Agricultural Research and Third World Food Production

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In the early 1960's considerable alarm was expressed about the food supply of the developing countries. Famine was occurring with increasing frequency and large-scale starvation seemed imminent. A catastrophe was forestalled by the Green Revolution of the mid-1960's with its rapid dissemination of high-yielding varieties of wheat and rice. This achievement is part of the impressive record of the International Agricultural Research Centers (IARC's), now banded together under the Consultative Group on International Agricultural Research (CGIAR). Ongoing efforts by these organizations to increase yields and protein levels of several staples grown in the Third World have raised hopes that barriers to productivity in crops and livestock will continue to be overcome.

Summary. By the close of this century the world may have to feed as many as 2 billion additional people. Most of them will be born in developing countries, especially in marginal lands ill-suited for food production. This article focuses on efforts by the International Agricultural Research Centers to increase food production in the Third World and addresses the social and ecological issues raised by the introduction of high-yielding varieties into fertile Third World lands and describe how varieties are being tailored for introduction into marginal areas.

History of CGIAR

Although CGIAR celebrated its tenth birthday in 1981, its origin can be traced back some 40 years. The oldest IARC was set up in 1943 near Mexico City by the Rockefeller Foundation and the Mexican government as a national program to work on wheat and maize. Later known as CIMMYT (Centro Internacional de Mejoramiento de Maíz y Trigo), the center gained worldwide recognition in the 1960's for its development of short-statured wheats. These wheats were quickly adopted in Mexico and the Indian subcontinent. The second oldest IARC, the International Rice Research Institute (IRRI), was conceived in 1959 and began operations 3 years later. Headquartered in Los Baños in the Philippines, IRRI soon produced a series of dwarf rice that responded well to fertilizers and gave abundant harvests.

The rapid and far-reaching payoffs of CIMMYT and IRRI soon prompted the Rockefeller and Ford foundations to provide funding for two more IARC's. CIAT (Centro Internacional de Agricultura Tropical) was established in 1967 near Cali, Colombia, to increase the productivity of cassava (*Manihot esculenta*), rice, kidney beans (*Phaseolus vulgaris*), and cattle pastures in the humid tropics of Latin America. At the same time, the New York–based foundations set up the International Institute of Tropical Agriculture (IITA) at Ibadan, Nigeria, to encourage research into stable farming systems for the humid tropics and raising yields of tropical staples such as the sweet potato (*Ipomoea batatas*), yam (*Dioscorea* spp.), cocoyam (species of *Colocasia* and *Xanthosoma*), and cowpea (*Vigna unguiculata*). In addition, IITA was assigned regional responsibility for developing cultivars of cassava, rice, maize (*Zea mays*), soybeans (*Glycine max*), pigeon peas (*Cajanus cajan*), lima beans (*Phaseolus lunatus*), and winged beans (*Psophocarpus tetragonolobus*) adapted to the diverse environments of Africa (*1*).

The Rockefeller and Ford foundations wanted to install more centers, but they realized that such an undertaking was beyond their financial means. A transnational framework for sponsoring IARC's was called for. To meet this ambitious task, CGIAR was formed in 1971 by the Food and Agriculture Organization (FAO) of the United Nations, the United Nations Development Program, and the International Bank for Reconstruction and Development (World Bank). Headquartered at the World Bank (Washington, D.C.), CGIAR acts on behalf of a consortium of 34 donors ranging from multinational organizations and national governments to private foundations. It is advised by a Technical Advisory Committee (TAC) composed of 13 scientists from industrial nations and the developing world. TAC's secretariat is located in the headquarters of FAO in Rome. Unlike many international bureaucracies, CGIAR is small and streamlined. Only six professionals staff the CGIAR headquarters. TAC has a full-time staff of four; the advisory board of scientists meets twice a year.

After the formation of CGIAR, nine new IARC's were inaugurated in rapid succession. The Centro Internacional de la Papa (CIP) was created in 1971 to work on the potato in the center of its origin, the Peruvian Andes. The West African Rice Development Association (WARDA) was conceived in 1971 in Liberia to promote self-sufficiency in rice in 15 West African countries. In 1972 the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) began research on groundnuts (*Arachis hypogaea*), chick-peas (*Cicer arietinum*), pigeon peas, pearl millet (*Pennisetum typhoides*), and sorghum (*Sorghum bicolor*) near Hyderabad, India.

In 1974 CGIAR unveiled three more institutes. One of these, the International Livestock Center for Africa (ILCA), based at Addis Ababa in Ethiopia, explores ways of improving the pastoral and mixed farming economies of Africa, while a sister institute operating out of Nairobi, the International Laboratory for Research on Animal Diseases (ILRAD), is tackling theileriosis and trypanosomiasis, livestock illnesses that severely limit the productivity of beef and dairy herds in at least 50 developing countries. The third center established in 1974, the International Board for Plant Genetic Resources (IBPGR), is based with FAO in Rome and promotes the conservation of crop diversity by sponsoring an international network of germ plasm collections.

In 1976 the International Center for Agricultural Research in Dry Areas (ICARDA) was added to the CGIAR system to examine the potential for boosting food production in dry subtrop-

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Table 1. Estimated area planted in high-yielding varieties of wheat and rice in 1977 (2).

Region	Wheat		Rice	
	Area (million hectares)	Percentage of total wheat area	Area (million hectares)	Percentage of total rice area
South and East Asia	19.7	72.4	24.2	30.4
West Asia and North Africa	4.4	17.0	0.04	3.6
Africa south of the Sahara	0.2	22.5	0.1	2.7
Latin America	5.1	41.0	0.9	13.0
Total	29.4		25.2	

ical and subtemperate areas, particularly in North Africa and West Asia. Based in Aleppo, Syria, ICARDA scientists are developing new strains of bread and durum wheats, barley, triticale (wheat crossed with rye), lentils (*Lens esculenta*), chick-peas, broad beans (*Vicia faba*), and forage plants. In its work with cereals, ICARDA collaborates with CIMMYT, while ICRISAT assists in the chick-pea program. ICARDA and ICRISAT thus cover the most important crops of the drought-prone portions of the developing world.

Two more centers joined CGIAR in the 1970's, bringing the total to 13. The International Food Policy Research Institute (IFPRI) was founded in Washington in 1975 to analyze strategies for meeting the world's food needs. By monitoring food production in developing countries as well as world trade in cereals and pulses, IFPRI provides information for policy-makers drawing up priorities for agricultural research and development. To help strengthen national agricultural programs so that research results benefit the inhabitants of developing countries, CGIAR created the International Service for National Agricultural Research (ISNAR) in The Hague in 1979. ISNAR helps developing countries start or upgrade their agricultural research and extension services.

Many initiatives have been undertaken by CGIAR to help overcome problems of food production in the Third World. Some 600 scientists from many countries are engaged in this far-flung effort. At the IARC's these scientists take advantage of good laboratory and field equipment, well-stocked libraries, and funds to attend international meetings and to conduct research with colleagues in other institutions. The IARC's avoid competing with national programs in the Third World; their mission is to help strengthen such efforts with training courses, collaborative research, and improved germ plasm collections. Whenever possible, the IARC's leave the final selection and naming of crop varieties to national programs.

Although the IARC's are linked to CGIAR, they are autonomous and set their own research policies in accordance with recommendations made by their staff, governing boards, and TAC. Decisions are reached by consensus rather than issued by a central authority. The lean, flexible design of CGIAR could serve as a model for efforts to develop other resources in the Third World, such as renewable energy, or to improve health.

Spread of High-Yielding Varieties

The two oldest centers in the CGIAR system, CIMMYT and IRRI, which are responsible for the development of high-yielding varieties of wheat and rice, have had the greatest impact on food production in developing countries thus far. This impact has resulted from a strategy to first improve yields by planting high-yielding varieties on the better lands, such as relatively fertile alluvial or volcanic soils, with the use of irrigation, fertilizers, and, in some cases, pesticides and herbicides (2). A major distinguishing feature of the high-yielding varieties is their short stature: more photosynthetic effort is channeled into seed production and less into stems.

Wheats developed by CIMMYT were first released in Mexico in the early 1960's. They now account for virtually all the wheat planted in that country. Production is concentrated in Sonora, where yields average 4 tons per hectare, a marked improvement over the average of 0.7 ton per hectare achieved with traditional varieties. High-yielding wheats were released in 1966 on the Indian subcontinent and currently occupy about three-fourths of the area planted in this cereal. Most of the wheats are grown in Punjab; yields average 2 tons/ha, up from 0.6 ton/ha prior to 1966. In one decade, the area planted in high-yielding wheats in the developing world had climbed to 30 million hectares (Table 1). These 30 million hectares represented half the land devoted to bread wheat cultivation in the developing world (3).

The speed with which the improved varieties of wheat have been dispersed is reflected by the growth in wheat production. In India, for example, wheat supplies tripled between 1961 and 1980, largely as a result of the adoption of high-yielding varieties rather than an expansion of the area planted in the cereal (4). Wheat production soared from 11.4 million tons in 1967 to 26.4 million tons in 1972 and reached 34.7 million tons in 1979. When the monsoon failed in 1966, India had to import 10 million tons of grain to feed its 490 million people. Today substantial stores of wheat and rice have accumulated despite a population increase of 190 million and a severe drought in 1979 (5).

The area planted in high-yielding dwarf rice has also increased greatly, although most of the expansion has taken place in Asia. IRRI plant materials account for one-fourth of the rice planted in the Third World today. This figure masks the spectacular gains registered in certain countries, however. In the Philippines almost 70 percent of the rice is high-yielding, up from 53 percent in 1973. In Colombia 90 percent of the irrigated rice is CIAT/IRRI material released through the national program. Before the distribution of these varieties, only half of Colombia's rice output came from irrigated land; now 90 percent of the national rice harvest is reaped in paddy fields (6). Whereas traditional cultivars produce around 3 tons/ha, high-yielding varieties normally yield 5 tons/ha (7). More important, these varieties have a shorter maturation period than the older varieties, so farmers can harvest up to three crops a year.

The dissemination of high-yielding maize in the Third World has been much slower than that of wheat or rice. Short-statured maizes have been issued by CIMMYT, but herbicides, fertilizers, and sometimes pesticides are necessary to produce satisfactory yields. The better lands are usually planted in more profitable cash crops, so maize is often relegated to marginal areas. In spite of the formidable socioeconomic and ecological constraints to improved maize production in developing nations, high-yielding maize varieties are making inroads in certain regions. In Mexico, for example, an estimated 1.8 million hectares are planted in high-yielding maize. This is almost one-fifth of the total area planted in maize. In Kenya the area devoted to high-yielding maize leaped from 400 ha in 1963 to 800,000 ha in 1973 (8).

The spread of high-yielding varieties

of rice, wheat, and maize has reduced and sometimes eliminated the need for grain imports in some Third World countries, thereby conserving capital for development projects. India has been self-sufficient in grains in most years since the introduction of high-yielding wheat and rice. Bangladesh has recently come within a few hundred thousand tons of feeding itself (*9*). The Philippines, which imported rice for decades, has only occasionally had to buy rice since 1970. In 1980 the Philippines exported 250,000 tons of rice. Mexico exports wheat in some years, a major turnaround considering its rapidly growing population and the fact that it had been importing substantial quantities of wheat for decades. Indonesia's food picture is much brighter now that more than 3 million hectares are planted in high-yielding rice (*10*).

Ecological and Social Impact

The substitution of traditional cultivars by high-yielding varieties has raised the specter of massive crop failure because of increased susceptibility to diseases and pests (*11*). But adoption of these varieties in developing countries has not led to any major disruption of food supplies by insect predators and pathogens. The earlier rice varieties, particularly IR-8, were damaged by pests such as leafhoppers, but the vastly increased yield usually compensated for the insect attacks. To counteract the susceptibility of rice varieties released in 1966, IRRI developed new lines with much greater resistance to pests; these were introduced as IR-26 in 1973 and IR-28 in 1975. Since then, IRRI has continued to upgrade the yield potential and stability of its rice lines.

Genetic resistance of crops to disease and insects is a high priority for plant breeders. In the constant struggle to combat pest and disease outbreaks, scientists at the IARC's fall back on a burgeoning collection of material deposited in germ plasm banks in their institutes. Maize breeders at CIMMYT, for example, choose from 13,000 accessions collected in over 50 countries when attempting to introduce desirable traits into a crop line (Table 2). Universities, national programs, and private seed companies all have access to the germ plasm banks.

High-yielding varieties are best suited to restricted environments, so they have not eliminated traditional varieties from entire regions. Three-fourths of the rice area and half of the wheat area in developing nations is still sown with locally selected cultivars. The thousands of crop varieties used by farmers in the Third World are an important source of material for the IARC germ plasm banks. The new varieties have clearly not caused a disastrous extinction of native crop varieties; the IARC's are keenly aware of the importance of conserving the genetic diversity of food plants and are striving to introduce varieties that appear uniform but are of mixed parentage.

Table 2. Crop accessions held in CGIAR germ plasm banks in 1981.

Crop	Accessions	Location
Rice	60,000	IRRI
Kidney beans	27,000	CIAT
Sorghum	20,000	ICRISAT
Pearl millet	17,000	ICRISAT
Cowpeas	15,000	IITA
Maize	13,000	CIMMYT
Chick-peas	12,000	ICRISAT
Pigeon peas	8,700	ICRISAT
Groundnuts	8,000	ICRISAT
Potatoes	8,000	CIP

Another ecological issue related to the adoption of high-yielding varieties is that the associated use of pesticides, fungicides, and herbicides may trigger environmental damage. Although there is no documented evidence of ecological disruption, the large-scale application of pesticides to rice paddies in India appears correlated with a recent surge in malaria (*12*). At least two vectors of the disease, *Anopheles culifacies* and *A. fluviatilis*, have acquired resistance to organochlorines used to contain the mosquito populations, and it seems that the use of such chemicals in agriculture may be partly to blame. Several of the IARC's are investigating biological control of insect pests. IRRI, for example, is studying the interaction of predators on rice pests and is exploring the use of pheromones to disrupt pest breeding.

Fig. 1. Tuxpanito, a semidwarf maize developed by CIMMYT, in an untilled field treated with herbicide.

Herbicides can raise crop yields with minimal environmental degradation. At CIMMYT, for example, a no-tillage system of dwarf maize cultivation is being tested which involves the spraying of quick-acting, short-lived herbicides. Traditional maize cultivars grow tall and thus avoid being shaded out by weeds; however, they are easily felled by wind or rain and sometimes respond poorly to fertilization. CIMMYT's dwarf maizes produce abundant harvests when effectively managed (Fig. 1). The judicious use of herbicides is preferable to ploughing, which can accelerate soil erosion. Also, if more food can be produced from a given area, then land can be freed for conservation purposes.

Social critics of the spread of high-yielding varieties in developing countries have argued that the new seeds and technology have only benefited the larger, more prosperous farmers, exacerbating an already skewed income distribution (*13*). Debate over the social impact has been confused by the difficulty of defining a large farm. In a crowded region with fertile soils a 50-ha holding may be considered large; in a sparsely settled area with poor soils 500 ha may be too small to make a living. The evidence marshaled by those trying to prove that high-yielding varieties favor the larger farms is inconclusive (*14*). The larger landholders tend to adopt the varieties first because they are more inclined to take risks. After a lag of a few years, most of the small farmers also benefit if they have access to credit, fertilizers, and a reliable seed supply (*15*).

In the Yaqui Valley of Sonora the average private wheat farm covers 69 ha (*16*), a reasonable size considering that these irrigated holdings were once barren desert. In the Indian Punjab 60 percent of the holdings planted with high-yielding wheat are under 4 ha, while in the Punjab and Sind provinces of Pakistan farms under 7 ha have a greater proportion of their area planted in high-yielding wheat than larger holdings (*17*). In some high-rainfall areas of Kenya up to 90 percent of the farms under 25 ha have adopted high-yielding maize.

Some have questioned the efficiency with which the new technology is utilized by small farmers. In some areas small farmers do not always apply optimal quantities of fertilizers, but yields

Fig. 2. Wheeled tool carrier near Hyderabad, India.

with the improved varieties are still substantially higher than yields with traditional varieties (*18*). In certain parts of Asia small farmers have reaped more bountiful rice harvests per unit of land than larger landholders because of the intensive use of family labor in paddies.

A more serious problem is the economic discrepancies that arise between regions that have the new technology and adjacent regions that do not. For example, in the Indian Punjab farm income and agricultural labor wages are much higher than in the rest of the country. The spread of high-yielding varieties should not be arrested in the interest of maintaining the status quo; rather, national programs and agricultural extension services need to be buttressed further so that even more farmers benefit (*19*). Part of the wealth generated by the farming of zones undergoing rapid development can be used to help the less economically dynamic regions. Stagnation and a dampening of initiative do not serve the interests of the rural or urban poor. Few Third World countries can afford to bypass the opportunity to maximize production in their better lands.

Some critics contend that high-yielding varieties reduce labor demand because of mechanization. But none of the varieties requires machines to produce high yields. Where tractors, mechanical threshers, and harvesters are in use, labor demand usually increases (*20*). Animals rather than people are replaced, freeing land for the cultivation of crops for human consumption. By permitting more intensive cropping, machinery can increase the need for labor by 20 to 50 percent.

The increased food supplies generated by the spread of high-yielding varieties have created additional employment opportunities in such service industries as the marketing of crop products and the manufacture, sale, and maintenance of vehicles, fertilizers, herbicides, and pesticides. Furthermore, food prices have been moderated by the increased volume of cereal production—a bonus for the rural and urban poor. (It is not unusual for low-income people to spend three-fourths of their income on food.) In Colombia, for example, the real price of rice dropped after the introduction of high-yielding varieties.

Excessive concern over the distribution of income in rural areas could lead to agricultural policies that extinguish initiative and impede food production. This would be to the detriment of poor people, especially those residing in towns and cities. In many developing countries close to half the population now lives in urban areas. The population of several Third World cities has recently swollen beyond 10 million. Examples are Mexico City with 14 million and São Paulo and Calcutta with 11 million each. By the end of this century 12 of the world's 15 largest cities will be in developing countries (*21*).

New Research Horizons

The major advances in raising food production have taken place in the better lands. While the productivity of such lands may be increased still further, as by developing crop breeds with even shorter maturation periods, the next advances must be made in the marginal lands. The dimensions of this challenge are staggering: close to 1 billion people eke out a living in environments that produce meager yields because of ecological limitations. Most of the 2 billion children that are expected to be born by the year 2000 will grow up on marginal lands.

Marginal areas are far more extensive than fertile zones, so even a modest increase in crop yields in marginal areas would greatly alleviate food shortages in developing countries. But drawing up a research strategy for the agricultural transformation of marginal lands is more difficult than breeding crops for fertile soils. Nevertheless, most of the IARC's share a commitment to developing crops characterized by drought resistance or the ability to thrive in soils that are excessively saline, alkaline, or acidic, that contain toxic amounts of aluminum, or that are deficient in phosphorus and nitrogen.

IRRI is developing rice lines that are relatively tolerant of saline soils (which cover between 400 and 950 million hectares of the earth). IR-42 grows well in brackish areas, and could prove useful in formerly productive irrigated land rendered virtually useless by the surface buildup of salts. Although water management can be used to correct this defect, limited supplies of water often do not permit an adequate flushing of fields. IR-42 could help revitalize such areas, which account for 70 million hectares, or one-fourth of irrigated lands, and which are expanding (*22*). At CIMMYT, preliminary results suggest that triticale tolerates saline soils better than other cereal crops. Breeders at CIMMYT and the Universities of Manitoba and Guelph have developed varieties of triticale that compare favorably in yield to the best wheats but are greatly superior in nutrient-poor, drought-prone soils. Also, CIMMYT breeders are wide-crossing wheat with several species of *Agropyron* (wild grasses) in an attempt to transfer genes that code for salt tolerance.

Strongly acidic soils are common in the humid tropics due to prolonged leaching. Toxic levels of aluminum are often found in acidic soils—a further complication for the farmer. Several IARC's are attempting to tailor crops to such adverse conditions. Triticale, for example, is being tested in the Brazilian cerrado, a savanna region of some 200 million hectares with little agricultural development due to highly leached soils containing large amounts of aluminum compounds. This man-made cereal makes excellent bread as well as nutritious livestock feed and could help transform the cerrado into an important food-producing region. In Asia, IRRI is developing rice lines that thrive in acidic soils under rain-fed conditions. Line IR-42 has flourished in farmer's plots with low levels of nitrogen fertilizer (*23*).

Another priority at the IARC's is finding plants that thrive with relatively little fertilization. Most of the nitrogen fertilizer produced commercially is based on natural gas or, to a lesser extent, crude oil. Hence fertilizer prices have been climbing along with the prices of these fossil fuels. Even fertilizers that are not based on petroleum, such as phosphorus and potash, are becoming more expensive because they require large amounts of energy to mine, upgrade, and transport. Some of the IARC's are focusing on the potential of biological nitrogen fixation to help boost crop yields. Both IRRI and WARDA, for example, are searching for partnerships between water ferns and blue-green algae which are especially prolific in capturing atmospheric nitrogen for paddy rice. Researchers at ICRISAT are screening germ plasm collections to develop pigeon pea, chick-pea, and groundnut lines that fix unusually large amounts of nitrogen through the action of symbiotic *Rhizobium* bacteria in root nodules. IRRI and ICRISAT are studying associative bacteria—particularly species of *Azospirillum* and *Azotobacter*—that fix nitrogen close to the roots of rice, sorghum, and pearl millet. It is hoped that lines of these cereals will eventually achieve much higher yields than traditional varieties without heavy nitrogen fertilization. ICARDA, ICRISAT, CIAT, IITA, and IRRI are examining the potential for inoculating crops with symbiotic and associative nitrogen-fixing bacteria to accelerate the development of populations of the beneficial microorganisms in fields.

Several centers are exploring the contribution of vesicular-arbuscular (VA) mycorrhizas to reducing the need for commercial fertilizer. Some 80 species of these fungi live in and around the surface of roots and enhance the nutrient uptake of plants. They also favor nitrogen-fixing bacteria and help plants to withstand drought. In field tests, VA mycorrhiza inoculation of onions, maize, and cowpeas in unsterilized soils has led to yield increases of 20 to 100 percent (*24*). CIAT recently confirmed the importance of VA mycorrhizas to the nutrition of cassava, especially the assimilation of soil phosphorus. Now the center is investigating the potential of this root crop to benefit from relatively cheap rock phosphate fertilizer. Although several obstacles remain before a VA mycorrhiza inoculum can be produced on a large scale, ICRISAT and ICARDA are studying the ecology of the fungi and methods of mass producing the inoculum.

Drought tolerance in crops is another high priority for breeders at the IARC's. At CIMMYT, wheat is being crossed with a tall bunch grass from Asia, *Elymus giganteus*, in order to incorporate genes that confer greater tolerance to water stress. At IRRI, scientists have developed rice lines, such as IR-43 and IR-52, that yield up to 4.6 tons/ha in rainfed fields during the wet season. Even if rainfall is well below expected levels, these new lines still produce a harvestable yield. Good yields of triticale have already been produced in the semiarid and highland areas of the tropics, and breeders are likely to benefit from work with VA mycorrhizas to increase the ability of plants to withstand deficits in soil moisture.

An excess, rather than a deficit, of moisture can be a problem in some marginal lands. In parts of Bangladesh and Thailand, for example, rice paddies are sometimes swamped in 1.5 m of water. This drowns traditional cultivars and early generation IRRI material. To help farmers cope with wildly fluctuating water levels in their paddies, IRRI has developed rice lines that can withstand submergence for short periods and grow taller. To accomplish this, scientists turned to wild rice to acquire traits that promote the rapid elongation of stems. Although the yield ceiling is lowered because the rice plants divert more photosynthetic effort to building stems rather than grains, the farmer is saved from catastrophic crop failure. Yield stability, rather than spectacular harvests, is a principal goal in the research strategy for marginal land crops.

Even in the semiarid tropics, too much water can turn soils into a quagmire and render them useless for agriculture. The deep black vertisols covering enormous areas of India and Africa are examples. In India these dark, heavy clays are found over 73 million hectares, some 26 million of which are left fallow during the torrential monsoon because they are too sticky to work (*25*). In such areas, farmers normally plant their crops when the rains subside so that the plants can tap the moisture stored in the soil.

In an effort to introduce double cropping to these deep vertisols, ICRISAT is testing a wheeled tool carrier, pulled by bullocks or water buffalo, which can be used to plow land, plant seeds, and apply fertilizer (Fig. 2). During the monsoon season, maize and pigeon pea or mung bean (*Phaseolus aureus*) are sown on a raised bed, followed by a crop of sorghum or pearl millet during the dry period. In this manner, 1.5 to 2 tons of grain per hectare can be produced annually, instead of the traditional 0.5 to 1 ton/ha. Although the yield gain does not qualify as a quantum leap, it is significant: India could produce an additional 25 million tons of grain per year from its deep black vertisols. The wheeled tool carrier costs about $1000 with accompanying implements; cheaper models are being developed. The economics of its use in India remain to be investigated, but the tool carrier could be owned collectively or rented if individual farmers find they are unable to purchase one. It seems likely that the high initial cost could be recouped in a few years due to the doubling of yields. This intermediate technology is already being successfully used by groundnut farmers in West Africa and will surely be adopted in other regions of the Third World.

Conclusion

After a decade of spectacular growth, the CGIAR system enters the 1980's in a consolidation phase. The annual budget of the network has grown from $20 million in 1972 to a little over $140 million in 1981; now, however, the supply of funds for the IARC's is tapering off or, in some cases, declining due to inflation. Faced with new challenges to raise food production, CGIAR is hard pressed to launch new programs or even to support ongoing research. The sum of $140 million may appear impressive, but it pales when compared to funds allocated to other sectors, such as defense, industry, and energy. Only 3 percent of the global research budget is allotted to agricultural research, and most of this is spent in the developed countries (*26*). Funds channeled into agricultural research for food production by international agencies and national governments clearly generate an enormous payoff. The value of the increased supplies of rice generated by high-yielding varieties based on IRRI germ plasm, for example, exceeds $2.5 billion (*7*).

Agricultural research alone is not a panacea for the food problems of the developing world. Social, economic, and ecological issues must also be tackled, such as control of deforestation, population growth, crop losses after harvest, and the agricultural extension services. But the new crop varieties and agricultural practices developed by strengthened national programs working in tandem with the IARC's will buy time.

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Amplification and Adaptation in Regulatory and Sensory Systems

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Summary. Biological systems respond to sensory inputs and changing metabolic conditions both by amplifying signals and by adapting to them. The mechanisms by which these apparently opposing goals are achieved by the chemistry of the cell are described and evaluated.

Living organisms have devices for sensing the external environment and internal metabolic changes, for adapting to them, and for regulating their internal machinery as a result of these signals. The basic mechanisms of control in most cases are mediated by induced conformational changes of proteins which either "turn on" or "turn off" the processing system. In this way, signals can feed back to inhibit synthesis of a product (*1*) that is in excess or can feed forward to activate a pathway that must be mobilized for a particular function. These changes in activity can be effected either by molecules that induce conformational changes by binding noncovalently (allosteric effectors) (*2*) or by covalent modification of residues on the protein surface (*3*). Such molecular mechanisms seem to operate within the cell in metabolic regulation, between cells in hormonal and neural signaling, and between cells and the environment in sensory receptors. Thus, similar molecular mechanisms operate for both sensing and regulation in biological systems.

Biological sensing and regulatory systems are particularly effective because of two additional properties, namely, the ability to generate amplified responses to low levels of stimuli and the ability to adapt to constant backgrounds of stimuli. Certain signals, such as a photon of light, the odor of a perfume, a faint sound in the distance, do not per se have the energy to generate a behavioral response and must be amplified within the organism by its metabolic and neural machinery. A highly sensitive amplification system would cause problems, however, because living organisms are constantly bombarded by background stimuli such as light, odor, and sound, which could saturate the sensory system. The organism prevents this by adaptation that tends to desensitize the sensing apparatus toward the background stimuli. In most systems the cell is the primary unit that can both amplify and desensitize signals (*4*–*6*); thus we must look largely to the biochemistry within the cell to explain fundamentals of the phenomena.

Since amplification involves enhancement of a signal and adaptation involves its diminution, the occurrence of both processes within the cell raises questions in regard to their mechanisms and compatibility. Can both occur in the same cell or are they mutually exclusive? Is there is fundamental difference between regulatory and sensory systems? Are there limits to the amplification of a signal and can adaptive systems show amplification? What molecular mechanisms can explain such processes and what are their potentialities? In this article we attempt to address these questions.

Nomenclature of Amplification

Amplification and adaptation have fascinated biologists for a long time and various aspects of these problems have been described and discussed (*4*–*10*). Inevitably, each investigator has defined terms in his own system and considerable redundancy and ambiguity has de-

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