prices results in a regressive shift in the distribution of income against low income groups.

Needless to say, urban workers are quite vulnerable to such changes. They also tend to be highly concentrated in major cities and often politically volatile. They go to the streets in protest, and governments come tumbling down. There have been enough examples of this in the recent past that policy makers are not about to risk it except under either especially propitious circumstances, or when finally pressed to the wall.

Devaluations are not the only policy change that can bring about such a reaction. Any reform that involves bringing about price enhancing liberalization will do it, especially if the increase in prices for producers is passed on to consumers.

The income distribution consequences do not stop there, however. If the wage sector is largely privatized, real and/or nominal wages may be forced up to employers. Nonfarm employment will likely decline, and the nonfarm sectors will become unprofitable, thus taking away the impetus for development. If the major employer of off-farm labor is the public sector, a rise in nominal wages for that sector can have important budget implications, leading to larger budget deficits, the need for enhanced revenue, and possibly inflationary financing.

Dealing with these problems requires careful analysis of the problem as it is expected to evolve, and the development of creative means for dealing with it. Sometimes there will be significant income redistributions within agriculture. In some cases the income transfer one group receives can be used as an opportunity to phase out other subsidies. For example, a rise in commodity prices can make it possible to phase out credit and/or input subsidies.

There are a number of implications here. The first is the need to trace through the income shifts as policies are changed and to assess their political feasibility. The second is to be creative in the reform process so that offsetting shifts in income can be created. Third, careful attention should be given to the institutional reforms that will constitute the basis of the policy reform. And finally, means must be found to deal with the income distribution problem if it is in fact a barrier to policy change.

Perhaps the most important reform needed in moving to a more rational regime of food prices is some means of providing food to disadvantaged groups. The U. S. Food Stamp Program, for example, has made it possible to have commodity programs in this country that in effect have made the domestic price of food higher than it otherwise would have been. Other institutional arrangements are possible, such as fair price shops in poor areas of cities, direct welfare payments, etc. Which of these is feasible and pertinent will depend on the individual country. The main point is to emphasize the need to deal with the food problems of the disadvantaged if there is to be any hope of liberalizing food prices in most countries.

Obviously, exchange rate realignments go much beyond the food and agriculture sector. However, the important issue is to find out just which sector is serving as a barrier or impediment to policy reform and then design measures to reduce or eliminate those impediments.

THE NEED FOR A MODERN FISCAL SYSTEM IF PRICE REFORMS ARE TO BE POSSIBLE

Feeding programs for the disadvantaged point to the need for fiscal resources to support such programs, and this in turn points to the need for reform of the fiscal system. More generally, however, it should be recognized that the implicit taxation inherent in overvalued currencies, explicit barriers to exports, and marketing boards are a logical response to the lack of an adequate fiscal system in most countries. In some cases, incomes are transferred implicitly from one group in society to another by means of distortions in prices. In this case the resources never go through the governments' coffers, but they are no less real for that. In other cases, resources are con-

fiscated directly either by means of explicit export taxes, excise taxes, or marketing boards that pay producers only a small proportion of what the commodity brings in the market.

In either case, policy reforms are not likely to be forthcoming unless alternative fiscal means are introduced. The implicit income flows are generally a reflection of the political reality. The lack of direct government revenue is a reflection of the lack of an appropriate fiscal system - for whatever reason.

International development agencies have probably not given enough attention to this problem. In many countries, these agencies will not be successful with their policy reforms until alternative fiscal systems are developed by the borrowing country. Thus an important part of any reform package should be technical and other assistance to reform the country's fiscal system.

In the case of agriculture, it is well known that a well-designed land tax will have minimal resource allocation effects. But it is politically difficult to implement land taxes in many countries, and administratively difficult in many others. Most countries have an income tax of some kind or another, although agriculture is notorious for not complying with such tax systems. That is one reason, of course, why they end up being taxed by implicit means.

There may be still other means of accomplishing the same result. The main point is the need to recognize the importance of designing and implementing alternative tax or fiscal systems, and the need for governments to make such reforms an important component of the reform package. Resources for the establishment of new fiscal systems would be a very proper investment for international development agencies.

THE NATURE OF THE RESPONSE FROM REFORM OF PRICE POLICY

Caught up in the enthusiasm for their newly discovered emphasis on policy reform, the rhetoric of many international agencies often sounds as if getting the prices right was the be-all and end-all of development policy. Nothing could be further from the truth, important as it is at the present juncture of history in many countries. If the nature of the response to be ex-

pected is not properly understood, the international agencies and their clients could be setting themselves up for disappointment and a lack of credibility in the future.

There is little doubt that policy reform can lead to a significant output response and a spurt of economic development. China is perhaps the best example of what can be achieved with such reform. The distortions in China's economy were huge, especially as a consequence of the emphasis on local self-sufficiency, and thus the gains from a more effective policy configuration are quite great. Although the distortions in most developing countries are not that great, they are sufficiently large to provide a significant response when reform takes place.

It is important to understand, however, that these responses are for the most part once-for-all gains. Price liberalization results in a shift from a point interior to an economy's transformation curve to a point closer to or actually on the curve. The gains are cheap, and for the most part forthcoming in a relatively short period of time. However, once these gains are realized, the economy returns to its longer-term growth trajectory. This may be a path of expansion that is no faster than what prevailed prior to the reform. In many cases that will not be sufficient to provide for a rapid rate of economic development.

The key is to use this breathing space of accelerated expansion to make the other reforms that will lead to higher rates of growth in the longer term. In the case of agriculture this means an accelerated effort to train people and establish effective research and extension systems, expanded efforts at evaluation and training of the rural labor force, the strengthening of the physical infrastructure and institutional arrangements, and the development of modern input-supply industries.

THE NEED FOR INTERNATIONAL ADJUSTMENT

Considerable pressure is being brought these days on the developing countries to make adjustments in their domestic economies that reflect contemporary international realities. Although these adjustments obviously have important trade implications, less seldom is it recognized that a significant degree of burden sharing on the international scene is required if the adjustments in the developing countries are to be successful.

An important barrier to international adjustment in today's world are the agricultural commodity programs of the United States and the European Community. The time is long past due when we focused the spotlight on these policies and began to bring them too into adjustment.

CONCLUDING COMMENTS

There are two main themes in this paper. The first and foremost is the need for careful attention to institutional detail and institutional arrangements in any attempt at policy reform. The short-term benefits from policy reform can provide the means for dealing with these problems if efforts are made to capture the "surplus" that results. If the proper reforms and investments needed for longer-term growth are not made in this interval of time, however, economic development over the longer term will be disappointing.

Finally, I would like to emphasize the complementarity between price incentives, on the one hand, and investments in science and technology, on the other. If a flow of new productive technology is being produced for an agricultural sector, proper price incentives will accelerate the adoption of that technology and thus result in a larger increase in output. If such a flow is not forthcoming, the best one can expect from policy reform is a one-time gain. The longer-term benefits for longer-term economic development may not be all that great.

THE PATH TOWARD FOOD SELF-SUFFICIENCY IN CHINA

Lu Liangshu

I shall present a report on China's efforts to achieve food self-sufficiency. In this report I will briefly describe our achievements and main experiences associated with our efforts to solve food self-sufficiency problems in China. Later I will discuss our plan for increasing food production in the future.

ACHIEVEMENTS IN SOLVING FOOD PROBLEMS IN NEW CHINA

China is a country with a large area and with rich natural resources. Agriculture was extremely backward under the semi-colonial and semi-feudal systems that existed for a long period of time.

Since the founding of New China in 1949, vast numbers of peasants have been involved in land reform. Large holdings occupied by landlord classes have been confiscated and freely distributed to peasants. For the first time it has been possible to combine agricultural laborers with the land, and other means of production, and make the peasants masters of agriculture. The socialist transformation of the small scale peasant economy into larger farm units established the present socialistic, agricultural cooperative economy. These changes have greatly contributed to the development of increased agricultural production.

Data shown in Table 1 reveal that total grain production in China reached 195.05 million tons in 1957 which was an increase of 71.3 per cent over the 113.8 million tons produced in 1949. Production of grain increased at an average annual rate of 7 per cent from 1953 to 1957. Grain production on a per capita basis increased from 209 kg in 1949 to 306 kg in 1957, an increase of 46.4 per cent. Because of inappropriate policies and administration during the period of 1958 to 1962, combined with natural calamities, agricultural production suffered a serious setback.

TABLE 1

Food Crop Production in China from 1949 to 1983.

Year	Food Grains*	Food Crops				
		Rice	Wheat	Corn	Soybeans	Potato
1949	11,318	4865	1381		509	985
1952	16,392	6834	1813	1685	952	1633
1957	19,505	8678	2364	2144	1005	2192
1965	19,453	8772	2522	2366	614	1986
1978	30,477	13693	5348	5595	757	3174
1979	33,212	14375	6273	6004	746	2846
1980	32,056	13991	5521	6260	794	2873
1981	32,502	14396	5964	5921	933	2597
1982	35,343	16124	6842	6030	904	2668
1983	38,730	16890	8140	6820	975	2925

*Units of 10,000 tons

TABLE 2

Yield of Food Grains in China from 1949 to 1983.

Year	Yield kg/ha	Percentage Increase
1949	1,027.5	-
1952	1,300.0	26.6
1978	2,527.5	94.4
1983	3,397.5	34.4

As a result of the determined effort by our people and better government policies, the decline in agricultural production was finally reversed. During the ten-year period of the cultural revolution, grain output increased significantly despite many difficulties. In 1978, grain production reached 304.77 million tons. Meanwhile, with increased economic development, the health and living standards of the total population in our country improved. At the same time, the cultivated area per capita declined. There were 0.104 hectares of cultivated land per person in China in 1978 or 43 per cent less than in 1949. This is only one-third as much land as is available per person over the entire world.

In 1979, per capita grain production reached 318.5 kg, an increase of only 4.1 per cent over 1957. Since 1978 we have adopted a series of policies for the development of agriculture, and especially for creating the output related production responsibility system. This system closely links the productive output of farmers with their economic returns. This system, combined with the constantly improving agricultural technology, has been a great motivating force for increasing agricultural production. Agriculture in China has developed rapidly in recent years. Grains and other major farm products have achieved an unprecedented level of production. In 1983, grain production in China reached 387.30 million tons.

Grain production in China increased from 150 to 200 million tons during the five-year period from 1953 to 1957, an average rate of increase of 6.6 per cent; from 200 to 250 million tons during the thirteen-year period from 1958 to 1970, an average rate of increase of 1.9 per cent; from 250 to 300 million tons during the eight-year period from 1971 to 1978, an average rate of increase of 2.5 per cent; and from 300 to 387 million tons during the five-year period from 1979 to 1983, an average rate of increase of 5.8 per cent. Yield increases in terms of kg per hectare during this period are shown in Table 2.

For many years certain remote provinces and autonomous regions have needed food assistance every year in order to meet consumption requirements. In addition, a number of population centers with concentrated industry have needed food shipments from other areas. This was especially true when natural disasters occurred. In 1983, almost all provinces and autonomous regions were self-sufficient. A number of provinces and autonomous regions have a surplus of food grains now. This suggests that

China is developing a solid agricultural foundation capable of resisting natural disasters and continuing to increase food production.

The cultivated land area per capita in China is small. There has been competition between grains, cotton, and other cash crops. One effect of this competition has been that none of the crops has increased in yield as much as possible. Since 1979, a series of policies for stimulating the rural economy has been implemented. The structure of agriculture has been gradually altered and good results have been obtained. Increased grain production has been obtained in many places despite the fact that the area devoted to grain production has decreased. Moreover, output of cash crops such as cotton, oil crops, tobacco, and jute also have been increased. Many counties have become high producing regions for both grain and other cash crops. This is a favorable situation for increasing China's animal production. If animal production can be increased, it will have a beneficial effect on food quality. Changes are underway to structure agriculture around cash crops, grain crops, and forage crops as the main components. It is believed that these changes will be beneficial both economically and ecologically.

Food is a special commodity, which is an essential daily necessity. People consider the availability of food to be of paramount importance. The most important consideration for our one billion people is to eat. For this reason it has been the practice of our country to give food production a very high priority in programs that are designed to develop the national economy and further social stability. This has been especially true since the Third Planning Session of the Eleventh Committee Meeting of the Party, when the output related system of contracted responsibility was implemented in rural areas. This brought about a stimulation of rural economic cells (individual families) and succeeded in increasing farmer motivation, which is the most important of all productivity factors. The development of farm productivity and the improvement of living standards of our people have high priorities. We will summon all our strength to elevate the rural economy and to promote rapid development of food production. In order to promote agriculture, we will undertake any technique, any measures, consistent with socialistic principles. Grain imports will be fixed at a definite quantity in order to facilitate attainment of production and cropping plan objectives. In this way our policy of "Sparing no effort

in promoting grain production and actively developing a diversified agriculture" will be implemented.

China has a large population with limited land suitable for cultivation and inadequate land resource reserves. Natural calamities occur frequently. It is believed that the best way to increase total production is to increase the yield per unit area. In order to achieve this we place great emphasis on the use of fertilizers, pesticides, and intensive management of agricultural enterprises. During the thirty years that have elapsed since the founding of the People's Republic of China, there has been a continuous effort to improve low yielding soils, increase the use of irrigation, develop better farm machinery, and to increase both the production and use of agricultural chemicals and fertilizers. Electric power has been widely used in rural areas for irrigation, drainage, chemical applications, threshing, home water supplies and the processing of farm products. Between 1952 and 1983 irrigated areas increased 1.2 times, amounts of available nutrients applied as fertilizers increased from 0.75 kg/ha to 168.75 kg/ha, farm machinery increased from 0.015 horsepower per hectare to 2.445 horsepower per hectare, electricity consumed in rural area (for all purposes) increased from 0.495 kwh/ha to 442.5 kwh/ha. It is believed that a substantial portion of the yield increases obtained since 1978 have been due to these material inputs. Agricultural production is a biological process of transferring energy. Final yields depend, in part, upon the amount of energy invested.

The reformation of agricultural technology in China consists of at least four considerations. First, we want to combine the traditional technology of intensive and meticulous cultivation that now exists in our country, with modern biological science and technology. Second, we want to make a greater effort to develop and introduce new technology that will increase the yields of major farm products. Third, we want to introduce agricultural technology from abroad as rapidly as it can be thoroughly evaluated under conditions in our country. Fourth, we want to adopt measures that will stabilize yields at high levels, improve the quality of farm products, conserve energy and otherwise contribute to the efficiency of agricultural production.

During the past 30 years we have made progress on most of the objectives enumerated above. We have developed advanced techniques adaptable to China that have permitted

retention of traditional technology related to intensive and meticulous cultivation methods. Special emphasis has been placed on the transfer of technology from abroad that could be converted into productive cultural practices. Such activities have included integrated cultivation techniques for grain production; the introduction of elite varieties and hybrid combinations of rice, wheat, and maize; integrated programs for the control of diseases, insects, and weeds; measures to minimize natural calamities; improved methods of irrigation and fertilization; cultural practices to improve management of dry lands; adoption of multicropping systems; more modern techniques for the management of saline, alkaline, lowland, red and yellow soils. The successful introduction of these techniques has effectively raised the production of grain crops.

During the past few years, grain production bases for commercial trade have been established by the state, as well as by local governments, in different areas of China. The selection of these areas has been based on the results of surveys of agricultural resources and on regional research. These grain production bases have played an important part in the increase of grain yields and have been one of the strategic measures adopted to ensure the state of obtaining the necessary quantities of grain each year on a dependable basis.

The principles used for the selection and establishment of special grain production areas were as follows:

1. Areas in which the potential is greatest for yield increases in the shortest period of time and with the least investment.

2. Areas in which high and reliable yields have been obtained.

3. Areas in which environmental, social and economic conditions are suitable for grain production.

4. Areas that are centrally located and where farm development can be readily carried out.

A large number of farming units specializing in grain production have come into existence. Each unit has adopted the household output related system of contracted responsibility.

This system is characterized by specialized crop production and relatively high labor productivity. With suitable support, these areas will play an important part in the future development of grain production. The establishment of grain production bases and the development of specialized farm units for grain production have helped to increase grain yields and have provided a foundation that will facilitate further development of grain production in our country.

PROSPECTS FOR INCREASED FOOD PRODUCTION IN CHINA

Since the founding of New China, great success in grain production has been achieved. During the past few years rich harvests have been reaped and yields per unit area, as well as total yields, have attained an all time high. However, 400 kg of grain per capita per year is a low level for human consumption and far below consumption in the developed countries. Some districts and mountainous areas in China will never be self-sufficient in grain production. As living standards improve in the future there will be a need for more meat, poultry, eggs, milk, and milk products by all of our people. The present levels of grain production cannot meet anticipated demands. It is apparent that steady increases in food grain production will be necessary for the foreseeable future.

At the present time about 72 per cent of all grain produced in China is consumed by people, 16 per cent is used for animal feed, and 12 per cent for seed and other purposes. It is expected that traditional foods will be changed to foods that more nearly meet nutritional requirements. There will be a greater demand for animal proteins and a reduction in the demand for food grains. Feed grain production must be increased in order to facilitate these changes.

It is projected that the production of food grains should reach 500 million tons by the year 2000 and that the average annual per capita consumption of grain should reach 425 kg.

In order to meet these objectives, China must not only increase production per unit area and skillfully utilize its natural resources, but it must also adopt appropriate economic, technical

and administrative procedures in order to create a stable agriculture.

Adjustment of Rural Structure. It is anticipated that three trends, related to agriculture, will emerge as food production increases and economic conditions improve. These are (a) the appearance of highly specialized farms, (b) the development of new agricultural activities such as forestry, animal husbandry and various side-line occupations, and (c) the development of rural industries such as processing, commerce, services, transport, construction, etc. The traditional, largely self-sufficient rural economy will become more specialized, commercialized and modernized. In order to accelerate these trends we will continue our policy of steadily increasing food grain production as well as our policies for the development of a diversified agricultural economy.

Agricultural Inputs. Scientific studies indicate that more than 750 kg of chemical fertilizer is needed for each hectare of land sown to grain crops and that the N:P:K ratio should be 5:3:1. About equal amounts of organic and chemical fertilizer should be used. Irrigated areas should be increased and comprise 55 per cent of the cultivated land or about 53 million hectares. Emphasis should be placed on irrigation projects that utilize advanced techniques for water conservation. Agricultural machinery used on farms should be increased to a level of about 20 horsepower per 60 hectares of arable land and at least 450 kilowatts of electrical energy should be available for each hectare of arable land. The useage of insecticides, fungicides, and herbicides should be increased.

Agricultural Extension Programs. The introduction of new agricultural technology needs to be facilitated by appropriate extension programs in order to continuously increase the yield per unit area of different crops. High priority should be given to the results of research that improve the efficiency with which material and energy inputs are used. It is important that comprehensive procedures be developed for different regions including the choice of superior varieties, cultural practices, kinds and amounts of fertilizer, irrigation, pest management and cropping systems. In this way the effects of individual techniques will be utilized as effectively as possible.

Agricultural Policies. We will continue development

and refinement of the production responsibility system with the household contract being the main form. Food grain production will be encouraged to move in the direction of greater specialization and will be gradually concentrated on certain types of farms in line with our policies for restructuring rural industry. These changes will increase food grain production efficiency. Food grains will be purchased from farms at two different prices. A quota representing 30 per cent of total production will be purchased at an established state monopoly price. After this quota has been purchased, the remaining grain will be purchased at market prices. In the event that market prices are below the state monopoly price, the state will activate a protection policy and purchase all grain at the monopoly price. This will be done to protect the interests of the peasants.

We recognize that agriculture in China is not sufficiently productive to withstand major natural disasters. There are large areas where yields are low and where crop production is wholly dependent upon natural rainfall. Under adverse conditions these areas contribute to substantial fluctuations in food grain production which are not controllable. The amount of arable land available for grain production cannot be increased.

There are other problems affecting agricultural development in China. The prices of agricultural products frequently do not represent their true value. A smoothly operating marketing system has not been developed. The storage of food products needs to be improved in order to reduce losses. If these problems cannot be corrected, the enthusiasm of the peasants for grain production will be adversely affected. A major strategic problem confronting China is the development of a marketing system for food products.

In order to promote the rapid development of grain production and of agricultural production in general, we will implement more aggressively our open door policy. We will expand collaboration with our international colleagues in an effort to learn from others and thus offset our weaknesses.

FAMINE PREVENTION IN AFRICA: THE LONG VIEW

Carl K. Eicher*

The current tragedy in Africa has created a climate of concern for long term solutions beyond emergency relief.

N. C. Brady, 1985

HISTORICAL PERSPECTIVE

A decade ago, a World Food Conference was convened in Rome because of the immediate threat of famine in the Indian sub-continent and the Sahelian region in West Africa, the drawdown of world food reserves to their lowest levels in 25 years and a dramatic increase in food prices over the 1972-74 period. The overriding assumption in the minds of many conference delegates was that real food prices would continue to rise in the 1970s and that mass starvation was a distinct possibility because of rapid population growth and the lack of a cushion of global reserves. But today the world is "awash with grain." India supplied 100,000 tons of grain (4 shiploads) to Ethiopia in 1985, and the EEC, Japan, and North America are competing for third world grain markets.

Although the world food crisis vanished a few years after the 1974 Rome conference, food production in Sub-Saharan Africa grew at half the population growth rate since 1970. Moreover, famine in Africa in 1985 captured world attention and

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resulted in 7 million tons of grain imports, triple the 1983 level. But the Sahelian famine of the early seventies and the Ethiopian famine of 1985 are dramatic manifestations of longer-term problems that have been building up for two decades—increasing rate of population growth, lagging food production, malnutrition and pervasive poverty (6).

This paper takes the long view of famine prevention and examines two interrelated problems: (a) the food production - population race and (b) the hunger-population battle in Sub-Saharan Africa, a vast sub-continent of 45 states, 1000 ethnic groups and complex farming systems (17, 18, 22, 26).

THE FOOD PRODUCTION - POPULATION RACE

The starting point for understanding the production-population race is the rate of population growth—not the population density or the total size of a nation's population. The current population growth rates in African countries - 2.5 to 4.4 percent - are extremely high by historical standards and imply a population doubling time of 15 to 25 years. For example, Africa's population is currently growing at roughly triple the rate of Japanese population growth of one percent over the 1878-1912 period. Kenya's population growth rate of 4.4 percent will require food production to be doubled in 16 years—a rate unprecedented in the early history of modern economic growth in Japan and in other industrial countries.

One of the simplest measures of what is happening to fertility in a country is the total fertility rate—a rough proxy for the average number of lifetime births per woman. Currently the total fertility rate in Africa is roughly 7.0 compared with 1.8 in the United States. But unlike China where there is a concerted campaign to implement the "one family—one child policy," there is little debate in Africa today—even among academics—on population and family planning, let alone on generating political support for measures to reduce the average number of children from seven to five per family. Demographers agree that family planning programs have been ineffective in Africa in the 25 years of independence, and that "no nation displays any significant sign of fertility decline" (5).

In summary, in many African states population growth

has slowly outstripped the rate of growth of food production—especially since 1970. Research and policy attention should increasingly focus on both dimensions of the food production-population race.

THE HUNGER AND POVERTY BATTLE

Hunger basically describes the lack of a calorie-adequate diet on a temporary or chronic basis. About 100 million or roughly one-fourth of the African people are hungry and malnourished in 1985. Until the past decade, it was commonly assumed that the lack of protein was the dominant cause of malnutrition. But research has shown that the key to good nutrition is getting enough calories because the protein needs of most people will be met if they consume enough calories from several sources. Pregnant and nursing women, however, usually need additional protein (19).

A great deal has been learned over the past decade about the complex linkages between hunger and poverty or what I shall describe as the hunger-poverty battle. Research has shown that hunger and malnutrition are primarily caused by one or more of the following: (a) a lack of access to land for families to produce adequate food, (b) low productivity of family labor on subsistence farms, (c) drought-induced instability of food production, and/or (d) a lack of income to purchase adequate food on a timely basis (9). But expanded food production by itself will neither eliminate hunger nor malnutrition. For example, the United States and India are both self-sufficient in staple food production but neither has solved its hunger and malnutrition problems.

Poverty is a major cause of hunger because it prevents people from producing or purchasing a calorie-adequate diet. The majority of the poor in Africa are subsistence farmers who are producing food for their families at low levels of labor productivity. One of the most effective ways of raising the real incomes of subsistence farmers in the short run is to increase the productivity of their main enterprise, staple food production. In summary, there is increasing recognition that hunger is a function of multiple causes and that the hunger-poverty battle is a complex political struggle over how a society deals with poverty—the root cause of hunger in industrial and Third World countries (23).

A few African states and donors are wisely discarding the emotionally appealing, but potentially misleading concept of food self-sufficiency and replacing it with the concept of food security as a strategic goal of national development. Food security is defined as the ability of a country to ensure that its total population has access to a timely, reliable, and nutritionally adequate supply of food from domestic production, food reserves and food imports (9). Food security is becoming an important policy goal in the Third World, as well as in industrial countries. We shall examine several complex food security dilemmas below.

PRIME MOVERS OF AGRICULTURAL DEVELOPMENT

The current rate of growth of agricultural production in many African states must be doubled in order to catch up with the population growth rate (10). No amount of political will, policy reform, or change in relative prices of single commodities can double the rate of growth of agricultural output and sustain it over a period of several decades unless attention is given to what I describe as the prime movers of agricultural development. African policy makers and donors should concentrate on five prime movers of agricultural change over the medium to long term:

1. New technology that is produced by public and private investments in agricultural research.

2. Human capital and managerial skills that are produced by investments in schools, training centers, and on-the-job experience.

3. Accretionary growth of biological capital investments (e.g., improving livestock herds) and physical capital investment in infrastructure such as dams, irrigation, and roads.

4. Improvement in the performance of institutions such as marketing, credit and national agricultural research and extension services.

5. Favorable economic policy environment.

A significant characteristic of the first four prime movers is their long gestation period (10 to 25 years). For example, experience has shown that it takes ten years of research, on the average, to produce a new plant variety, and another five to eight years to gain widespread farmer adoption. It takes ten to fifteen years of graduate study and on-the-job training for an agricultural research scientist to be productive. However, most donors are avoiding long gestation investments to develop indigenous scientific, managerial and technical capacity. For example, the World Bank has a tendency to finance "showcase" components of human capital and agricultural research projects. The Bank is currently allocating roughly two-thirds of its $19 million loan to Senegal's agricultural research service over the 1982-88 period to

(a) develop and rehabilitate six research stations, including laboratories and office space, and 106 houses on the stations, and

(b) purchase 11 trucks, 20 tractors, 27 tillers, and 205 vehicles.

But delivering vehicles and constructing buildings can be completed in two to three years. Who will train the research staff after the present project in Senegal is completed in 1988?

The second characteristic of the prime movers is their complementary nature. The payoff to investment in applied research will be low unless there is an effective extension service to diffuse the new technology. Likewise, the payoff to investing in agricultural extension services in Africa has generally been low because many research services have had little to offer to extension agents. Let us turn to the first prime mover—agricultural research to generate new technology.

Technology Generation. The shelf of improved, farmer-tested food crop technology is almost bare today in Africa with a few notable exceptions such as maize in eastern and southern Africa, and cassava in West Africa (8, 25). There is a growing realization that the national agricultural research services in Africa are generally extremely weak, that the direct international transfer of plant varieties is proving to be more difficult than earlier imagined, and that the International Agricultural Research Centers have not been performing well in Africa (7). Presently,

many of the national research services do not have the scientific capacity to screen and borrow technology from neighboring countries, regional institutes, the International Agricultural Research Centers (IARCs) and the global research system.

There is growing support for the proposition that expanded rural income from multiple sources is a strategic variable in addressing the hunger-poverty battle. Agricultural research that generates new production technology for food crops, export crops and livestock can be important sources of income generation for farmers and a means for families to purchase an improved diet (20). In short, combating hunger is a more complex process than merely increasing food production. Hunger can be combated by expanding the production and sale of food crops, export crops, livestock, food and income earned from rural off farm employment.

Human Capital and Managerial Skills. Kenneth Shapiro (24) recently reported that the stock of human capital in scientific fields per million people in Africa in 1980 was about one-fourth the relative scientific strength of Asia in 1970. Because the enrollment ratios (percent of population in secondary schools and universities) were lower in Africa in 1980 than in Asia and Latin America in 1960, it will be difficult for Africa to catch up with Asia and Latin America.

A major challenge facing educators and professional agriculturalists in African states and donor agencies is figuring out how foreign assistance can most effectively assist in strengthening Africa's indigenous scientific, technical and managerial capacity in food and agriculture. Starting with great confidence in the 1960s, the major donors and the U. S. foundations have retreated from investment in human capital in the 1970s and 1980s. For example, The World Bank allocated 10.6 percent of its Africa budget to education in the 1960s and 4.1 percent in 1980-84 (12).

Nobel Laureate T. W. Schultz (21) recently reflected on the leadership role that the United States played in financing human capital in India in the 1960's and 1970's and its record in Africa to date:

> The role that U. S. foreign aid and that of American leadership...played in assisting the Indian political and academic leaders in establishing

> the agricultural universities in India, stands as a major achievement of permanent value. It was not a short term undertaking. It entailed building a new institution (the state agricultural university) for the long term. But regretably, U. S. aid has failed to undertake any corresponding enterprises since then; to wit our dismal record throughout most of tropical Africa.

The U. S. recently announced an innovative, long-term plan to strengthen national agricultural research services and Faculties of Agriculture in Africa (2). Hopefully, the World Bank and other donors will cooperate with AID and African states in developing a coordinated approach to strengthening national research services, regional research networks and Faculties of Agriculture. As a first step, donors should design national agricultural research and Faculty of Agriculture projects with a ten-year life of project. Moreover many of the existing farming systems projects should be incorporated into ten-year projects to strengthen national research services.

Rural Capital Formation. The history of agricultural development in industrial countries has been fueled by the mobilization of family labor for clearing land, picking stones and building fences, an accretionary type of capital formation whereby family labor improves land productivity and the productivity of livestock herds over generations. Security of tenure plays a strategic role in converting family labor into capital formation because, with security, farm improvements can be passed on to the next generation. In Africa, there is a tendency for donors to concentrate on financing new agricultural projects while overlooking how to help African farmers and rural communities mobilize family labor to finance their own farm improvements.

Rural Institutions. The fourth prime mover is strengthening the performance of rural institutions ranging from farmer irrigation associations to fertilizer, credit and seed companies. But there is a paucity of proven strategies on how to strengthen rural institutions such as national agricultural research, credit, and extension services. Research, pilot projects, seminars, and workshops are urgently needed on how to strengthen basic agricultural institutions over the next 10 to 15 years.

Economic Policy Environment. The fifth prime mover—

favorable economic policy environment—is crucially important in facilitating the implementation of the first four prime movers. Foreign aid administrators have recently focused on the need for policy reform as the overarching issue in restarting African economies. For example, several donors have reported that pricing policy reform has boosted the production of a single commodity such as maize by 30 to 50 percent in Zambia, sorghum in Somalia and cocoa production in Ghana. Unfortunately, newspaper reports of single commodity responses to higher prices oversimplify the complex parallel actions that have to be taken to boost the production of a broad range of commodities. It is time to shift the debate from pricing policy to the difficult art of gaining national political commitment and consistent donor support for the five prime movers as a policy package.

This analysis has highlighted the strategic importance of public and private investment in the prime movers of agricultural development to strengthen the productive capacity of African agriculture in the medium to long term. Food aid can be used to buy time until investment in these prime movers pays off (17). But donors need to come to grips with long gestation investments by making an explicit, up-front commitment to financing human capital and institution building projects for 10 to 15 years in Africa, just as they did in Asia in the 1960s and 1970s. These institutional investments should be designed as a "core policy package" under the aegis of a Consultative Group of donors. But many donors will probably swing their weight behind the prime movers before the African states. Since the ruling elite in most African countries generally do not view agriculture as a motor of change, most will be reluctant to shift gears from short term projects (with immediate political benefits) to the prime movers of agricultural development (8, 10). The difficult art of gaining African and donor support for the five prime movers is especially difficult in an era of abundant food aid from industrial countries. As one minister of Agriculture remarked informally at a Lusaka conference during the height of the drought in 1984: "now that food aid is arriving, the pressure is off my government to reorder our national priorities in favor of agriculture."

FOOD SECURITY POLICY DILEMMAS: SENEGAL AND ZIMBABWE

Many African nations have adopted explicit food security strategies and have prepared food security plans. In this section,

we briefly examine the strategies of two countries: Senegal, a food-deficit state, and Zimbabwe, a food exporter, in order to illustrate some of the complex dilemmas in food policy reform (9).

Senegal. Senegal, a West African country with some 8 million people, is currently importing about 1,000 tons of rice a day, mostly broken rice from Asia. The Senegalese government is faced with some tough questions: Should food production be increased on rainfed or irrigated land? What is the appropriate role of the state in helping assure food security?

Since the 19th century, Senegal has followed a policy of agricultural specialization, exporting groundnuts and importing broken rice, not only to supply urban areas but also for large towns in rural areas. The state has historically played an important direct role in agricultural trade, holding the legal monopoly on the groundnut trade, rice imports, and until 1980, coarse grain (e.g., millet, sorghum) marketing. Hence, price and marketing policies have had a major influence on the government budget as well as on food security.

Over the past 15 years drought has reduced domestic foodgrain, and groundnut production. As a result Senegal has imported roughly half of its annual cereal consumption in recent years. If present production and population trends continue, the country will produce only a third of its food grain needs by the year 2000 (1).

In order to deal with the deteriorating food production-population race, the government announced a "New Agricultural Policy," in 1984. The policy called for increased food grain self-sufficiency, primarily through irrigated rice production in the Senegal River Valley and millet and sorghum production in the Groundnut (Peanut) Basin; a greatly expanded role for private traders and farmers' cooperatives in input and output marketing; and a reduction in the activities of regional development organizations and parastatals (state agencies). The goal of the new Agricultural Policy is to produce 75 percent of the nation's food grain consumption by the year 2000 and to reach self-sufficiency as soon thereafter as possible.

In implementing the new policy the government has had to face competing objectives (e.g., its desire to stimulate

long-run agricultural growth through higher prices to farmers and cushioning higher short-run increases in food prices for the poor) and the difficulty of developing an institutional environment favorable to private traders after years of heavy state involvement in the cereals market. For example, in early 1985 the government raised the price of imported rice by over 20 percent in order to reduce the budget deficit and to stimulate production of millet, sorghum and locally produced rice. Yet, when the retail price of millet and sorghum rose in response to this change, there were calls by some government officials for strict price controls on these cereals to help protect consumers. Furthermore, the policy of promoting self-sufficiency primarily through price policy has had a mixed effect on the poor. The cost of rice production in the large irrigated perimeters (fields of 200 to 2000 hectares) in the Senegal River Valley is extremely high by world standards.

Senegal's stock of improved food grain technology - rice, millet, wheat, and sorghum - is almost bare because its agricultural research service is weak. Senegal's high cost of food production calls into question the strategy of trying to assure food security through food grain self-sufficiency. Dakar is a major seaport and broken rice, the preferred staple food of many Senegalese, is usually available on the world market from Thailand at a relatively low price. Perhaps Dakar's food security can be secured through imports of broken rice while rural food security can be achieved through the increased production of local food grains (millet and sorghum) and the sale of export crops. Alternatives to rice production in the irrigated perimeters of the north (e.g., vegetables and tomatoes for canning factories) need to be considered as Senegal seeks more cost-effective ways of assuring the food security of its people. The bottom line is that Senegalese farmers cannot compete with Thai rice farmers given present agricultural technology and the overstaffed and inefficient agricultural institutions in the country. Senegal has discovered that the mere announcement of a new Agricultural Policy is no substitute for the lack of food crop technology and ineffective rural institutions.

Zimbabwe. When Zimbabwe became independent in 1980, it inherited a dual agrarian structure of about 5,000 large commercial farms and 700,000 smallholders. At independence, the fundamental problems in agriculture were the low productivity of smallholders, widespread poverty among rural workers on

large commercial farms, a large landless population and a rural infrastructure that had been battered during the war in the 1970s (3). In 1981, the government identified the achievement and maintenance of food self-sufficiency and regional food security in Southern Africa as an important national objective (29). In attempting to improve the food security of its population, the Mugabe government has tried to balance the redistribution of income to the urban and rural poor, who are at the most risk nutritionally, with the need to maintain the productive capacity of the agriculturally based economy.

Despite the substantial incidence of poverty and malnutrition among families of rural smallholders and workers on commercial farms, Zimbabwe has decided to maintain its dual production structure in the short run because its 4,200 commercial farms (in 1985) are producing about 50 percent of the marketed surplus of maize and cotton and 99 percent of the tobacco crop, a major earner of foreign exchange. The government has, however, tried to improve the food security of the rural poor by raising the minimum wage of farm workers to Z$600 per year (about $375 U.S.) and by purchasing commercial farms on a "willing buyer-willing seller" basis and transferring the land to the landless. At the same time, aggressive steps are being taken to help smallholders expand their rainfed production, especially of cotton and maize, and to promote smallholder irrigation.

The government has generally followed a price policy favorable to agriculture, even when this may have increased the food insecurity of the urban poor in the short run. In 1983/84, the government eliminated Z$100 million of consumer subsidies on wheat bread, meat, dairy products, and refined maize flour. In an attempt to lessen the impact of these changes on the urban poor, subsidies were retained on coarsely milled maize meal (consumed mainly by the urban and rural poor) and the minimum wage was increased. Following a three-year drought, the government raised maize producer prices 28.5 percent in June, 1984, four months before planting time for the 1984/85 crop. With favorable weather, farmers responded with a large maize crop in 1985. Zimbabwe is now developing trade agreements to sell 500,000 to 750,000 tons of maize in international markets.

Although the experience of Zimbabwe is frequently cited as an example of the successful use of price policy to stimulate agricultural production, the favorable production response

is more complex than higher prices and good weather. Zimbabwe raised the producer price of maize from Z$85 at independence in 1980 to Z$180 in 1985, an increase of 112 percent. Farmers were able to respond to higher prices because they had access to well-functioning input and output markets, an extension system that has given increasing attention to smallholders in recent years, and one of the strongest agricultural research services in Africa. For example, Zimbabwe became the first country after the U. S. to develop hybrid maize (corn) varieties in 1949, after 17 years of research (7). Although short-season hybrid maize varieties were available to smallholders 10 years ago, it was only with improvements in the marketing, credit and extension systems, an end to the disruption caused by war, and favorable prices that smallholders widely adopted the new varieties. For example, smallholders increased their share of the marketed surplus of maize and cotton production from 10 percent at independence in 1980 to roughly 50 percent in 1985. The experience of Zimbabwe underlines the important interactions among technology, institutions, and agricultural policies in increasing food production and food security.

In spite of its success in increasing total food production and becoming a maize exporter, the long-term food security of Zimbabwe also depends on its ability to deal with its rapid rate of population growth because a population which doubles in size in 15 to 20 years can undermine the per capita availability of food. As the experience of India demonstrates, achieving food self-sufficiency (in the sense of becoming a food exporter) is not necessarily synonymous with achieving food security for all of its people.

ATTACKING THE TWO CORE PROBLEMS

Bumper harvests in many countries in 1985 have dramatically changed the food outlook for Africa in 1986. Instead of 24 countries requiring food aid as in 1985, the Food and Agriculture Organization (FAO) recently reported that only five countries will likely require food aid in 1986. But beneath this welcome forecast for 1986 are two core problems: the food production-population race and the hunger and poverty battle. Much of the advice that Africa is receiving on attacking these two problems is based on a shallow understanding of the nature of the agrarian crisis, a tendency to oversell one or two of the five

prime movers of agricultural change (e.g., policy reform or new technology), and a tendency to underestimate the gestation period required to develop human capital, managerial and financial skills and productive national agricultural research and extension systems. Moreover, there is a tendency for most donors and PVO's to make the case to increase aid flows to Africa at a time when many African countries are having great difficulty in absorbing much of the piecemeal aid that is metered out to livestock, irrigation and rainfed farming projects. In this paper I have taken the long view of laying the foundation to combat famine because it will take time to gain and develop support for family planners, time to develop new food crop technology, and time to gain African political support to increase public investment in agriculture over the coming decades.

Turning to the first core problem (the food production-population race), it will take several decades before there is a broad base of political support for family planning in Africa. Hence, over the next 10 to 15 years expanded staple food production is the first line of attack in the food production-population race because the majority of the poor are engaged in subsistence food production. In the short run, one of the most direct ways of increasing the real incomes of subsistence farmers is to increase the productivity of their main enterprise, staple food production. Expanded staple food may increase the per capita availability of home-produced foods, the cash income of farm families by generating a marketable surplus of grain and tuber crops, or allow subsistence food needs to be produced with fewer resources, thus freeing resources for other income-earning activities. But improving the productivity of the food system involves not only generating improved technology but also investing in marketing, processing and transport of staple crops. Farmers are usually reluctant to try to increase their income through crop specialization if there is not a reliable market for food. In the long run, efficient input and output markets are a key in developing the intersectoral linkages that characterize economic development, which by generating increased incomes, reduces food insecurity.

It is time to stop thinking of African countries as if they were all the same. Because of differences in initial population densities, natural resource endowments, rainfall, and the availability of technology, there are vastly different prospects for agricultural development among individual countries in Africa. For example, Uganda, Ivory Coast and Guinea are blessed with

fertile land, high rainfall, and have enormous reserve production capacity. Moreover, some countries, such as Sudan and Zaire, have large areas of idle land and can rely on area expansion, like the U. S. in the frontier era in the last century and Thailand over the past two decades, in expanding production. Other countries such as Rwanda, with a population density approaching that of India, will have to rely on increasing yields with the aid of science-based technologies. In summary, there are vastly uneven prospects for increasing food production by country and by sub-region in Africa.

It is also time to shelve the misleading cliche that Africa is a land abundant continent. Because of vastly different patterns and levels of rainfall and availability of locally tested technology, there are significantly better prospects for food production in southern Africa than in the semi-arid zone of Sahelian West Africa. There are generally three broad groups of countries according to land/population ratios. About one-third of the continent can be classified as land abundant (Sudan, Zaire, Cameroon, Guinea, Sierra Leone, Zambia, Mozambique, and Angola). In the foreseeable future, seasonal labor shortages, not land, will be the major constraint on expanding production in these countries. About one-third of the countries are in semi-arid areas where the land frontier is rapidly being exhausted (e.g., Senegal, Niger, etc.). About one-third of the countries are in a land scarce environment where the frontier is already exhausted and yield-increasing innovations and intensification of production are already in progress (e.g., Rwanda, Malawi, Burundi, and parts of Nigeria). The implication of this analysis is that technology has to be carefully developed and targeted to different country specific situations instead of assuming that the sole aim of research in Africa is to produce yield-increasing innovations.

Africa's food surpluses of 1985 are a reminder of the vast physical production potential of African agriculture, the dependency of food production on rainfall and the need to take the long view when discussing the rationale for expanded research investments in Africa. While Sudan's transport system is struggling to move food aid from the seaport to feeding centers in late 1985, a team of experts was helping the Sudan develop a buffer stock scheme to store Sudan's bumper sorghum harvest. Malawi has 300,000 tons of maize for export in 1985/86 and it has been a maize exporter for eight of the last ten years. Zimbabwe will have at least 500,000 tons of maize for export in 1985/86 after

rebuilding its stock pile following three years of drought.

In dealing with the second core problem (hunger and poverty) it is important to recognize that many of the hungry, particularly the chronically hungry, are malnourished not because the aggregate supply of food (domestic production plus potential imports) is inadequate, but because the poor lack the purchasing power to buy a calorie-adequate diet. Improving the food security of the poor requires measures to help the poor increase their purchasing power or what others call their effective demand (18) or food entitlement (22, 23).

Food security should replace food self-sufficiency as a policy goal for African states and become the focal point of donor assistance to food and agriculture in Africa. Food security is defined as the ability of individuals and households to gain access to land, jobs, income, or food aid to secure enough food to meet their food requirements throughout the year. Since poverty is a major cause of food insecurity, it follows that increased food production by itself, and the achievement of food self-sufficiency, will not achieve the goal of food security. The implication for African states and donors is to reduce the food self-sufficiency rhetoric in policy pronouncements and projects and concentrate on the two core problems to step up food production and reduce poverty.

FOREIGN AID AND FAMINE PREVENTION

Famine in Ethiopia, the Sudan, Mozambique, and Mali in 1985 brought forth a flood of compassion from the world community, and generous supplies of food, medicine, blankets, and other assistance. The United States supplied about 3 of the 7 million tons of food aid to Africa over the 12-month period October 1984 to September 1985. But amid this vast outpouring of international support for Africa's famine of 1985, it is important to keep in mind that Africa is flooded with project aid that is difficult to absorb because of the critical lack of managerial, financial, and technical capacity. For example, in late 1985 Kenya has around 1000 development projects, including 139 in agriculture. Forty of the 139 are agricultural research projects or research components in agricultural and rural development projects. Imagine the frustration of the Director of Kenya's Agricultural Research Service as he tries to cope with the re-

volving door of expatriate researchers and the financial reporting requirements of 40 foreign aid-financed research projects. For more details on the shortcomings of piecemeal aid see Morss (15) and Eicher (10). It is also important for PVO's to keep in mind that annual per capita aid levels of $40 to $60 in some of the Sahelian states in West Africa are extremely high relative to aid levels in other continents. By comparison, India received annual per capita aid of only $1.50 from 1951 to 1970. Although India's aid was large in absolute terms ($14 billion) over the 1951-70 period, per capita aid was small relative to current aid flows to Africa (13). Malaysia allocated around 25 percent of its public investment to the agricultural sector from 1971-1981 (11). Currently most African states are investing 7 to 12 percent of their public expenditure in the agricultural sector. There is no specific level of public investment in the agricultural sector that is optimal. But most knowledgeable experts agree that African states should increase the share of public investment from the present 7 to 12 percent to 12 to 20 percent over the next few years.

The role of foreign assistance in famine prevention in Africa is complex, highly political; it requires debate and some important changes. In my opinion, donors, large and small, bilateral and multilateral, do not have a credible plan to assist Africa in combating hunger and poverty in the 1980s and 1990s. Moreover, the U. S. Congress is not getting good advice on Africa. For example, the Office of Technology Assessment (OTA), the advisory office to the Congress, recently completed a shallow report (16) that counted all the trees in the forest but did not come up with a credible plan to address hunger and poverty in Africa. In many sectors—rainfed farming, irrigation and livestock—more aid cannot be absorbed with integrity given Africa's limited absorptive capacity, lack of profitable technical packages, project mode of delivering aid, and ineffective donor coordination. Donor attention should shift from short-term pricing policy to focusing on the prime movers of agricultural development as a policy package on a country-by-country basis. Each of these prime movers must be examined as part of a core investment package covering a period of 10 to 20 years.

It's time to jettison the donors' fixation on increasing the quantity of aid to Africa and refocus public aid and PVO assistance on increasing the efficiency of foreign assistance. As part of this process, the following problems should be addressed

by PVOs and public aid agencies: absorptive capacity, indigenous scientific and managerial capacity, recurrent costs, standards of performance, donor coordination, and marshalling African support for the prime movers—the investments with 10 to 20 years gestation periods—of agricultural development.

SUMMARY

Africa's agrarian crisis is complex and it has been building up for several decades. Neither simplistic statements about external forces nor calls for open market, export-led growth, and increased foreign aid are the answers. The crisis is rooted in the neglect of agriculture during the colonial period and further neglect in the 25 years of independence largely because of the dominance of imported models of development that gave priority to cement, shoe and beer factories, and hotels, and to the political realities of expanding highly visible social services: health, education and rural water supplies. Stop-gap measures have been tried—crash production campaigns and mass infusion of foreign aid—but these have not been effective. To address Africa's two core problems, one must turn to agricultural-led growth. But, based on historical experience in developing improved crop and livestock technology, a famine prevention strategy for Africa should be considered in no less than a 15- to 20-year horizon and should focus on the five prime movers of agricultural development as a policy package because each by itself is limited.

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THE INTERNATIONAL LIVESTOCK CENTRE FOR AFRICA: Its Objectives, Activities, and Future

Peter J. Brumby

INTRODUCTION

Africa is poor and hungry; it is the only major region of the world where food production per caput is declining (Table 1). It is also the only major region where population growth rates are still accelerating. Imports of basic food staples, now 10 million tons per year, are growing by some 7 percent each year; they are projected to reach 40 million tons by the year 2000.

TABLE 1

Trends in Food Production for Three Subregions of Africa, 1980-84

	1980	1981	1982	1983	1984
			(1000 tons)		
West Africa	5145	5624	5233	4664	3593
Eastern Africa	13342	16151	16017	15566	11574
Southern Africa	4181	5357	3868	3163	3539

The poverty of the people working Africa's small farms, which dominate the agriculture of all countries in the continent, results in widespread hunger and malnutrition even in countries where overall food supplies should be adequate. This poverty also prevents the investment in fertilizers and better seeds essential to reverse the downward trend in food availability. The

dilemma for many of Africa's farmers is that increased cash income is needed to increase food production but increased production is needed to increase cash income.

African land productivity is essentially static and labor productivity is low in relation to that observed in smallholder agriculture elsewhere in the world. In Africa, about 400 hours of labor are needed to produce 600 to 700 kilograms of food grain. In spite of a rapidly increasing population, low labor availability during peak periods of demand is regarded by many observers as a key limitation. A combination of low agricultural productivity and relatively high urban wages leads to a rapid rate (about 6.5 percent per annum) of urbanization.

High urban wages arise largely because of the substantial inflow of funds occurring in many African countries. This movement of funds from external sources draws skilled manpower into the sector where it is invested and from which considerable spending power is then directed to the purchase of imported foods and services.

The implications of this scenario are that growth in food output depends critically on technological innovations that reduce unit costs, especially labor costs, and that better research services and greater use of fertilizer, seeds and other farm inputs, together with more efficient market systems, are critical to making Africa's production system work better. Realities in the continent's rural areas dictate that a low input process of agricultural development is essential and that more and better agricultural research, with long term continuity, is central to improving labor and land productivity.

FARMING PATTERNS AND LIVESTOCK

The small farms which characterize Africa's farming patterns produce a mixture of food crops and livestock. On many farms, livestock and their products frequently provide the bulk of the family cash income. In addition, livestock provides transport, draft power for crop production, manure for crop fertilization, and a cash reserve for use during during adverse times. From studies of these close links between livestock and crop production, it is clear that there is a close positive association between crop areas and yields on the one hand, and the number

of animals a farmer owns on the other (Table 2); it is also clear that this association is mediated by incremental fertilizer use arising from the better cash flow produced by more livestock.

These relationships can also be seen in the global picture of production statistics reported by national authorities. The data available indicate that those countries that have had the greatest increases in stock numbers have also had the greatest increases in cereal production; animal productivity also increased more in these countries than in others.

TABLE 2

Percentage changes in food production in Sub-Saharan Africa, 1969/71 to 1979/81

	Percentage Change		
	Average change[a]	Best 8 countries	Worst 8 countries[b]
Cattle numbers	16.1	31.9	13.6
Cereal production	12.3	36.5	-12.5
Meat production	27.8	34.1	24.5
Milk production	21.8	29.1	23.2

[a] Weighted average of percentage change in the decade, 48 countries.

[b] Excluding countries producing < 0.5 million tons cereal grain per year.

A similar picture emerges when the performance of groups of individual farms is considered. In Table 3 the source of cash income of a group of Ethiopian highland farmers is summarized.

TABLE 3

Annual cash income Debre Berhan control farms, 1980-1981

Source	Annual cash income (Eth. Birr)	
	1980	1981
Sales of cereals	45	51
Sales of pulses	14	22
Livestock products	97	92
Net trade in animals	289	211

The importance of livestock to the cash income of small farms is also evident in India. Returns to incremental investments in livestock are usually very attractive, even in areas where overgrazing is very evident.

Table 4 indicates the relationships among cash income, crop area, crop yield and livestock ownership of some Ethiopian highland farmers.

TABLE 4

Cattle ownership and cropping characteristics Ethiopian highlands, 1984

Debre Berhan

Cattle owned	Area cropped (ha)	Barley yield (kg/ha)	Total grain output (kg/farm)	Income (Birr/farm)
0-1	1.1	474	407	104
3-5	1.9	757	1320	438
6-8	2.5	1146	1845	672

TABLE 4 (Continued)

Debre Zeit

Oxen owned	Area cropped (ha)	Teff yield (kg/ha)	Fertilizer (kg)	Total grain (kg/farm)
1	1.7	830	61	1290
2	2.3	985	81	1933
3+	2.8	1055	121	2771

THE NEXT DECADE

Much of Africa's land which has the potential to support arable farming remains unused; the practical opportunities for expanding the area under cultivation are limited by present technology levels. The bulk of the remaining high potential land lies in the subhumid and humid tropics where the presence of trypanosomiasis and the fragility of the lateritic soils common in these regions limit land use. For the next decade it seems likely that a further decline in farm size and a consequent intensification of land and animal productivity, together with more effective use of labor and energy resources, will be the prevailing pattern. At the farm level a heavy reliance on family labor, a scarcity of cash, small localized markets and very limited credit seem likely to continue as common features of the farming scene. The security of subsistence food supplies will remain an overwhelming consideration.

SOCIAL, ECONOMIC AND POLICY CHALLENGES

Although technology development and its application to maximize the efficient and sustained use of national resources must be the key objective in the next decade, improved technology alone will not ensure adequate increases in food production; the political, social and economic environment of the agricultural sector of Africa has clearly a major influence on food production and distribution and determines the most appropriate research

objectives. Key factors in this milieu include:

- the policy environment for agricultural and livestock production;
- the composition of food demand;
- the level of infrastructural development and agricultural services; and
- the structure and organization of farming units.

The pivot around which these non-biological factors revolve consists of a sound analysis of constraints to production plus adequate policy formulation to overcome those constraints. The complexities in identifying constraints are many and the interactions of optimal policies with changing technology are largely unexplored in the African environment. Policy research is a subject that rivals technology research in importance.

A significant structural change in the demand for food occurs with urbanization and rising income levels. With higher spending power, demand shifts to higher quality foods, particularly animal products. Increased incomes also raise the demand for improved pastures and animal feeds. Based largely on the increase occurring in the relative demand for livestock products, a significant increase in the resources being spent on livestock production problems in Africa appears desirable.

The incremental infrastructural development requires much stronger national research institutions and much larger and more efficient credit and extension services. Better input-output market facilities and transportation networks are also prerequisites to improving food output.

The challenge for research workers in Africa is to design technologies appropriate to the type of farm units that will characterize African agriculture in the years ahead. All present indications suggest that small, subsistence-oriented farms will continue to predominate.

THE ESTABLISHMENT OF ILCA

The International Livestock Center for Africa (ILCA) was established in the mid-1970s. Its mandate is outlined in

a complex and lengthy document which, in essence, states that the purpose of the Center shall be to engage in those research and related training and information activities which will assist national efforts to improve the output of livestock products and human welfare in Sub-Saharan Africa. The origins of ILCA stem from an initiative of the Rockefeller Foundation and the Center is now one of the thirteen international centers which make up the CGIAR (Consultative Group on International Agricultural) system of agricultural research. The Center is funded, to the extent of about U.S. $14 million per year, by the voluntary contributions of 30 international donors, amongst the largest of which are the U. S. Government and the World Bank.

The Headquarters of ILCA are in Ethiopia and field units are based in the five major ecological zones of Sub-Saharan Africa. A simple breakdown of these zones, their area and the livestock and human populations of each is provided in Table 5.

TABLE 5

Livestock populations by ecological regions of Sub-Saharan Africa

Zone	Land Area (million Km^2)	Population (millions)				
		Humans	Cattle	Sheep	Goats	Livestock Units (250 kg)
Arid	8.3	24.8	31.5	37.1	48.3	41.7
Semi-Arid	4.0	65.7	45.4	23.1	33.2	37.4
Subhumid	4.8	59.4	32.7	14.2	20.3	26.4
Humid	4.1	50.3	8.8	8.2	11.6	8.1
Highlands	1.0	38.0	29.0	21.4	11.9	23.6

An approximate breakdown of Africa's livestock units by the type of farming system in which they occur is shown in Table 6.

TABLE 6

Livestock distribution by farming system, Sub-Saharan Africa

	No of livestock units	
	(millions)	(%)
Ranching	8	6
Pastoral	29	20
Mixed farming	32	23
Agropastoral[1/]	74	51

[1]This is a residual classification: animals in this group cannot be clearly assigned to other systems: This reflects the large number of animals that use communal lands for part of the year and farm land for the remainder.

The distribution patterns which emerge from these tables provide criteria by which a first attempt at assigning priorities for livestock research in Africa can be made. These tables highlight the importance of smallholder and agropastoral systems, of the concentration of livestock in the Sahel and eastern Africa, and of the density of animals in the humid zone.

PRIORITIES AND BUDGET

The present pattern of ILCA's expenditures provides for about 63 percent of the total funds being spent on research activities, about 21 percent on capital, maintenance and operating costs (Table 7).

TABLE 7

ILCA's Core Budget, 1985 (Mid-year estimate)

Component	No. of Senior Man-years	Million US$	% of Total
Field research	20.1	4.7	33.1
HQ research	10.0	1.9	13.4
Research support	6.0	1.4	10.0
Networks	2.7	0.9	6.3
Total Research	38.8	8.9	62.7
Training/Information	3.8	2.2	15.5
International Liaison	2.0	0.3	2.1
Board/Management	2.5	0.5	3.5
Operations	4.0	2.3	16.2
GRAND TOTAL	51.1	14.2	100.0

The research activities of ILCA are based on the concept of complementarity, i.e., that an international institute such as ILCA has a comparative advantage in assembling experienced international scientists at key locations, and in moving information, technology, germplasm and other materials internationally. In contrast, the comparative advantage of national research groups lies in undertaking the adaptive research essential to generating site specific recommendations.

An important consequence of this concept is that ILCA is continually seeking to increase its collaboration with specialized research institutes in the developed world and with national research groups in Africa. It seeks to occupy the middle ground of a spectrum ranging from basic to adaptive research, and to provide a linkage between research on livestock production in the developed world and in Africa.

The importance of this bridging mechanism is well illustrated by a simple analysis of the world's agricultural research publications. A search of abstracts produced by the Commonwealth Agriculture Bureaux (CAB) of the U.K. between 1972 and 1984 reveals a total of 1.81 million agricultural and livestock reports. Of those less than 3 percent relate to African agriculture (Table 8).

TABLE 8

Distribution of CAB research publications by subject area, 1972-1984

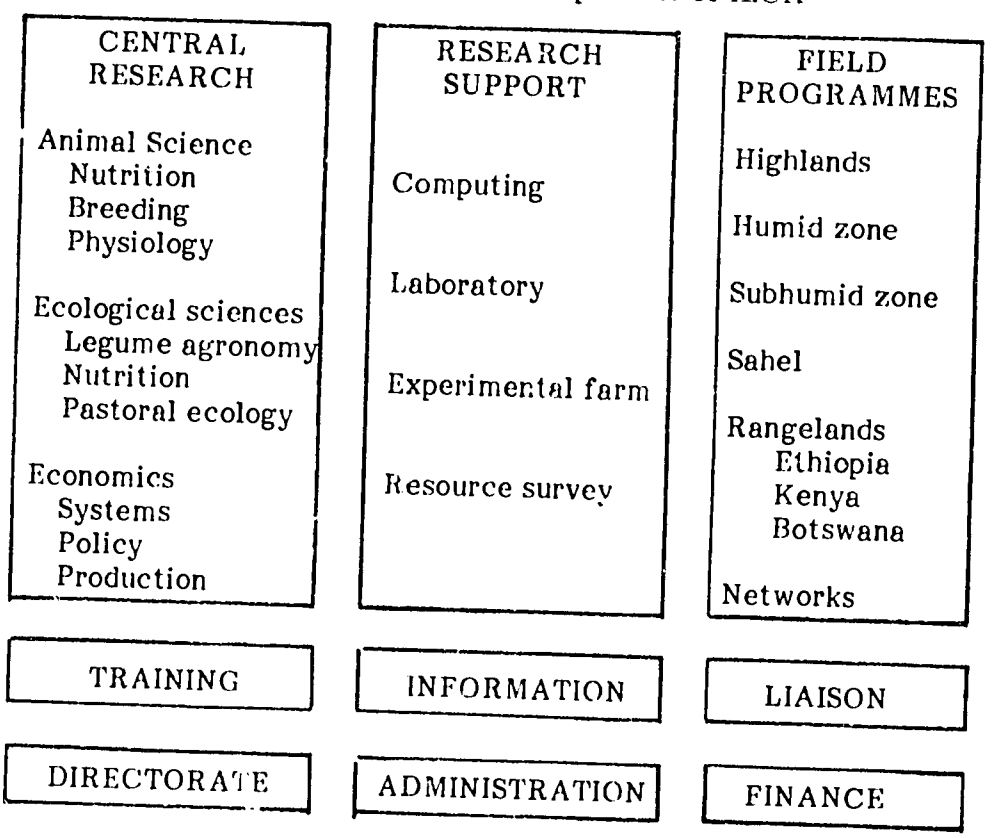
Subject area	Sub-Saharan Africa	World
	% of total	
General Agriculture	15.2	18.2
Agricultural economics/ Social Science	25.6	7.3
Veterinary Science	23.8	26.1
Nutrition	3.7	8.3
Breeding	8.9	13.1
Dairy Science	1.4	5.0
Herbage	3.9	3.3
Field Crops	6.7	5.9
Weeds and Pests	6.3	7.2
Soils and fertilizers	4.5	5.6
Total	100.0	100.0
Total Reports (No.)	(52,569)	(1,811,460)

The paucity of research literature related to African problems, and the low percentage of basic animal sciences within the literature published on Africa, emphasizes the important role of ILCA in transferring and adapting research from other countries to an African context.

STRUCTURE

The basic structure of ILCA is shown in Figure 1. Research activities have three major components, namely central research which addresses problems that transcend ecological zones, field research directed to zonal specific problems and research support facilities that service all research activities. Other support for the research effort is provided by substantial training and documentation units, together with an international liaison unit and the usual finance and administration services.

Figure 1. Structural components of ILCA



THE TARGET AUDIENCE AND WORKING CONCEPT

ILCA's immediate clients are the scientists, teachers and planners of African agricultural institutions. ILCA's role is to undertake those activities that contribute to and complement

the efforts of these clients; it is not ILCA's role to do those things that national groups can more readily do.

This statement, simple and clear as it is, does, however, present ILCA with a dilemma: if the client group does not adopt and use the ideas and results emerging from research and technological development at ILCA, these efforts are largely in vain. Where the essential national capacity is absent, ILCA cannot be effective. ILCA cannot undertake responsibility for these national services, but in their success ILCA has a very vital stake.

Arising from this observation is the importance of ILCA's field programs, network activities, workshops, conferences, seminars, training and documentation activities. These have the specific objective of strengthening national research institutions and their programs, as well as seeking guidance from the staff of these institutions on how ILCA can be most productive. Support services at ILCA emphasize those activities that national scientists cannot readily undertake; ILCA provides a large collection of germplasm for localized testing, maintains sophisticated computing, data analysis facilities, biochemical and physiological facilities, develops new methods of resource survey and farm research methodology, and seeks an entry into the science of the 21st century via biotechnology and remote sensing. In doing these things ILCA seeks to adopt and demonstrate a multidisciplinary team approach utilizing the physical, biological and social sciences. It also seeks to provide the continuity, concentration and resource base that the solution of difficult problems requires.

The research networks established by ILCA in Africa provide the mechanism linking ILCA to national research groups. These networks now cover eight major research topics and are made possible by the excellent computing, documentation and laboratory facilities ILCA provides. These units support and backstop the ILCA networks as well as all other ILCA training and research activities. The network activities are in the following fields:

Trypanotolerance	Small Ruminants & Camels
Animal Nutrition	Legume Agronomy
Animal Productivity	Livestock Policy
Animal Traction	Information

These networks are a new activity and each has a very large scope for expansion. They are a rapid growth area at ILCA and fulfill a widespread demand for greater ILCA assistance to national research groups. They also provide an excellent mechanism for ILCA staff to better understand localized problems and to assess priorities in research, training, and documentation.

Network activities have produced an impressive database on many aspects of livestock production in Africa, and of the factors affecting it. The relationships between lactation length and calving interval, between body condition and fertility, and between sex of calf reared and subsequent conception delays, are now quite clear, as are the large differences in breed productivity in areas of differing trypanosomiasis challenge and other environmental stresses. Very large differences in the productivity of grazing cattle and sheep herded in communal areas and in the output of smallholder farmers of similar resources are also apparent.

RECENT ACHIEVEMENTS

Legumes and land use. In Africa, as in so many parts of Asia and Latin America, low nitrogen levels in soils and forages, limit both plant and animal production. It is in these circumstances that forage legumes provide a critical link between the enhancement of soil fertility and crop yields, and an increase in the quantity and quality of forage available to livestock. Much of ILCA's work is directed to exploring the critical role of legumes in improving the fertility cycle, and ILCA scientists are working with many types of herbaceous, grain and browse legumes seeking to find legumes adapted to particular ecological conditions and farming systems. A very large collection of forage germplasm has been established, carefully documented, and seeds distributed throughout the forage legume network. In many areas of Africa small amounts of added phosphorus dramatically improve the growth and nitrogen fixation of these legumes, and often simple untreated rock phosphate in very small amounts is sufficient for this purpose.

Many alternative ways of using appropriate legumes have been developed. In highland areas the use of self-regenerating, herbaceous, annual legumes interplanted with cereal crops is practical; in the subhumid zone fodder banks of legumes

are a success; in the humid zone the use of the browse legumes Leucaena and Glyricidia planted in rows or alleys with cereal crops grown between the browse rows is proving a promising technique.

Simple technological innovations for land and water conservation recently introduced by ILCA include the construction of simple water ponds using bullock-drawn scoops. These ponds are used principally for domestic and stock water but also have a valuable role in irrigating specialized crops, particularly for tree establishment and for fish culture. ILCA has also adapted single ox bullock plows that facilitate crop planting at optimum sowing times, and has made a simple modification of local plows to create a system of broad bed and furrow cultivation on heavy clay soils.

Better cultivation systems using broadbeds and furrows allow for the productive development of the heavy, waterlogged and highly fertile soils commonly found in the bottom of upland valleys in Africa which hitherto have been largely unused. These broadbeds and furrows offer a means of cultivating presently unused land and result in large yield increases over flat land cultivation. By developing a reversible mouldboard on the local plow, it is also possible to construct terraces simply and cheaply on eroding hillsides.

Rangelands and survey techniques. Many of Africa's cattle are raised by pastoral and agropastoral groups in rangeland areas. The scarcity of stock water limits the use of these range pastures, while very high labor requirements, in lifting water manually from deep wells, and in desilting surface ponds, further reduce output levels. ILCA's work has shown that the simple sealing of the water holding ponds associated with deep wells, and the use of ox-drawn scoops to desilt surface dams, increases greatly the efficiency of water use.

Throughout Africa calves and humans are in competition as consumers of milk from lactating cows. The widely varying sizes of the livestock holdings of individual families, and large seasonal variations in the availability of green grass, greatly influence milk availability and the subsequent cash expenditure on purchased food. When subsistence milk is in short supply consumption of purchased cereals rises markedly, as does the purchase and consumption of tea, sugar, fats, and oils; addition-

ally, calves experience particularly high stress conditions and high mortality rates. The use of limited feed supplementation for these calves greatly increases their liveweight, reduces mortality and improves the effective use of rangeland feed supplies. A modest increase in calf weaning weights to 100kg at 8 months of age greatly increases the productivity of African rangelands.

ILCA's aerial survey team has developed a rapid resource inventory technique for development planning. This three-phase interlinked approach comprises remote sensing, aerial surveys and socio-economic investigations on the ground. The team has also developed a new technique for surveying cropping activities from aircraft as neither traditional aerial photography nor satellite imagery is suited to such surveys. The new technique uses low-altitude aerial surveys and a combination of wide-angle and telephoto photography giving enhanced resolution and clear identification of individual crop species.

The use of ground interpretation of satellite imagery at ILCA has recently increased and a strong ILCA-NASA collaborative program focusing on the development of early warning systems for drought is in place. A new computer program which assesses and specifies areas of overlapping ecological characteristics has also been developed.

Policy studies. ILCA's Livestock Policy Unit began operations in 1983. Three major studies have focused on the identification of factors influencing the performance of the livestock sector, the effects of imports of dairy commodities on domestic consumption, production and welfare, and the magnitude and impact of government expenditures on livestock output. Initial results indicate that many governments spend on their livestock sector only a small proportion of the revenue they raise from that sector through taxation and various fees, and that an excessive and increasing proportion of expenditure on livestock services in most countries goes to staff costs, with a consequent shortage of money available for vaccines, drugs and transport. The policy studies also indicate strong positive correlations between growth in cereal and in livestock output, between changes in livestock output and livestock number, and between GNP and growth in milk output.

Nutritional issues. Ruminants account for the major

proportion of the biomass of domestic livestock in Africa and the work of ILCA center on ruminant livestock. Feed supplies for these animals fluctuate widely both in quality and quantity during the year. In cropping areas, major stress periods occur during the main rains when extensive planting restricts the availability of grazing. In rangeland areas the main feed problems occur during the long dry periods between seasonal rains when inadequate levels of dietary protein restrict feed intake and its efficiency of utilization.

Crop residues and coarse pasture are the major feed resources for cattle, sheep and goats in Africa. The principles underlying the efficient use of these feed materials center on maximizing their utilization, rather than on achieving an optimal nutritional status for each animal. The difference in these two contrasting concepts of animal nutrition is an extremely important one. The premise underlying ILCA's work in animal nutrition is that the key task is to use what is available in African smallholdings rather than what is best for feeding animals. It is worth stressing that the quantities of straw, cane tops, peanut hay and other crop residues that are not used for animal feeding in Africa are prodigious.

A second premise on which the nutritional work at ILCA is based is that improved ruminant nutrition in Africa can best be achieved by providing the microbial organism of the digestive rumen tract with an improved supply of fermentable nitrogen, and ensuring intake of critical microbial growth factors such as sulphur and fermentable carbohydrate. Dramatic evidence is available showing that minor modifications in the composition of the diet greatly influence microbial activity in the rumen and in feed utilization by ruminant species.

The supply of nutrients to the rumen of animals consuming the widely available roughages can be supplemented with agricultural byproducts, particularly oil seed cakes, but limited availability, high costs and distribution problems essentially limit the use of these byproducts to cows supplying milk to urban markets. An important alternative is the use of molasses/urea mixtures, preferably with some form of leguminous forage or other protein source added.

Molasses/urea mixtures can be readily fed to livestock in liquid form and the intake of the mixture can be regulated

by varying the urea content in the range of 0 to 15 percent without greatly varying actual urea intakes of about 50 grams per day. The mixture can also be turned into a block form using calcium oxide or monosodium phosphate as a coagulating agent, and other supplements such as phosphorus and bypass protein can be added. Recent results at ILCA suggest that a response of roughly one liter of milk for each 500 grams of block can be expected in crossbred cattle producing 3 to 5 liters per day on a basic roughage diet. Increases in milk fat content of 10-20 percent are also normal; these yield and quality effects are considerably enhanced when leguminous fodder, oil seed cake or poultry litter are also added to the diet in small amounts. Substantial gains in productivity are noted in the growth of cattle and sheep supplemented in this way, with liveweight gains of 500 grams and more a day being possible in aged working oxen fed on straw with 500 grams of molasses/urea and a little protein supplement.

Critical minimal levels of rumen ammonia appear to be about 150 mg/l and a strong positive association between rumen ammonia levels and the nitrogen balance of sheep is evident. Assessment of the need for additional fermentable nitrogen in animal diets can easily be made by a simple colorimetric test of the ammonia level in rumen fluid; these tests are readily carried out under field conditions. It is also relatively easy to make a rough estimate of supplemental nitrogen needs by estimating feed nitrogen levels and knowing that about 3 grams of microbial nitrogen are produced by each 100 grams of digestable organic matter (DOM) available to the rumen. DOM estimates, in turn, can be approximated under field conditions by measuring dry matter disappearance from feed samples using fistulated animals. Species differences in rumen ammonia levels are surprisingly large.

Animal breeding. Milk production is the prime criteria for cattle ownership in Africa and total milk output is now about 5.8 million tons annually. Over the last decade this milk supply has increased by about 2 percent a year, essentially by an expansion of stock numbers rather than by increases in productivity. Over the decade commercial imports have increased sixfold and, with current levels of food aid of milk powder and butter oil, now amount to over 2 million tons annually of liquid milk equivalent, with a value of about US$800 million.

Lactation yields of 500 to 700 liters of milk are the norm, most of which is used for human consumption; calves usually receive only sufficient milk for minimal growth. Consequently, calf mortality is high, weaning weights are extremely low, mature body weights are reduced and sexual maturity is delayed by 1 to 2 years.

The progress that might be obtained by a selection program for increased milk production in local stock depends on the magnitude, extent and interrelationship of the genetic parameters involved in milk yields, the size of the population that can be accurately recorded and the extent of the selection differential that can be imposed on that population.

ILCA's evidence on these points indicates that heritability estimates for milk production and weight for age in African cattle are not dissimilar to those recorded in temperate breeds, and that genetic gains of 1 percent or so a year would be feasible if it were possible to put into place appropriate breeding programs. There are, however, two major problems in doing so. The first is that a 1 percent increase in a lactation yield of 600 liters or so is not particularly exciting, given the costs of attaining it; the second is that putting into place the herd recording, artificial insemination, progeny testing and bull selection programs necessary to achieve the 1 percent annual gain under smallholder conditions is essentially impractical. The Indo-Swiss project in Kerala, India, is making valiant efforts to do this but it is fair to say their experience does not provide hope for Africa. The results of this project indicate that some 1500 inseminations are required to produce even a rough progeny test based on 50 daughters. The resulting scope for using selected bulls in the residual portion of the cows available is extremely small. The key problem is the small size of each herd and the consequent difficulty of obtaining contemporary comparisons within herds. Using sire means which cannot exclude herd variability greatly increases the numbers of records required for a reasonable progeny test.

Crossbreeding with temperate dairy breeds can increase lactation yields fourfold in one generation. Indian data on this subject is now extensive and very large cross-breeding programs, based mainly on Jersey bulls, are in place there. In Africa, essentially similar results are available from many crossbreeding trials. Maintenance of the crossbreds in future generations

by using F1 bulls as the main sires seems the best approach to conserving a reasonable balance of exotic blood.

Utilization of increased milk supplies either through extensive smallholder milk collection schemes, or by simple but efficient village processing technology, provide an adequate and profitable means of marketing incremental milk and there is enormous scope for putting these practices into much wider use in Africa. In brief, if attempts are made to provide adequate vaccination and better feeding, it is clear that smallholder milk production can be rapidly and dramatically increased.

Breed productivity. For the production of beef and for the provision of draft power, local animals are usually most adequate. Breed comparisons are conveniently made by estimating productivity indices based on reproductive performance, cow and calf viability, milk production, calf growth and cow body weight. These productivity indices are usually expressed as the equivalent weight of calf produced per 100 kg of cow maintained per year. Undertaking these comparisons on a research station is, however, prohibitively expensive and most situations force an assessment of these characteristics under local farming conditions. ILCA has used this latter approach very extensively in a large program of comparative breed studies involving many national institutions. Overall results indicate that it is unwise to replace indigenous cattle in the more arid areas, that the trypanotolerant breeds of Africa have considerable potential in the tsetse-infested belt, and that crosses of indigenous breeds with exotic cattle are likely to be useful only under improved environmental conditions. Important observations confirmed by this work are that the realized productivity of any animal is the result of the potential of that animal's performance in the absence of environmental stress, coupled with the animal's resistance to environmental stress, and that genetically these two factors are negatively correlated.

SYSTEM STUDIES AND TECHNOLOGY GENERATION

When ILCA was established in the mid-1970s it was generally believed there was an array of technology suitable for African small farm conditions waiting to be used, provided a way could be found to slot techniques into small farm systems. The pathway to the application of this technology was considered

to lie in a greater understanding of the socio-economic problems under which small farmers operated.

Ten years later the validity of this argument is less certain. Certainly more is known about a "systems approach" as well as of the livestock production practices in use in Africa. It has also become evident that the stock of technology available is both less extensive, less relevant, and less applicable than was believed just a few years ago.

This critically important judgement underlies important changes in the work priorities at ILCA over the last few years; it is also one which emphasizes the need to strengthen greatly national research capacity in Africa.

Given this changing perception, a recurring question is 'What role might systems studies have in helping to generate new technology?' In considering this, it is convenient to start by distinguishing three main categories of farming systems research (FSR). These are:

a. "FSR sensu stricto", i.e., research on farming systems as they exist, their description, analysis, classification and understanding. It is holistic and seeks a description of the whole system. It analyzes the chosen farming system with the aim of understanding and describing the system.

b. "On farm research with a farming systems perspective" (OFR/FSP). This approach analyzes the farming systems just enough to define the on-farm research that appears necessary for practical progress. It then seeks to do that research using on-farm experiments.

c. "New farming systems development" (NFSD). This approach seeks to build radically new farming systems ab initio, rather than to evolve them from existing ones. It has little, or none, of an "on-farm research" element.

In brief, category "a" of FSR is essentially an academic activity with little direct impact on technical change; category "b" seeks to generate stepwise changes in farming practice and has become a standard approach in much of Africa's agricultural research; category "c" represents radical innovation and is essentially a research station concept.

OFR/FSP is carried out using the now familiar steps of diagnosis, design and testing; it is an approach widely used by the IARC's and other research groups. But the use of OFR with livestock under smallholder conditions presents many practical problems. On-farm trials with livestock and smallholders do not readily provide the researcher with statistically meaningful results relating to animal productivity measurements, as the Kerola experience of progeny testing in India clearly demonstrates. The multiple products from livestock, the difficulty in ensuring within-farm replicates, the long timespan involved in measuring reproductive traits, the critical role of livestock management factors and the risk perceptions associated with the use of the substantial assets that livestock represent for the smallholder farmer, indicate that experimental work with livestock is more easily done under research station conditions than on the farm.

The dilemma posed by this conclusion is how to ensure the "relevance" of research station experimentation in Africa. A close contact between researcher and farmer is crucial to cost-effective research, but the reality is that on-farm experimentation with livestock is rarely cost effective. A reasonable compromise lies in conducting "relevant" experimentation under the controlled conditions of well-organized research stations followed by on-farm trials that seek, essentially, to assess the rate of adoption of the proposed new technology. With this approach it is possible to ensure that research staff personnel are aware of the nature and priority of the production problems of the smallholder farmers they are trying to assist.

SUMMARY

In the search for a greater production of food in Africa the role of livestock is critically important; they are the catalyst to low-cost improvements in agricultural output. The more animals subsistence farmers have, the greater is their cash income, the larger the area they cultivate, the better seed they can buy and the more fertilizer they apply. In brief, animals contribute directly and in large measure to both the area cultivated and the yield per unit area of food crops. Better livestock technology provides an important option in the strategy for overcoming Africa's food crisis.

At ILCA a first generation of livestock-based improvements is now being tested. Under reasonable management, and contrary to earlier views, Africa's trypanotolerant livestock breeds prove to be highly productive, while excellent results from chemotherapy programs for trypanosomiasis have been achieved; improved animal feeding, as well as crop production, is possible using forage legumes; better utilization of crop residues is feasible; crossbred dairy cows outyield local breeds fourfold; ox-drawn scoops can build small ponds and dams for irrigation; improved cultivation and planting implements facilitate control of soil erosion and reduce high seeding rates.

These initial results and the improvements they lead to are now starting to make an impact on smallholder production practices in the ecologically more favored areas. In the drylands, where famine takes its largest toll, their potential impact is less likely to produce important changes. More and better research is desperately needed to forge technical answers to Africa's age-old problems of erosion, declining soil fertility and poor crop yields. New plants, animals, and farming systems that will flourish under dry and difficult conditions are needed. Africa needs the best that international science can offer: biotechnology, embryo transfer and tissue culture, recombinant DNA technology, genetic mapping, computer analysis and satellite imagery are some of the key techniques that must be used much more widely in association with well-proven and more traditional research technologies.

ILCA's facilities and skills in both traditional and new research methodologies, as well as in documentation, training, laboratory techniques and policy analysis, are providing a useful start to the type of international scientific support that many national research institutions require. It is the growth and strength of Africa's national institutions that will determine the future of agriculture in the continent. What is needed, now, is a greatly enlarged and sustained commitment to both national and international agricultural research that the productivity of Africa's agriculture may be vastly improved.

STRATEGIES FOR SOLVING CROP PRODUCTION PROBLEMS OF SUB-SAHARAN AFRICA

Ermond H. Hartmans

INTRODUCTION

Perhaps at no time in the 200 years' history of the Philadelphia Society for Promoting Agriculture have its aims and objectives had more relevance to the problems of the world than today. Let me recall that the purpose of those farmers, merchants and professional people who were your founders, was to establish commumications links so that farmers in the Delaware River Valley were well informed about technical and economic developments elsewhere. These were deliberate efforts by private individuals to promote the transfer of new technology, and we can be sure that they made good use of what they learned. We can also be sure that they were not only encouraged to do so by their local and state governments, but that those authorities did everything possible to create an economic and social environment within which private enterprise, and especially farming, could thrive.

It is partly upon this theme that I shall speak, for I see in the original objectives of the Philadelphia Society for Promoting Agriculture and in the subsequent development of American agriculture, features which Africa would be well advised to emulate in the years to come. Furthermore, the Society's interest and concern for agriculture far from the Delaware River Valley is clearly evidenced by the theme which has been selected for this Bicentennial Forum. It is a great honor for me to have been invited to participate in it.

I must acknowledge the importance of central planning and the government's role in stimulating and implementing development programs in Africa. Indeed, I have spent the greater part of my working life engaged in such activities. Without question, African governments have a major role to play, a

theme to which I shall return. But for a moment I wish to highlight the importance of the private individual, the role of private enterprise, and of commerce in future strategies for food production in Africa. African governments must enable and encourage these private initiatives to succeed. Most of the State and parastatal agricultural organizations have been complete failures.

INNOVATION AND PRIVATE ENTERPRISE

Let us not underestimate the abilities of African farmers. They know their business. Long before the advent of agricultural research and extension, long before colonization by Europeans, African agriculture had received and adopted as major food crops cassava, peanuts, Asian rice, maize and plantains. These milestones in the history of African food production were reached through the actions of individuals, without direction or encouragement from any central authority.

I have evidence of the same kind of innovative enthusiasm in the Africa of today; small examples to be sure, but indicative of the kind of private enterprise I believe to be so important.

In recent years the International Institute of Tropical Agriculture has developed a profitable new method for the production of "seed" tubers of that very popular and important root crop, yams. In the traditional Nigerian system one-fifth of the annual crop, or about 4 million tons of tubers, is reserved as seed for the ensuing year. The new method requires one-half to one-tenth of this amount to be reserved for planting, thereby greatly decreasing costs of production and increasing the proportion of the crop available for sale and consumption. No sooner had they learned of this new and profitable technology than a large group of Nigerian farmers joined together to form the "Nigerian Seed Yam Growers' Association." Their objectives are much the same as those of your founders, and I have no doubt that they are going to succeed in their own small way.

The new so-called "minisett" and "microsett" methods for seed yam production require the use of costly plastic mulch. In the context of traditional yam production this is high technology indeed, but it has been adoped and it is spreading fast.

It is a wonderful example of innovation and enterprise, and it is evidence for all to see that the Afr' an farmer, far from being bound by tradition, is ready to assess and adopt appropriate and proven technologies that come his or her way.

A second recent example, but on a different and commercial scale, relates to hybrid maize in Nigeria. Once the undoubted merits of hybrid maize bred at IITA for the Nigerian environment were proven, it was not long before no less than three private and well endowed seed companies were incorporated in the country to produce and sell hybrid seed. I am delighted to see that they are prospering, and that their forecast is for 75,000 hectares of hybrid maize in 1986 and maize self-sufficiency for Nigeria in the 1990s.

Here then is the spirit of the founders of your Society at work in modern Africa. No wonder that I feel confident in emphasizing the importance of private enterprise and its role in African agriculture to this audience. Clearly, this is a matter close to my heart, and one which I believe is highly relevant to the subject I have been asked to discuss today - aspects of recent agricultural research in Sub-Saharan Africa from which we might derive strategies to alleviate crop production problems over the next quarter century. From the outset let me assure you that there are many more good things to tell - so many, in fact, that I make a habit of refuting the prophets of doom and gloom when I urge my African audiences to take an optimistic view of the medium and longer term future for food production on the continent. I express this optimism as often as possible because there is a need, in the face of widely publicized pessimism, to sow the seeds of hope in Africa, and to give the policy makers there a sense of urgent and positive purpose. This afternoon I hope to be able to convince you that I am right to do so, and to persuade you that there is a successful way ahead to alleviate Africa's food crisis.

THE HISTORICAL CONTEXT

Let me first try to put the response of agricultural science to Africa's present plight in some kind of historical context. The history of crop production here in the United States serves as a good example. For perhaps 200 years before the second World War food production from a unit of land or

labor had remained more or less static, increasing only as the population increased and as more land was broken to the plow. Farming was a hazardous, back-breaking, and poorly rewarded occupation. The farming communities of those years were accustomed to hardship and their continued survival required a dedication and commitment which your Society was founded to promote.

The great surge forward came during and after the second World War, and there can be little doubt that the subsequent ability of this country to produce an abundance of food was and has been firmly founded upon science, in particular upon the well-established methodologies of "classical" breeding, but also through the wise application of other carefully designed and applied agricultural research and development programs. The products of this research were quickly put to use by private, innovative action, and by hard dedicated work on strong family farms. The productivity of the American farmers may well now have reached a plateau from which further advance will depend upon the new discoveries of biotechnology.

The "Green Revolution" of India and Southeast Asia offers another example on a more recent time scale. Its essential feature was its foundation in science; semi-dwarf wheats and rices able to respond in grain yield to good management, nitrogen fertilizer, and above all to the wisdom of the individual farmer able to recognize and profit from his opportunities. But the success of the green revolution draws to our attention another factor of great importance when we try to develop strategies for increased crop production in Africa.

THE COMPLEXITY OF TRADITIONAL AFRICAN AGRICULTURE

The "miracle" wheats and rices from CIMMYT and IRRI were adopted within farming and social systems which for centuries had been based predominantly upon the cultivation of one or other of these major crops. It is of the greatest significance to note that Africa's traditional agriculture consists of low input, but nonetheless complex mixed cropping systems, within which labor productivity and crop yields are low and where the improvement of but one component can have relatively little impact on food production.

From the point of view of research, this complexity of existing systems is one of the most important factors which must influence future strategies for crop production in Africa. What do we do about them? How can we promote improvement or change within them? Or, more drastically, should we recommend that they be replaced, and if so, by what?

Before I attempt to answer those questions I want to refer to a complexity on an even larger scale - that which is associated with the great diversity of agro-ecological environments in Africa. When we speak of the ecological zones of the continent we are referring essentially to regions which differ in the amount and distribution of annual rainfall. Other factors, like altitude and soils, are important, but the overriding determinant of natural vegetation and of the distribution and productivity of crops is rain. The farther away we go from the equator in tropical Africa the less certain we can be about when and how much rain will fall. This is a feature of central importance to agricultural science and, as we have recently become so tragically aware, for human welfare.

In the Sahelian zone where rainfall is both least in amount and most unpredictable in duration, there are arid regions where agriculture without irrigation cannot sustain the human population. We will do wrong to ignore this blunt truth, but on the other hand, many countries of the Sahel do have semi-humid areas where realistic strategies for increasing food production can have impact. We must look to these, and to all the other regions of Africa which are blessed with assured rainfall to give the continent food self-sufficiency in the coming decades.

To return now to research and the complexity of traditional farming systems in Africa. These systems evolved in response to a harsh environment and within ancient farming communities which had abundant land and adequate labor, but few if any other resources. Their soils were infertile and unstable under cultivation, soon losing irreplaceable plant nutrients, and easily eroded. The ancient response to this inherent fragility of the soil was the widespread development of a system of shifting cultivation wherein a cropping cycle of 2 to 5 years was followed by a period as long as 20 years during which indigenous fertility was restored with the regrowth of natural vegetation.

Shifting cultivation and bush fallow was a stable system

in which the risks associated with low input crop production were minimized. It supported the relatively small human populations of the time. Sadly for Africa, the continent's population is now so great that these long established farming systems can no longer feed the people. Even worse, the African environment for food production is susceptible to the intensified use to which it is subjected by today's population explosion, and in this sense we describe it as being fragile. Informed commentators speak of population pressure causing an irreversible deterioration in the biological systems upon which human existence depends. The more pessimistic among them visualize a vicious circle leading to inevitable starvation.

I do not subscribe to this view. In a moment I shall suggest a brighter future when I describe the exciting prospect which we believe has been made possible by research - that the next quarter century will see advances in African crop production such as those in this country and in Southeast Asia to which I have referred. But it would be naive to suppose that agricultural science alone can provide the solution to Africa's dilemma.

STRATEGIES FOR DEVELOPMENT

An essential prerequisite for the success of future strategies based upon the results of research is that African politicians must create a social and economic environment which not only encourages agricultural development, but which favors it.

In the simplest of terms farmers, both large and small, must be enabled to earn a decent living from their labor, and a reasonable return on their investments. Governments must ensure, either by their own action or by stimulating and encouraging commercial involvement, that farmers have access to markets and are paid fair prices for their produce; and that they have an assured supply of the inputs, including credit, which are known to be essential for any sound agricultural development. These are all conditions fully recognized in the agricultural policies of developed countries.

The so-called "peasant farmers" of Africa have a low social status, and their way of life is one of hard, unrewarding

physical labor. Farming is not a favored occupation, and the rural community of modern Africa has little or no political influence. It is hardly surprising that mass migration to inevitable poverty in growing cities goes on apace, removing a significant proportion of the young labor force from the food producing rural sector. Governments must foster policies which are designed to change this, and by their actions allow farming to become a profitable and respected profession.

As well as this need for political action, there are several other strategies for development which can and must be implemented if the promising new technologies derived from agricultural research are to have impact. I will not go into detail about them here, but I do believe that they are sufficiently important to be listed.

- An effective indigenous capacity for agricultural research and extension must be established and supported vigorously by the international development aid community.
- In support of such efforts we must ensure that appropriate training for Africans is expanded. Appropriate in the sense that the curricula and text books are relevant to local ecological and social conditions of the people being trained and are not, as so often in the past, simply transferred without modification from the developed countries.
- Of the many kinds of training needed seed technology in particular demands most urgent attention. If the many good crop varieties coming in increasing numbers from the breeders are to have impact, African countries must have seed industries of their own.
- In the formulation of research policies and development aid projects, the relevant national authorities of each country must be encouraged to play the major role. There is no doubt that, in the past, "aid" has too often been imposed by donors with little consideration for the needs and aspirations of its recipients.
- The crucially important, perhaps predominant role of women in African agriculture must be acknowledged. Women must be encouraged and trained to enter the profession of agriculture so that they will eventually play an important role as policy makers.

THE CONTRIBUTION OF RESEARCH

Having given you the basic philosophy and framework of my approach for solving the food problem south of the Sahara, let me now return to the more direct question of strategies for food production based upon the results of agricultural research. Over recent decades, and with emphasis on food for internal use rather than for export, a very large body of knowledge has been gathered by research scientists in their study of African agriculture. The accumulated results of this work lead us to several important conclusions.

At the heart of the matter is the complexity of African husbandry to which I have already referred. It seems unlikely that piecemeal improvements in single components of complex mixed cropping systems will raise productivity to the level which must be achieved if there is to be a balance between home produced food and human population. Instead we must take a broader view in which our objective is not only to improve the components of diverse farming systems, but also to improve, and if necessary to change the systems themselves.

In the traditional system of bush fallow and shifting cultivation the average African farmer of today is constrained by lack of labor and by the kinds of tools and machines available so that he or she can clear the bush fallow, and then sow and weed no more than two hectares of land, commonly in several widely scattered small plots. As the pressure of people on the land has grown, land use has inevitably become more intense. The length of the fallow period has gradually decreased until it is at last too short to restore fertility. Crop yields are declining, and the food crisis caused by greatly enlarged populations becomes increasingly severe.

LAND AND SOIL MANAGEMENT

The salient features of this system are its obvious instability as soils are leached and eroded, the low productivity of labor, and the low yields of crops per unit of land area.

While much remains to be done to find solutions to these seemingly intractable problems, research has identified the components of appropriate technologies which offer great

hope. They consist of low input systems which minimize soil erosion, nutrient leaching and weed growth, and which maximize nutrient recycling, labor productivity and crop yields so as to permit stable agriculture to replace shifting cultivation.

I refer here to various systems of crop production suitable for both small and large farms involving minimum or zero tillage and the use of mulches and crop residues to greatly decrease rainfall run-off and soil erosion, while improving the soil's permeability and its physical structure for root growth. Herbicides control weeds and live mulches, and newly designed small machines decrease the drudgery which is so characteristic of existing systems.

Allied to these concepts is the well-tested package of technologies based on alley cropping or alley farming in which crops of improved germplasm are planted between rows of leguminous woody perennials whose prunings, when regularly spread on the land, provide nitrogen and other plant nutrients for the associated crops, and together with the mulches and residues, smother weeds. The trees stabilize the soil and recycle nutrients which otherwise would be lost to the crops through leaching.

In their various locally applicable combinations these technologies replace shifting cultivation and bush fallow with continuous cropping. Labor is released from the annual task of bush clearing to cultivate more land and for other kinds of more productive work. With the land in continuous use the control of perennial weeds becomes ever less of a burden. Finally, the size and total productivity of the small family farm are increased, and the productivity of labor is greatly improved.

I am convinced that the application of appropriate land and soil management practices such as these must lie at the heart of future strategies for increased food production in Africa. They are applicable to large scale, mechanized commercial agriculture as well as to small family farms. And while large commercial farms will become increasingly important, Africa is going to depend upon its millions of small farmers for the greater part of its food in the foreseeable future.

Research at the International Institute of Tropical Agriculture has shown that the small family farm in West Africa must increase in size from the present average of two hectares

or less, up to about five hectares if the family is to have a decent standard of living. Under the system of bush fallow and shifting cultivation such an increase is impossible; the family farm simply does not have the labor to clear and weed such an area of land. On the other hand, alley-farming, further developed, adapted and improved has enormous potential for the family farm practicing permanent crop production on about five hectares. Small hand-operated machines, like the rolling injection planter and an inexpensive two-wheeled tractor, have been developed for such a farm, and some are already being manufactured in Africa. Together with the limited use of herbicides, they enable the small farmer to increase the productivity of his family's labor to the extent that they are able to manage a five-hectare holding effectively.

IMPROVED, WELL-ADAPTED NEW CROP VARIETIES

Appropriate land and soil management must go hand-in-hand with the production, efficient distribution, and adoption of new crop varieties. Such new varieties must have resistance to a wide spectrum of destructive pests and pathogens, they must be locally adapted to the great range of Africa's agro-ecologies, and they must be acceptable as food to populations with very diverse consumer preferences. If they meet these requirements, the industrious African farmers will adopt them.

With these objectives in mind, plant breeders in national, regional, and international agricultural research centers have made great progress with Africa's major food crops in recent years. Let me give you some examples from the International Center of which I was Director General.

Tropical Maize. The regions of Africa best suited to maize production are some 9 million hectares at mid-altitudes between 1000 and 1500 meters where adequate rain, relatively cool temperatures, and intense solar radiation favor large grain yields. To some extent this favored ecology has been exploited in parts of eastern and southern Africa with the breeding and adoption of hybrid maize and superior open-pollinated varieties and composites. But there remains great potential for increased production based upon hybrids and varieties which are resistant to mid-altitude rust, blight, and streak virus diseases. This work is in hand, and we can look forward with confidence to

significant impact on mid-altitude maize production in the coming decade.

Elsewhere, and particularly in West Africa, there has been a big change in maize production, initially made possible by the breeding of open-pollinated varieties resistant to lowland rust and blight which give on-farm grain yields of 3 or 4 tons per hectare compared with 1 or 2 from unimproved local varieties. For example, during the past ten years, maize as a major field crop has spread northward from Nigeria's forest and transition zones, several hundred miles into the northern plains of Nigeria's savanna. The country's maize crop now covers about one million hectares.

Similar varieties are spreading in other West African countries, and the potential impact throughout Africa of newer material resistant to maize streak virus is immeasurable. The significance of maize streak resistance is in the security it gives to the farmer once he knows that his crop will not succumb to a maize streak epidemic, such as the ones which have devastated local maize crops in recent years.

Tropical hybrid maize developed at IITA has given on-farm yields in the Nigerian forest zone of 4 to 8½ tons per hectare compared with 4 tons from the best open-pollinated, streak resistant lines, and 2 tons from local maize. Hybrid yields range from 6 to 10 tons per hectare on farms in the savanna zones with their more intense solar radiation.

Rice. Rice is considered to have the greatest potential for increased production of all crops in Africa, and for good reason. Asian rice reached mainland Africa from Madagascar several hundred years ago, but although African land races have since evolved, there has yet been little or no impact of modern varieties or production technology south of the Sahara. Excellent new high yielding upland and paddy varieties are now available based on Asian land races crossed with African material and the breeders continue to make rapid progress. Their improved materials are locally adapted to diverse African conditions having resistance to such important diseases as blast and yellow mottle virus, and tolerance of drought and of acid or iron toxic swamp soils; and they have grain types acceptable to African consumers.

Starting from what is effectively a zero base, the impact of the adoption of these new technologies is certain to be great. But perhaps more important for the future of rice production are Africa's 20 million or so hectares of undeveloped lowlands and inland valley swamps. They represent a vast untapped resource which, with appropriate water management and improved germplasm, can provide rice enough for African self-sufficiency in the crop. Intensive research to develop these areas is underway.

Cassava. Cassava reached Africa from South America some 400 years ago, and is now estimated to provide the staple food for around 200 million Africans. Other than the fact that it is commonly grown on exhausted soils, the major constraints to production have historically been bacterial blight and mosaic virus diseases. Now we have cassava clones completely resistant to these diseases, and with a potential for three times the tuber yield of the unimproved old varieties. They have already spread widely in many West and Central African countries, and are so popular that a trade has developed to sell stems for planting.

Since 1972 two exotic insect pests, the mealybug and green spider mite introduced from South America, have devastated the cassava crop throughout Africa. They are responsible for yield losses averaging 30 to 40 percent of the annual crop. Research has achieved substantial success in combatting these pests. The breeders have found genotypes which are resistant to them and are incorporating this resistance in their improved varieties. And in a remarkable research program, effective biological control of the mealybug, using a parasitic wasp from South America, has begun to have significant impact. The search for more beneficial parasites or predators of the mealybug continues in South America, and intensive work on the biological control of green spider mites is in progress.

Pulses. The pulses are especially important for Africa as sources of protein in diets which commonly lack adequate meat. There are many pulses, both indigenous and exotic, but here I will refer to only two as examples of the kind of impact on food production we can expect from research.

First cowpeas, or blackeye peas, which were domesticated in Africa, and which are the chief grain legume of West Africa. Improved varieties bred within the last decade are resistant

to all the major African pathogens of the crop, tolerant of some field pests and resistant to the cowpea storage weevil. A wide range of plant types for both seed and "snap" bean production are now available, and have been distributed to and tested in 51 countries worldwide, 28 of them in Africa. While it is still not possible to get large grain yields in Africa without chemical pest control, only two applications of insecticide are necessary on improved cowpea varieties for on-farm yields as large as 2 tons per hectare.

One very early maturing new cowpea variety has spread widely in Southeast Asia, and is now being adopted in West Africa. It is grown in the stubble following paddy rice, using only the residual moisture in the soil to give a crop where none has been grown before. The "60-day" cowpea has great potential in semi-arid regions with little and uncertain rainfall.

Finally, the soybean which is little known in Africa and which has never become widespread in the diets of the people there. Nonetheless, its potential as a source of vegetable protein, oil and soy-milk products is enormous. With the well-adapted soybean varieties which the breeders are now producing I believe that we can expect the crop to become just as important in Africa as it is in Asia and North America.

CONCLUSION

Contrary to the expressed view that a lack of new and appropriate technology is holding back agricultural development in Africa, I could report to you similarly exciting progress, not only in crop improvement, but in crop husbandry and in land and soil management as well. And so I refute the suggestion that agricultural research in Africa has failed to meet, or to begin to answer the challenge it faces. In saying this, I do not intend to suggest that the status of agriculture in Africa is good, and I certainly do not wish to appear to be complacent about it. Far from it. There is an enormous amount yet to be done, most especially in transferring recently developed technologies to the farmers.

Greatly increased efforts must be made to give farmers themselves the opportunities to assess and, if they wish, to adopt new improved varieties and farming methods. Here I

believe that the potential for well-conducted farm demonstrations has yet to be adequately exploited in Africa. I would like to see a major program to involve small farmers in the on-farm demonstration of new varieties and technologies to their local communities. In most developed countries this form of agricultural extension has played a significant role in agricultural development. It need be no different in Africa.

For it is at the national and local level that new technologies are finally put to the test - do the farmers think they are appropriate and will they adopt them? We must enable African countries to do this work for themselves. Training will be an important component of this effort, and no doubt there is much to be done with carefully applied material aid. But perhaps most important of all, we must promote in every way possible indigenous, national capabilities in both agricultural research and extension, and increase greatly the involvement of Africans in the decision and policy making processes which are associated with their agricultural and rural development.

In conclusion, let me reaffirm my optimism for the future of food production in Africa. I believe that agricultural research has already achieved results which, when adopted, will lead to an agrarian revolution in the continent. Now governments must act to provide the stimulus and economic environment in which a new generation of enterprising African farmers, served by profitable commerce as well as state agencies, can succeed and prosper.

IMPROVING AGRICULTURAL PRODUCTION IN DEVELOPING COUNTRIES: AN INVESTMENT IN THE FUTURE

Nyle C. Brady

INTRODUCTION

I have been asked to comment on the support the U. S. Government is providing for international agriculture and particularly for agricultural research. Before doing so, however, I would like to comment briefly on support others are providing and have provided for agricultural research.

At the top of my list of such donors are the Rockefeller and Ford Foundations. The Rockefeller Foundation initiated the first significant, sharply focused agricultural research in a developing country (Mexico) more than 40 years ago. In the 1960s, the Rockefeller and Ford Foundations established the first four of the international agricultural research centers (IARCs) which gave birth to the green revolution. These two organizations took the leadership in founding the Consultative Group on International Agricultural Research (CGIAR) which currently supports the work of 13 international agricultural research centers. The foundations continue to support these and other organizations that are concerned with agricultural development.

A.I.D.'S CURRENT SUPPORT FOR AGRICULTURAL RESEARCH

Turning, now, to the involvement of the U. S. Government in international development, I would like to stress that during the last twenty-five years, the U. S. Agency for International Development (A.I.D.) has helped developing countries to improve their economic circumstances. Much of this effort has focused on improving agricultural technology. In Asia and areas of Latin America, the Agency helped support research that led to the Green Revolution which produced higher-yielding, more productive strains of wheat, rice, and maize and stimulated increased and more efficient use of irrigation and fertilizers.

The Agency has also supported a second important development area—the creation and strengthening of agricultural universities and faculties in developing countries. Perhaps the best example of this effort is the assistance the Agency gave to India as it created the first 12 agricultural universities which now provide that country with thousands of trained and educated agriculturalists to help with its food and agricultural efforts. Similar results were achieved in other Asian countries and in a number of Latin American countries, as well. The educated men and women who graduated from these universities are now the national leaders, not only in agricultural research and extension, but in all aspects of agricultural production and utilization.

Because successful agriculture is often basic to development in other economic sectors, A.I.D. continues to focus a substantial portion of its resources on helping developing countries to improve their agricultural production. In FY 1985, $755 million (45% of total "Functional Development Assistance" funds of $1,683 million) were allocated to agriculture, rural development and nutrition programs.

A.I.D. supports agricultural research and development activities through a variety of institutions. The largest single effort is partial support of the 13 international agricultural research centers of the Consultative Group on International Agricultural Research. Five of these centers have research facilities in Africa and 5 others have significant programs in that continent. We currently provide about $45 million annually for these centers.

Our second major effort is to fund collaborative research support programs (CRSPs) which focus on 8 specific elements of food production and utilization. Forty U. S. universities and research institutions are involved in 143 different research projects under the 8 CRSPs. The U. S. institutions work with 63 host counterparts in 30 countries, several of which are in Africa. The Agency provides nearly $20 million a year for these CRSP programs.

Third are A.I.D.'s mission programs which provide support for institution building and training within developing countries. Their primary purpose is to help strengthen national research programs. They complement the specialized efforts of the international centers and universities and focus on specific in-country problems.

The products coming from these three research efforts are most encouraging. They are at least in part responsible for the remarkable progress the agricultural sectors of Asia and Latin America have made in the past decade. But Africa south of the Sahara has not been so fortunate. Per capita food production in that region has actually declined in the past 15 years. Agricultural production has not been able to keep up with population increases. For this reason, A.I.D. is focusing much of its support on means of increasing Africa's agricultural production.

AFRICA'S CRITICAL PROBLEMS

It is well to recognize that constraints on agricultural development in Africa are more severe than those in Asia and Latin America. I would like to mention a few such constraints.

Physical and Climatic Conditions. While there are fertile, productive areas in Africa, much of that continent is composed of fragile soils that often vary greatly from site to site. In fact, these soils create management problems that have not yet been properly addressed by agricultural researchers.

Because there is little knowledge to extend about cultivating crops in these unfavorable conditions, large areas may become deforested and devegetated when agriculture is expanded to new areas. More fertile, traditionally cultivated areas become less productive as they are farmed more intensively to satisfy the food needs of growing populations. Erosion, depleted fertility and reduced water-holding capacity of the soil often follows.

Low and undependable rainfall levels in much of Africa also create problems. Use of irrigation, which could alleviate some of the problems, is limited by financial and management constraints. Fertilizer use, in turn, is limited by lack of water resources and appropriate superior crop varieties. Per hectare use of fertilizer is a fraction of that for Asia and Latin America and has not increased very much during the past 10 years.

Economic Policies. Another major barrier to productive agriculture is created by unfavorable economic policies. Trade and exchange policies overprotect industry while providing little incentive for increased agricultural production. Government-created production, marketing and input-supply organizations

are often too large and unwieldy to properly carry out their mandated tasks. In addition to these constraints, most African governments have not established economic incentive systems that would stimulate increased agricultural production.

Institutional and Human Resource Capacity. These policies also mitigate against creating the financial and human resources required to build strong agricultural institutions. Throughout Africa, and particularly in Sub-Saharan Africa, countries do not have the infrastructure to actively participate in and contribute to agricultural development. Likewise, inadequate education systems produce insufficient numbers of trained personnel. Even those that do receive an education are often poorly prepared to meet the technological challenges generated by the problems in their countries.

Human and Animal Disease. Some of the human and animal diseases, which are unique to Africa or more virulent on that continent, directly curtail agricultural productivity. Debilitating human diseases, such as malaria, cholera, snail fever, sleeping sickness, and diarrhea, are widespread, sap human energy, and cause high infant mortality. Governments do not have the financial resources to alleviate the basic causes of disease by providing clean water and waste disposal.

Domestic animal diseases severely limit the areas in Africa where cattle and ruminants can be raised. In central Africa, in an area the size of the United States, trypanosomiasis prevents the production of livestock both for milk and meat, and as a source of power for tilling and other farming activities.

Slash-and-Burn Farming Systems. Because the population of Africa is increasing rapidly, traditional systems of shifting, or slash-and-burn, agriculture are no longer appropriate. There are too many people and too little land. Areas that used to lie fallow for at least 10 years to replenish soil nutrients are now being brought back into cultivation after only about five years. The shortened fallow period is reducing soil fertility which causes declining agricultural productivity.

RESEARCH AND UNIVERSITY DEVELOPMENT

To help Africans alleviate these serious constraints

to agricultural production we are developing a focused dual approach. First, we are concentrating on selected aspects of agricultural research to help the Africans develop improved technologies. Our long-range plans focus support on countries and food commodities that will most effectively use Agency financial and human resources. We anticipate that 20 to 25 years of continuous support will be needed to built a research and human capital base that can achieve the desired results. This effort will access AID's resources at home and in the field, working with African countries and other donors in a sustained, cooperative, focused program.

National agricultural research systems will be strengthened in approximately 8 countries. Strong adaptive research capacities will be build in neighboring countries so that in-country scientists can choose the most appropriate technologies and adapt them to local environments. Networking will be encouraged among national, international, and regional research programs, and with the research efforts of other donors. We are taking vigorous action to help establish and implement these networks.

We are also planning to help Africa strengthen its agricultural universities. Initially, four to six faculties of agriculture will receive assistance like that provided to similar institutions in Asia and Latin America. We will work with national leaders and other donors in selecting the universities to be assisted. These institutions will be strategically located in major agroclimatic regions of Africa, but they will be national, rather than regional, in nature. We will collaborate in the development of a long-term (probably 20-year) plan to strengthen the agricultural faculties of these universities.

As was done in Asia, we expect to involve American universities as partners in the development effort. U. S. professors will be asked to replace the overseas faculty members who will come to the United States for advanced academic and research training. Significant research programs will be developed at each Third World university to complement the institution's academic programs. Over a period of time, we hope to help create a half-dozen quality institutions of higher education in Africa. We are encouraging collaboration with the World Bank and other donors in further development and implementation of this effort.

The bottom line is that new technologies must be devel-

oped and transferred and poor countries in Africa and elsewhere must be helped to develop the skills and institutions that can build and maintain improved systems.

This will not be a short-term effort. Our country and other donors must be willing to commit financial and human resources for at least another two decades. This is an investment in a brighter future for the human family.

SPECIFIC RESEARCH PRIORITIES

To help Africa generate improved technologies, A.I.D.'s initial efforts to achieve this goal focus on three major areas:

- o creation of improved crop cultivars;
- o removal of constraints to animal production (with primary emphasis on diseases and feed availability); and
- o improvement of soil and crop management systems.

Progress With Plant Crops. Recent research on wheat, rice, and maize has yielded significant results of importance to Africa. Over a fifteen-year period, scientists in Zimbabwe have produced hybrids with high-yield potential. Now, there are highly successful corn programs in both Kenya and Zimbabwe. Small- and large-scale farmers in these countries have widely adopted the hybrid maizes and have greatly increased national production, proving once again that, contrary to common belief, small-scale farmers are willing and able to quickly adopt truly superior new technologies.

The International Institute of Tropical Agriculture (IITA) in Nigeria and A.I.D.'s Beans/Cowpeas CRSP are making significant progress in improving cowpeas. One result of this research is a new cowpea variety, tested in Senegal, that takes only 60 days to mature, is more drought resistant, and 2.5 to 5 times more productive than local varieties. Other new varieties are resistant to various diseases and pests that plague this crop.

In the Sudan, a new sorghum variety has been introduced which tolerates the droughty conditions and yields 2 to 3 times what the old varieties produce. This breakthrough was the result of a truly collaborative effort between the International Center

for Research in the Semi Arid Tropics (ICRISAT) and U. S. universities that have trained people to help develop this variety and have provided some of the genetic resources that were used in the research.

More prolific and hardier varieties of cassava, sweet potatoes, and other African food crops are also being introduced to African farmers and a newly identified strain of rhizobium is being tested in Africa and elsewhere for its ability to increase yields and produce extra nitrogen for subsequent crops.

Progress in Animal Research. A.I.D. also supports a variety of research projects aimed at improving the health and productivity of farm animals.

Animal trypanosomiasis (sleeping sickness) is proving to be a difficult disease to overcome. Scientists have not been able to develop a vaccine because the organism is very adaptable and quickly generates resistance to experimental vaccines. However, researchers at the International Livestock Center for Africa (ILCA) have uncovered a degree of tolerance among some of the native (Ndama) cattle. They are now attempting to isolate the cause of the tolerance so that it can be cross-bred into disease-susceptible native cattle. Since the disease-resistant animals are rather small, researchers are focusing on building the tolerance into larger, more productive breeds.

Progress has also been made in controlling East Coast Fever of cattle. Using isolated strains of this disease-producing organism, researchers at the International Laboratory for Research on Animal Disease (ILRAD) have successfully vaccinated cattle in Kenya. The vaccine trials will be extended to other areas of Africa affected by this devastating disease.

The Small Ruminant CRSP has identified and eradicated a goat arthritis disease [Caprine Arthritis-Encephalitis (CAE)] which had entered Kenya with foreign breeds and was wiping out small flocks. In Morocco, this CRSP identified a prolific breed of sheep and is working to preserve this valuable resource. With proper management and disease control the improved animals are expected to more than triple the number of lambs produced by non-prolific breeds.

Farming Systems Research. Progress is also being made

on various aspects of farming-systems research. Particularly, researchers are testing viable alternatives to slash-and-burn agriculture.

"Alley cropping," a method of interspersing rows of leguminous trees and food crops, sometimes augmented with a little phosphorus, is receiving considerable attention in these research efforts. Instead of the yield going down a year or two after the land is cleared—as it currently does when the slash-and-burn system is practiced—on experimental alley-cropped fields, the yields have stayed high for three or four years. In addition, the trees prevent soil erosion, and provide forage for small ruminants, as well as enough residue for use as a nutritious green manure on the food crop.

Three of the international centers are working on alley cropping and another is focusing on other agroforestry systems that combine the growth of trees and crops. Such systems work well under experiment-station conditions. Successful demonstrations on their own or neighbors' fields will encourage farmers to use these alternative systems. They will be able to give up traditional patterns of shifting agriculture, stay on the same land year after year and improve it with fertilizer.

Use of Fertilizer. Soil fertility obviously plays a key role in determining crop production levels. As was the case in Asia, the availability and wise use of fertilizers in Africa is a requisite for increased food crop production.

The International Fertilizer Development Center (IFDC) is conducting soil and crop management research on the response of African upland crops to fertilizers. The results of these experiments clearly establish that chemical nutrient deficiencies seriously constrain upland crop production and that food security for Africa will require several-fold increases in the use of fertilizer for rainfed crops.

The Potentials of Biotechnology. Traditional breeding methods have done much to move agriculture forward by modifying crops and animals so that they fare better in less-favored environments. The more recent use of biotechnology adds potentially powerful, time-saving tools to the research arsenal. As agricultural research capacities develop in Africa and elsewhere in the developing world, this new science will not replace traditional

methods but will enhance the work of the newly strengthened research institutions.

CONCLUSIONS

Science and education offer great hope to developing nations as they continue efforts to feed their expanding populations. Already, scientists have clearly demonstrated that agricultural research can provide improved technologies to fuel increased agricultural production. The green revolution of Asia and Latin America was based on such technological advances.

The challenge of the next generation is to use science and technology to bring similar advances to Africa. While the environmental, institutional, and human resource challenges in Africa are formidable, I am convinced that, with sharply focused support from the more developed world, Africa can succeed.

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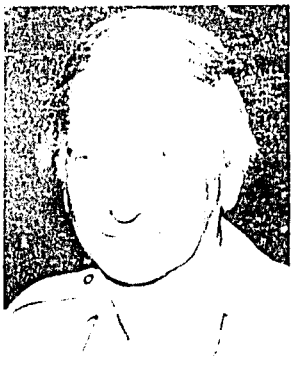

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