

SCIENTIFIC AND TECHNOLOGICAL OPPORTUNITIES IN AGRICULTURAL DEVELOPMENT IN LESS-DEVELOPED COUNTRIES

Ralph W. Cummings¹

108 1911 Building, North Carolina State University, Raleigh, NC 27650

Agricultural development, in the third world, as in any part of the globe, is a very complex phenomenon on which as yet we have a very imperfect understanding of how it can be addressed and influenced in a positive and constructive way. We do realize that it involves many human, political, institutional, and economic dimensions. And at the same time, I hope we all appreciate the fact that there must be available a sound, well-understood, and dependable scientific-technological base on which to devise the interventions designed to promote development if these forces are to work effectively.

I think it is quite appropriate that this symposium brings together the 3 phases—human and political, economic, and scientific and technological. Each has its own character, but all are inseparably interlinked and interdependent. I shall dwell on food production in addressing the scientific and technological opportunities in agricultural development, recognizing that other commodities are important in the total agricultural picture.

The problem

The world has more than 4 times as many people as it did when ASHS held its first meeting early in this century. And we can anticipate a further growth of almost 50%, to 6-fold or more than 6 billion people, by the turn of the next century. Thus far, agriculture has been able to produce enough food to meet effective market demands, even though there are immense disparities in the adequacy of food supply and in the quality of the diets of different population groups. There are also great disparities in access to food for different economic groups within given regions.

J.S. Kanwar set forth some of the basic problems quite clearly in his presidential address to the 12th International Congress of Soil Science, held earlier this year. It is clear that a major portion of the increased agricultural production, for the next generation at least, must come from land already cleared and under cultivation and this will require the development, verification, testing, and application of advances in science and technology aimed at improved production at a greatly accelerated rate.

Data assembled by the International Food Policy Research Institute as a background for the Consultative Group on International Agricultural Research (CGIAR) Technical Advisory Committee's study on Priorities of the Group for Investment in Agricultural Research reveal some very great regional differences (Table 1).

The distribution among calorie sources for Canada, Western Europe, and Australia would be much closer to that of the United States than to that of the developing regions listed.

These figures represent estimates of gross consumption on a regional basis, and obviously entail some compromises as to what items are to be included in each grouping. Furthermore, the inequities in income among different families within a region that determine what the lower income groups within a population may be able to produce or purchase from the market result in still greater contrasts.

I would like to call particular attention to the following:

- 1) The United States and other more affluent and industrialized countries consume much larger amounts of animal products and smaller proportions of cereals, roots, and tubers than do populations of the less-developed countries (LDCs). People

tend to put higher proportions of their food budgets into animal products, fruits, and vegetables as development takes place and incomes rise. The higher demand for animal products in turn places increased pressure on grain supplies for animal feeds.

- 2) Consumption of livestock products is especially low in the humid regions of equatorial and West Africa. Livestock products supply 8% or less of the calorie supply throughout the developing regions of Asia, the Middle East, and the other African regions.
- 3) The consumption of pulses does not appear to be high enough in most of the LDCs to offset the low consumption of animal products in supplying protein balance, quality, and quantity. In this connection, rapid advances in high-yield technology for cereals, which has not been equalled with the pulses, has resulted in putting cereal production in a more favorable competitive position than pulses, and the relative supply of pulses has tended to decline.
- 4) Fruit and vegetable consumption is low in the LDCs and especially so in those of the African continent. One must question the reasons for this and consider the implications. Some of the answers may be rooted in cultural traditions, in historic origins of the crops and their indigenous presence or absence, or perhaps in the lack of cultivars or selections adapted to the climate and soils of the region concerned.

The food requirements of developing countries, whether at current levels or to meet increased demands as economic development moves forward, must, to a very large degree and with few exceptions, be provided within these nations themselves. The record of the past generation has been mixed and not completely reassuring. Quite a number of nations which had historically produced substantial quantities of food grain for export no longer produce surpluses and have become importers. Only 5 or 6 nations now are able to export sufficient quantities of food grains to make any substantial impact. Lester Brown calls attention to the fragility of this situation dramatically in one of his Worldwatch series papers, entitled "The Politics and Responsibility of the North American Breadbasket." A few nations, such as India, Pakistan, the Philippines, and Indonesia, which had fallen behind and become net importers, have within the last 2 or 3 years been able, with improved technology for wheat and/or rice production, to achieve or closely approach a balance between production and consumption. They are making strong efforts to cross over into the exporting column, but their continuing population growth, with little new land to come under cultivation, requires ever-increasing yield levels to maintain the status quo on per capita food supplies.

The last generation has witnessed some very significant advances in our understanding of how the tools of modern science and technology can be put to work in a very effective way to improve food production by small-and large-scale farmers in the developing world. We learned that some of the initial premises, which were based on the assumption that technological advances enabling farmers in the more industrialized, temperate countries to grow "2 (or several) blades of grass where one grew before" could be applied directly to the climate, soils, and cultural patterns of the tropical, developing world, were somewhat naive and over-simplified, and, in many cases, were not applicable.

International agricultural research network

I shall not dwell on the pioneering work of the Rockefeller Foundation in its earlier work with national programs in Mexico, Col-

¹Ex-Chairman, Technical Advisory Committee, Consultative Group on International Agricultural Research.

Table 1. Major components in diets in selected regions.

Region	Calorie consumption (%)						
	Cereals	Roots, tubers, plantains, etc.	Animal products	Pulses	Fruits & vegetables	Sugar	Oil & fats
USA	20	3	37	4	5	12	18
South America	35	15	18	5	3	16	8
Central America	50	4	11	8	4	15	8
Middle East/N. Africa	63	2.5	8	2	5.5	9.5	9
South Asia	65	2	7	8	3.5	10	4.5
Southeast Asia	66	9	7	7	3	3.5	4
Equatorial Africa	21	54	4.5	10.5	2	3.5	4
Semi-arid West Africa	72	4	8	10	1	2.5	3.5
East Africa	68	10	7	8	1	3.5	2.5
Humid West Africa	48	33	2.5	6.5	1	2	7

ombia, Chile, India, and in the earlier cooperative regional networks. I shall move directly to the present day when we have in place or in the making an increasingly effective, cooperative world community of dedicated agricultural scientists who no longer work in isolation from one another but who share experiences, information, materials, and performance data to work out principles and practices whereby a much larger portion of the world's less privileged people may share in the fruits of science and technology as applied to their needs. It was standard practice when the International Rice Research Institute (IRRI) initiated its production training programs for rice scientists for a simple test to be given to entrants asking them to identify 40 or more symptoms of plant development, deficiencies, diseases, and pests found in rice fields in the tropics. On initial exposure, even the most experienced rice scientists from temperate regions failed these tests. They simply had not encountered the limiting problems, thus represented, in their own countries. This was a sobering experience to most of them, but it served to make them acutely conscious of the need to observe and address the actual limiting problems of these regions.

The IRRI, in cooperation with several Asian countries, successfully developed the short-statured, lodging-resistant, fertilizer-responsive cultivar, IR8. The International Center of Maize and Wheat Improvement (CIMMYT) also successfully developed short-statured, lodging-resistant, fertilizer-responsive wheats, capable of new and higher levels of production. The "Green Revolution," as it was popularly referred to, gave hope that at least for the near term food needs for the developing world could be met. It certainly elevated agricultural science and the image of the agricultural scientist in the developing world. At the same time, there was real concern that these advances would be applicable to only a fraction of the farmers of the developing world. These producers would benefit and the urban consumer would be assured of supplies of these food grains at more reasonable prices. There was real concern that other segments of farm producers who did not have access to irrigation and adequate credit, as well as urban consumers of other food products, would be left behind, with the possibility of even greater inequities in access to the accrued benefits.

It should be pointed out that each of the above 2 developments, which were real landmarks of progress, were not the result of isolated efforts of a few scientists. The IR8 cultivar brought together: 1) short-stature from a Chinese source, from the mainland via Taiwan; 2) yield, quality, and some other desirable economic characteristics from Indonesian cultivars; 3) breeding, selection, and testing by rice scientists at IRRI in the Philippines and several other Asian countries; and 4) full exchange and sharing of data by all. The short-statured, lodging-resistant, high-yielding varieties of wheat drew on dwarfing genes obtained from Japan, crosses with spring wheat varieties of the United States, subsequent crossing and testing with materials in Mexico, and widespread testing in Mexico, India, Pakistan, and the Middle East. In both programs, scientists from cooperating countries came together for workshops, planning sessions, and in-service and academic training programs. The development of a broad range of experienced, competent, and confident talent from many disciplines and many countries which were participants in this joint effort was, in retrospect, one of the greatest, lasting benefits. The research and

technology program served as the vehicle for talent and institutional development.

Following the achievements with rice and wheat, additional programs have emerged and international programs now have been developed for most of the major commodities. These programs involve 16 or more international centers on 5 continents, 13 of which are supported by the CGIAR. The International Agricultural Research Centers (IARCs) help to focus attention on the limiting problems associated with the concerned commodities and may provide leadership and assist in coordinating the overall cooperative efforts. They can perform this role only if: 1) they are centers of research and professional strength in their own right; 2) they earn the confidence, trust and respect of the growing body of scientists working in national programs; and 3) they are able to provide inputs that make real contributions to the strength and effectiveness of the national efforts.

The International Centers are reaching out increasingly in 2 ways: 1) participation in and assisting in the development of cooperative networks of scientists in national programs, and 2) working out collaborative programs with laboratories and institutions of advanced research to develop the necessary scientific background information on which advances in production technology must depend.

On the network approach, one could draw examples from several institutes, but for illustrative purposes I shall refer to the experience of the IRRI, the oldest of the IARCs and the one with widest experience in this technique. IRRI is a participant and plays a leading role in 4 major international networks—International Rice Testing Program (IRTP), Genetic Evaluation and Utilization (GEU), International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFER), and the Asian Cropping System Network (ACSN). The effectiveness of the cooperative network approach is increasingly evident around the world, but at least one illustration would seem appropriate here. I shall refer to the development and introduction of the rice cultivar IR36. This is an early maturing and high-yielding rice variety with excellent grain quality, multiple resistance to the major insects and diseases of rice in the Tropics, and tolerance for various problem soil conditions. Grown on more than 10 million hectares, it is now the most widely planted rice variety in the world. Its performance has held up well for over 7 years, but other varieties having the same general performance, characteristics, and resistance obtained from different gene sources are in the pipeline as a backup in case some new and unforeseen problem should arise.

The ancestry of IR36 (so named on its first release by the Philippine Seed Board in 1976) involves 13 cultivars from 6 countries. Each of these 13 parent cultivars was selected on the basis of some important performance characteristic it could contribute. Initial crosses were made in 1969. These were followed by selections, evaluation, additional crosses and backcrosses to incorporate additional agronomic, disease, and insect resistances, and adaptations to environmental stresses and challenges of the progenies to all the stresses where they seemed most acute. Evaluations were carried out in a multitude of different situations over more than 10 nations before its range of adaptability and the stability of its yield, grain quality, and resistance to several diseases and insects could be determined with confidence. This multilocal and multinational contribution

to the parentage of IR36 and to its stepwise development and performance evaluation was made possible only because scientists from the various countries and institutions involved had, over a period of years, visited IRRI headquarters, participated in workshops and conferences, and contributed their breeding lines and technological information which would otherwise not have been available. They had already developed into a team with common goals and objectives. The number of scientists and the range of disciplines involved in this development are most impressive. It is this multidisciplinary, multinational open cooperation and participation, and the free and unfettered exchange of genetic material and information which is contributing today to such rapid progress in the development of the science and technology necessary for raising production in farmers' fields in the various situations across the developing world.

Multinational, interdisciplinary cooperation needs to be promoted and fostered in all facets of agriculture. Some concern has been expressed that recent emphasis on plant breeders' rights (PBR) and promotion of PBR legislation too soon in LDCs (i.e., before evaluation) might threaten to erode this process and slow down the advance in development and application of relevant technology. The technical advisory committee of the CGIAR has been examining the implications of such developments over the past 2 years and will soon release its conclusions.

IRRI has been devoting its attention to the advancement of technology for rice production and rice-based farming systems; however, other groups have focused on other aspects of agriculture and food production in the LDCs. Some examples are: 1) CIMMYT—maize, wheat, barley, and triticale; 2) International Potato Center (CIP)—potatoes; 3) International Center for Tropical Agriculture (CIAT)—cassava, beans, and tropical pastures; 4) International Institute for Tropical Agriculture (IITA)—cassava, maize, and rice in Africa, with cowpeas, sweet potatoes, yams, and soybeans on a wider geographical basis, and the means of maintaining the quality and productivity of soils of the humid tropics as the population increases and moves from forest cover to crop cultivation; 5) International Crops Research Institute for the Semi-arid Tropics (ICRISAT)—sorghum, millets, groundnuts (peanuts), chickpeas, and pigeonpeas and the rational management of soils and water under seasonally dry rainfed tropics; 6) International Center for Agricultural Research for Dry Areas (ICARDA)—rainfed agriculture in the semi-temperate winter rainfall regions of the Middle East and North Africa, including a commodity focus on large-seeded chickpeas, lentils, and broadbeans, and regional attention to wheat and barley; 7) International Livestock Center for Africa (ILCA)—systems of livestock production in Africa south of the Sahara; and 8) Asian Vegetable Research and Development Center (AVRDC)—the problems of vegetable production in the lowland humid or semi-humid tropics and subtropics. (It is encouraging here to see growing cooperation in AVRDC between Taiwan and mainland China.)

Regional organizations such as the West African Rice Development Association (WARDA), CATIE in Central America, and the Southeast Asian Regional Center for Agriculture (SEARCA) should also be mentioned. And there are certain factors of production which may transcend commodity lines and require international attention over and above that related to specific commodities such as: 1) the collection, conservation, and utilization of plant genetic resources (International Board for Plant Genetic Resources); 2) animal diseases which may forestall livestock production in major continental areas (International Laboratory for Research on Animal Diseases); 3) food policy (International Food Policy Research Institute); 4) technology for utilization of local fertilizer materials and the efficiency in use of fertilizer nutrients (International Fertilizer Development Center); 5) insect physiology and ecology (International Center for Insect Physiology and Ecology); and 6) the problems of strengthening agricultural research capabilities and organization in the LDCs (International Service for National Agricultural Research). Other topics in this latter category include: 1) the problem of managing our soil resources to enhance and preserve their sustained productive capacity, and 2) the efficient utilization of water resources, under both rainfed and irrigated conditions.

The challenge and the opportunity

Thus far, I have emphasized the networks of scientists in the International Centers and in the cooperating LDC national institutions. However, resources and talents are limited and no International Center or national agricultural research program can address adequately all the problems it needs to solve to optimize agricultural production. Many institutions in the more highly developed countries have facilities, talent, resources, and interests that can link with institutions in the LDCs on problems of mutual interest and value to both parties, if we can find better ways to bring them together.

Brady and others present here could speak with more authority on the ways that this is being addressed by the U.S. agricultural scientific community and the government. Other nations also are giving substantial thought to this question. The newly authorized Australian Council on International Agricultural Research is being given substantial funding for the purpose of mobilizing the national scientific community to play a more effective role in accelerating progress in agricultural science and technology for the developing countries. Grants will be made to Australian institutions, but only for support of agricultural research activities which have been jointly identified and which will be carried out in full collaboration between the Australian and the LDC institution. The Cooperative Research Support Projects (CRSP) under Title XII have many similar features.

The rate of progress in total food production in LDCs, in aggregate, has been keeping pace with overall population growth. There have been serious regional disparities, however, with Africa south of the Sahara lagging seriously in per capita food production. We need to accelerate the pace.

I have indicated that very substantial progress has been made over the past generation in development and deployment of an institutional base for generating the scientific technology needed for rapid advances in agricultural production among the LDCs. Furthermore, the growth in size and competence of the scientific talent in the LDCs has been impressive. There is great challenge and opportunity to utilize these institutions and talent to further develop, verify, adapt, and *apply* science and technology so that the goals, aspirations, and real needs of the next generation are achieved.

Genetic advances in recent years have not only produced impressive gains in their own right but also have been an effective, popular, and convenient vehicle for carrying forward a package of advances in techniques for disease and insect control, improved plant nutrition, knowledge of how to deal with problem soil situations, and improved water management. We should not lose sight of the fact that the realization of gains from genetic improvement is dependent upon wise management of these and other factors.

Genetics will continue to be a key tool upon which we shall place heavy reliance in the future. Diseases and insects themselves change and plant varieties which are highly productive and useful at a given point in time may prove susceptible to new and previously unknown enemies, new strains, races, or biotypes of known enemies. Constant vigilance to identify such potential enemies at an early stage and to ensure the development of new combinations capable of coping with them will be necessary. New techniques of tissue culture, cell fusion, and anther culture are making it possible to deal with, manipulate, and maintain large populations *in vitro* and greatly speed up certain processes of genetic manipulation. The collection, maintenance, description, and continued availability of the total world genetic diversity of our important agricultural crops are matters deserving priority, and the widening of this diversity and improvement of techniques for utilizing it are likewise essential. We are probably nowhere near the limit of our abilities to conceive and utilize such tools.

The major portion of the world's food supply now comes from a very small number of species. The National Academy of Sciences has identified a substantial number of little-used species which may have greater future potential. A great deal of research will be required to assess this potential and, when clearly identified, to develop the technology for its exploitation on a significant scale. A tropical legume, the winged bean, is one of this class of plants which has recently been cited as worthy of greater attention. The Asia Foundation has spearheaded efforts to focus attention on the winged bean.

An International Winged Bean Research Institute, with headquarters in Sri Lanka, is now under development.

Energy may well become a major constraint to agricultural advance before the end of this century. Energy is required for a multitude of purposes including soil preparation and tillage, planting, harvest, weed control, pest and disease control, fertilizer, nutrients, drying, processing, transport, storage, and many others. And, high-yield technology may increase the amount and cost of energy required for at least some of these. Attention must be directed to economies in energy requirements consistent with high production levels. The incorporation of pest and disease resistance into the genetic makeup of crop varieties reduces the cost and energy requirements for their control.

Reductions in nutrient losses from volatilization, leaching, and soil fixation must receive careful attention. Various mechanisms for enhancing biological nitrogen fixation which will be examined include: 1) development of more efficient strains of rhizobia for legumes, especially when grown in less favorable environments; 2) development of legume varieties having the ability to nodulate promiscuously with the indigenous rhizobia strains present in tropical soils and fix nitrogen efficiently; 3) transfer of symbiotic nitrogen-fixing capacity to nonlegumes with appropriate and effective symbiont organisms; and 4) culture of Azolla and blue-green algae in such a way as to supply significant portions of the nitrogen requirements of rice while still maintaining high grain yields.

No combination of the above will reduce the requirement for increased use of fertilizers but the future will require us to reduce losses and improve efficiency of recovery and efficiency in utilization of plant nutrients to the maximum extent possible.

A recent paper by Sanchez and Nicholaides, prepared for the CGIAR, gives an excellent treatment of the present knowledge of plant nutrition in relation to soil constraints. The effective management of the world's precious and limited soil resources for sustained maintenance of quality and productive potential is one of the great challenges before us.

And along with the challenge of management of our soil resources (resources not easily renewed) for a sustained quality and productivity to serve the requirements of mankind for future generations, the challenge of learning how to manage our water resources (a renewable resource) effectively and efficiently is assuming front rank importance and attention. The amount of water and the variations in certainty and dependability on the timing of its availability are among the great risks faced by farmers. These risks profoundly affect their willingness and their ability to make investments in improved seeds, fertilizers, crop protection measures, and all other interventions affecting their productivity. Farmers are dependent in much

of the developing world exclusively on rainfall, which may come at irregular and undependable intervals. When it falls on unprotected soil surfaces much of it may not infiltrate and may be lost by runoff to streams, carrying with it much valuable soil and plant nutrients. Much can be done to increase retention of rainfall at or near the place it strikes the earth, but much more needs to be known about how to accomplish this under the wide variety of situations encountered in the LDCs.

The development of irrigation systems and their management is receiving increasing attention and represents a frontier on which a great deal of reliance is being placed for achieving the levels of production required by the LDCs. Massive investments are being made for this purpose. It is estimated that \$75 to \$100 billion will be spent in South Asia alone for this purpose in less than a generation. India is currently spending about \$3 billion per year for this purpose and expects to do so for the remainder of this century, doubling its current area under irrigation command. Sri Lanka likewise is in the process of doubling its irrigated acreage. Pakistan and Egypt are dependent on irrigation for most of their agricultural production. Three-quarters of the world's irrigated acreage is in 22 developing countries. This is the single largest object of infrastructural investment being made to help ensure attainment of food requirements for the next generation.

In spite of all of this, efficiency, effectiveness, and equity in use of water and the resulting increases in agricultural production which have been attained in developing countries have been disappointing and far below potentials and expectations. Here, one can see reasons in all 3 of the areas addressed in this session—1) human, institutional and political, 2) economic, and 3) scientific and technological. Agricultural and engineering sciences frequently have been inadequately coordinated in the past. It is a subject which deserves high priority and current efforts are underway to develop an international institutional approach to the subject. Solutions must be tailored to numerous specific locations once the overall approach and the basic technologies are understood and concerted and systematic efforts have been made to address local problems within the overall principle guidelines.

In conclusion, I would like to reiterate the fact that the last generation has witnessed very substantial advances in development of an impressive institutional base for generating and applying science and technology to agricultural development of the LDCs, that a large number of the LDCs have substantially augmented and improved their indigenous pool of scientific talent, competence, and confidence, and that we now know better than we once did how to mesh the talents and resources of DCs and LDCs. We should be able to find the ways to meet these great challenges in the years just ahead.

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