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The Green Revolution, Peace, and Humanity

Civilization as it is known today could not have evolved, nor can it survive, without an adequate food supply. Yet food is something that is taken for granted by most world leaders despite the fact that more than half of the population of the world is hungry. Man seems to insist on ignoring the lessons available from history.

Man's survival, from the time of Adam and Eve until the invention of agriculture, must have been precarious because of his inability to ensure his food supply. During the long, obscure, dimly defined prehistoric period when man lived as a wandering hunter and food gatherer, frequent food shortages must have prevented the development of village civilizations. Under these conditions the growth of human population was also automatically limited by the limitations of food supplies.

In the misty, hazy past, as the Mesolithic Age gave way to the Neolithic, there suddenly appeared in widely separated geographic areas the most highly successful group of cereals, legumes, and root crops, as well as all of the most important animals that to this day remain man's principal source of food. Apparently, nine thousand years ago, in the foothills of the Zagros Mountains[1], man had already become both agriculturist and animal husbandry-man, which, in turn, soon led to the specialization of labor and the development of village life. Similar discoveries and developments elsewhere soon laid the groundwork from which all modern agriculture and animal industry and, indeed, all of the world's subsequent civilizations have evolved. Despite the tremendous value of their contributions, we know none of these benefactors of mankind by name. In fact, it has only been within the past century, and especially within the last fifteen years – since the development of the effective radio-carbon dating system – that we have begun even vaguely to understand the timing of these epochal events which have shaped the world's destiny.

The invention of agriculture, however, did not permanently emancipate man from the fear of food shortages, hunger, and famine. Even in prehistoric times population growth often must have threatened or exceeded man's ability to produce enough food. Then, when droughts or outbreaks of diseases and insect pests ravaged crops, famine resulted.

That such catastrophes occurred periodically in ancient times is amply clear from numerous biblical references. Thus, the Lord said: "I have smitten you with blasting and mildew."[2] "The seed is rotten under their clods, the garners are laid desolate, the barns are broken down; for the corn is withered… The beasts of the field cry also unto thee: for the rivers of waters are dried up, and the fire hath devoured the pastures of the wilderness."[3]

Plant diseases, drought, desolation, despair were recurrent catastrophes during the ages – and the ancient remedies: supplications to supernatural spirits or gods. And yet, the concept of the "ever-normal granary" appeared in elementary form, as is clear from Pharaoh's dreams and Joseph's interpretation of imminent famine and his preparation for it, as indicated by this quotation from Genesis: "…And the seven years of dearth began to come, according as Joseph had said: and the dearth was in all lands; but in all the land of Egypt there was bread…"[4] For his time, Joseph was wise, with the help of his God.

But today we should be far wiser; with the help of our Gods and our science, we must not only increase our food supplies but also insure them against biological and physical catastrophes by international efforts to provide international granaries of reserve food of famine in the future instead of merely trying with pious regret to salvage the human wreckage of the famine, as he has so often done in the past. We will be guilty of criminal negligence, without extenuation, if we permit future famines. Humanity cannot tolerate that guilt.

Alfred Nobel was also very conscious of the importance of food, for he once wrote: "I would rather take care of the stomachs of the living than the glory of the departed in the form of monuments."

The destiny of world civilization depends upon providing a decent standard of living for all mankind. The guiding principles of the recipient of the 1969 Nobel Peace Prize, the International Labor Organization, are expressed in its charter words, "Universal and lasting peace can be established only if it is based upon social justice. If you desire peace, cultivate justice." This is magnificent; no one can disagree with this lofty principle.

Almost certainly, however, the first essential component of social justice is adequate food for all mankind. Food is the moral right of all who are born into this world. Yet today fifty percent of the world's population goes hungry. Without food, man can live at most but a few weeks; without it, all other components of social justice are meaningless. Therefore I feel that the aforementioned guiding principle must be modified to read: If you desire peace, cultivate justice, but at the same time cultivate the fields to produce more bread; otherwise there will be no peace.

The recognition that hunger and social strife are linked is not new, for it is evidenced by the Old Testament passage, "...and it shall come to pass, that when they shall be hungry, they shall fret themselves, and curse their King and their God..."[5]

Perhaps no one in recent times has more pungently expressed the interrelationship of food and peace than Nobel Laureate Lord John Boyd Orr[6], the great crusader against hunger and the first director-general of the Food and Agriculture Organization, with his famous words, "You can't build peace on empty stomachs." These simple words of wisdom spoken twenty-one years ago are as valid today as when they were spoken. They will become even more meaningful in the future as world population skyrockets and as crowding, social pressures, and stresses increase. To ignore Lord Orr's admonition would result in worldwide disorders and social chaos, for it is a fundamental biological

It is a sad fact that on this earth at this late date there are still two worlds, "the privileged world" and "the forgotten world". The privileged world consists of the affluent, developed nations, comprising twenty-five to thirty percent of the world population, in which most of the people live in a luxury never before experienced by man outside the Garden of Eden. The forgotten world is made up primarily of the developing nations, where most of the people, comprising more than fifty percent of the total world population, live in poverty, with hunger as a constant companion and fear of famine a continual menace.

When the Nobel Peace Prize Committee designated me the recipient of the 1970 award for my contribution to the "green revolution", they were in effect, I believe, selecting an individual to symbolize the vital role of agriculture and food production in a world that is hungry, both for bread and for peace. I am but one member of a vast team made up of many organizations, officials, thousands of scientists, and millions of farmers – mostly small and humble – who for many years have been fighting a quiet, oftentimes losing war on the food production front.

During the past three years spectacular progress has been made in increasing wheat, rice, and maize production in several of the most populous developing countries of southern Asia, where widespread famine appeared inevitable only five years ago. Most of the increase in production has resulted from increased yields of grain per hectare, a particularly important development because there is little possibility of expanding the cultivated area in the densely populated areas of Asia.

The term "The Green Revolution" has been used by the popular press to describe the spectacular increase in cereal-grain production during the past three years. Perhaps the term "green revolution", as commonly used, is premature, too optimistic, or too broad in scope. Too often it seems to convey the impression of a general revolution in yields per hectare and in total production of all crops throughout vast areas comprising many countries. Sometimes it also implies that all farmers are uniformly benefited by the breakthrough in production.

These implications both oversimplify and distort the facts. The only crops which have been appreciably affected up to the present time are wheat, rice, and maize. Yields of other important cereals, such as sorghums, millets, and barley, have been only slightly affected; nor has there been any appreciable increase in yield or production of the pulse in irrigated areas. Nor have all cereal farmers in the irrigated areas adopted and benefited from the use of the new seed and the new technology. Nevertheless, the number of farmers, small as well as large, who are adopting the new seeds and new technology is increasing very rapidly, and the increase in numbers during the past three years has been phenomenal. Cereal production in the rain-fed areas still remains relatively unaffected by the impact of the green revolution, but significant change and progress are now becoming evident in several countries.

Despite these qualifications, however, tremendous progress has been made in increasing cereal production in India, Pakistan, and the Philippines during the past three years. Other countries that are beginning to show significant increases in production include Afghanistan, Ceylon, Indonesia, Iran, Kenya, Malaya, Morocco, Thailand, Tunisia, and Turkey.

Before attempting to evaluate the significance of the green revolution one must establish the point of view of the appraiser. The green revolution has an entirely different meaning to most people in the affluent nations of the privileged world than to those in the developing nations of the forgotten world. In the affluent, industrialized nations giant surpluses of wheat, maize, and sorghum are commonplace; cattle, swine, and poultry are fed and fattened on cereal grains; meat, milk, eggs, fruits, and vegetables are within the economic reach of most of the population; well-balanced diets are more or less automatically achieved, and cereal products constitute only a modest portion of the "daily bread". Consequently, most of the people in such societies have difficulty in comprehending and appreciating the vital significance of providing high-yielding strains of wheat, rice, maize, sorghum, and millet for the people of the developing nations. Understandably then, the majority of the urbanites in the industrialized nations have forgotten the significance of the words they learned as youngsters, "Give us this day our daily bread". They know that food comes from the supermarket, but only a few see beyond to the necessary investments, the toil, struggle, and frustrations on the farms and ranches that provide their daily bread. Since the urbanites have lost their contact with the soil, they take food for granted and fail to appreciate the tremendous efficiency of their farmers and ranchers, who, although constituting only five percent of the labor force in a country such as the United States, produce more than enough food for their nation.

Even worse, urbanites often vociferously criticize their government for attempting to bring into balance the agricultural production of its farmers with the domestic and return to the farmer and rancher.

Contrasting sharply, in the developing countries represented by India, Pakistan, and most of the countries in Asia and Africa, seventy to eighty percent of the population is engaged in agriculture, mostly at the subsistence level. The land is tired, worn out, depleted of plant nutrients, and often eroded; crop yields have been low, near starvation level, and stagnant for centuries. Hunger prevails, and survival depends largely upon the annual success or failure of the cereal crops. In these nations both under-nutrition and malnutrition are widespread and are a constant threat to survival and to the attainment of the genetic potential for mental and physical development. The diet consists primarily of cereals, which provide from seventy to eighty percent of the calories and sixty-five to seventy percent of the protein intake. Animal proteins are so scarce and expensive as to be beyond the economic reach of the vast majority of the population. Although many of these nations were self-sufficient and some were exporters of cereals before the Second World War, they are now net importers, victims of population growth's outrunning agricultural production. There is little possibility in these countries of expanding the cultivated area to cope with the growing demand. The situation worsens as crop yields remain stagnant while human numbers continue to increase at frightening rates.

For the underprivileged billions in the forgotten world, hunger has been a constant companion, and starvation has all too often lurked in the nearby shadows. To millions of these unfortunates, who have long lived in despair, the green revolution seems like a miracle that has generated new hope for the future.

The significance and magnitude of the impact of the so-called green revolution are best illustrated by changes in cereal production in India, Pakistan, and the Philippines. In both India and Pakistan the rapid increase in yields per hectare of wheat has been the major thrust of the green revolution. Increases in rice yield also have played a major role in West Pakistan, but hitherto only a minor role in India. Increases in maize production have played a modest but significant role in expanded cereal production in both India and Pakistan; and increases in rice yields and production have been largely responsible for the change in cereal production up to now in the Philippines, Ceylon, and Indonesia.

The green revolution in India and Pakistan, which is still largely the result of a breakthrough in wheat production, is neither a stroke of luck nor an accident of nature. Its success is based on sound research, the importance of which is not self-evident at first glance. For, behind the scenes, halfway around the world in Mexico, were two its production in other countries. It was in Mexico that the high-yielding Mexican dwarf varieties were designed, bred, and developed. There, also, was developed the new production technology which permits these varieties, when properly cultivated, to express their high genetic grain-yield potential – in general, double or triple that of the best yielders among older, tall-strawed varieties.

There are no miracles in agricultural production. Nor is there such a thing as a miracle variety of wheat, rice, or maize which can serve as an elixir to cure all ills of a stagnant, traditional agriculture. Nevertheless, it is the Mexican dwarf wheat varieties, and their more recent Indian and Pakistani derivatives, that have been the principal catalyst in triggering off the green revolution. It is the unusual breadth of adaption combined with high genetic yield potential, short straw, a strong responsiveness and high efficiency in the use of heavy doses of fertilizers, and a broad spectrum of disease resistance that has made the Mexican dwarf varieties the powerful catalyst that they have become in launching the green revolution. They have caught the farmers' fancy, and during the 1969-1970 crop season, fifty-five percent of the six million hectares sown to wheat in Pakistan and thirty-five percent of the fourteen million hectares in India were sown to Mexican varieties or their derivatives. This rapid increase in wheat production was not based solely on the use of Mexican dwarf varieties; it involved the transfer from Mexico to Pakistan and India of a whole new production technology that enables these varieties to attain their high-yield potential. Perhaps seventy-five percent of the results of research done in Mexico in developing the package of recommended cultural practices, including fertilizer recommendations, were directly applicable in Pakistan and India. As concerns the remaining twenty-five percent, the excellent adaptive research done in India and Pakistan by Indian and Pakistani scientists while the imported seed was being multiplied, provided the necessary information for modifying the Mexican procedures to suit Pakistani and Indian conditions more precisely.

Equally as important as the transfer of the new seed and new technology from Mexico to India and Pakistan was the introduction from Mexico of a crop-production campaign strategy. This strategy harnessed the high grain-yield potential of the new seed and new technology to sound governmental economic policy which would assure the farmer a fair price for his grain, the availability of the necessary inputs – seed, fertilizers, insecticides, weed killers, and machinery – and the credit with which to buy them. Collectively these inputs and strategy became the base from which the green revolution evolved.

scale, in so short a period of time, and with such great success. The success of this transplantation is an event of both great scientific and social significance. Its success depended upon good organization of the production program combined with skillful execution by courageous and experienced scientific leaders.

Experimentation with dwarf Mexican varieties was initiated in both India and Pakistan in 1963 and continued in 1964. Results in both countries were highly promising. Consequently, in 1965, 350 and 250 tons of seed of the Mexican dwarf wheat varieties were imported into Pakistan and India, respectively, for wide-scale testing on farms. Again, the results were highly promising, and India reacted by importing eighteen thousand tons during 1966. A year later Pakistan imported forty-two thousand tons. With these importations, the revolution in wheat production got under way in both countries. It was the first time in history that such huge quantities of seed had been imported from distant lands and grown successfully in their new home. These importations saved from three to five years' time in reaping the benefits from the green revolution.

During the past three years, wheat production has risen spectacularly in both countries. Using as a base the pre-green revolution crop year 1964-1965, which produced an all-time record harvest in both countries, the production in Pakistan increased from the 1965 base figure of 4.6 million tons to 6.7, 7.2, and 8.4 millions of tons, respectively, in 1968, 1969, and 1970. West Pakistan became self-sufficient in wheat production for the first time in the 1968 harvest season, two years ahead of our predictions. Indian wheat production has risen from the 1964-1965 pre-green revolution record crop of 12.3 million tons to 16.5, 18.7, and 20.0 million tons during 1968, 1969, and 1970 harvests, respectively. India is approaching self-sufficiency and probably would have attained it by now if rice production had risen more rapidly, because, with a continuing shortage of rice, considerable wheat is being substituted for it.

The introduction into West Pakistan of the high-yielding dwarf rice variety IR 8, developed by the International Rice Research Institute (IRRI) in the Philippines, together with the new technology that makes it highly productive, has also resulted in phenomenal increases in yield and production during the past two years. Unfortunately, this variety has been less well adapted to climatic conditions in the monsoon areas of India and in East Pakistan, and therefore has had only a modest and occasional impact there. Newer varieties which are now being multiplied promise to correct this situation.

and the economy. It is estimated that Indian and Pakistani farmers who are cultivating the new Mexican dwarf-wheat varieties under the recommended management practices have increased their net income from thirty-seven dollars per hectare with the local varieties to 162 dollars with the dwarf Mexican varieties. During the past three harvests, a total of 1.4 billion dollars and 640 million dollars have been added to the gross national product (G. N. P.) of India and Pakistan, respectively, from the increase in wheat production above the record 1965 base. The injection of this large increase in purchasing power into the economies has had many effects.

Large numbers of tube-wells are being sunk by farmers in both India and Pakistan in order to expand the irrigated area and improve the control of irrigation water. It is estimated that a total of seventy thousand private tube-wells were sunk during the 1969-1970 crop season in India, which brings about 1.4 million hectares of additional land under controlled irrigation, thereby greatly expanding the food production potential. It is estimated that at present less than half of the irrigation potential of India has been developed.

If the high-yielding dwarf wheat and rice varieties are the catalysts that have ignited the green revolution, then chemical fertilizer is the fuel that has powered its forward thrust. The responsiveness of the high-yielding varieties has greatly increased fertilizer consumption. The new varieties not only respond to much heavier dosages of fertilizer than the old ones but are also much more efficient in its use. The old tall-strawed varieties would produce only ten kilos of additional grain for each kilo of nitrogen applied, while the new varieties can produce twenty to twenty-five kilos or more of additional grain per kilo of nitrogen applied. Consumption of nitrogen fertilizer in India has increased from fifty-eight thousand metric tons of nutrients in 1950-1951 to 538 thousand and 1.2 million metric tons in 1964-1965 and 1969-1970 crop cycles, respectively; and about sixty percent of this amount was produced domestically. Phosphate consumption is approximately half that of nitrogen. A large part of the fertilizer currently being used is for wheat. The targeted consumption and domestic production needs of nitrogen for 1973-1974 are three million and two and a half million metric tons, respectively, a fantastic threefold increase in consumption and a fivefold increase in production. These fertilizer targets must be attained if the targeted production of 129 million metric tons of cereal is to be realized.

Mechanization of agriculture is rapidly following the breakthrough in wheat production. Prior to the first big wheat crop in 1968, unsold tractors accumulated at the two factories of eighteen thousand units per year, are now producing tractors, thirty-five thousand units were imported in 1969-1970.

The traditional method of threshing by treading out of the grain with bullocks, followed by winnowing, is now inadequate for threshing the increased volume of wheat before the onset of the monsoon rains. Consequently, hundreds of thousands of small threshing machines have been produced and sold by hundreds of small village machine shops during the past three years, thus avoiding the loss of much of the crop after harvest and also providing additional employment in many new small-village industries.

Moreover, mechanization has had another very important indirect effect on the intensification of cereal production. When small mechanical threshers replace bullocks for threshing, the bullocks are released for use in the timely preparation of the land for the next (summer) crop. This need for timely preparation of land is also one of the main reasons for the surge in demand for tractors. Before the adoption of the new wheat and rice varieties, in combination with heavy applications of chemical fertilizer, the time of sowing was relatively unimportant because yields were limited primarily by the low level of available plant nutrients. Most farmers would expect to harvest about one metric ton of wheat during the winter (rabi) season and about one and a half metric tons of rice during the summer (kharif) season, or a total of two and a half metric tons of grain per hectare per year. But by using the high-yielding varieties, fertilizing heavily, sowing at the right time, and managing the fields properly, the same farmer can now harvest five tons of wheat and seven tons of rice per hectare from the same land, a total of twelve metric tons of food grain per hectare per year, as contrasted with the two and a half tons which he obtained with the old varieties and methods. If plantings are not done at the optimum time, however, the yield of wheat may drop to three tons and that of rice to four tons per hectare, a total production of seven tons per year instead of the twelve tons when all operations are proper and timely. A few of the most progressive farmers now use triple cropping, involving wheat – mung beans – rice, or wheat – rice – potato, or three consecutive crops of rice during the same year. By increasing the intensity of cropping, both food production potential and employment are increased. Yields must then be calculated on the basis of kilos per hectare per year rather than on the basis of kilos per hectare per crop.

The increased mechanization in cereal production has tended thus far to increase rather than decrease the employment opportunities for labor, and above all it has helped to reduce drudgery and increase the efficiency of human energy, especially in India.

of agro-industry by increasing the demand for fertilizers, pumps, machinery, and other materials and services.

Farmers in many villages are investing in better storage facilities. In some locations, brick houses are beginning to replace those made of rammed earth. More electricity is being used to light the houses and to drive the motors on the wells. There also has been a rapid increase in demand for consumer goods. The purchase of transistors and radios for use in the villages has increased rapidly, and thereby the government for the first time can effectively reach the remote villages with educational programs. Sewing machines, bicycles, motor scooters, and motorcycles are coming to the villages, and truck and bus service between villages is improving.

The green revolution has forced the Indian government to improve many of its public services. Although there was an extreme shortage of storage space for the first record-breaking wheat crop in 1968, the government improvised satisfactorily and very little grain was lost. During the past two years, stimulated in part by criticism by farmers and the press, warehouse capacity has been expanded greatly to provide adequate storage for the increasing grain production. The villages are demanding better roads, better public transportation, and better schools; and they are beginning to get them. Thus the divorce between intellect and labor, which the great Indian leader Mahatma Gandhi over forty years ago regarded as the bane of India's agriculture, is coming to an end.

The changes wrought by the green revolution, which I have illustrated by the vast improvement of wheat production in India, have had similar effects in West Pakistan, Ceylon, the Philippines, and Thailand, although the effects in different countries were produced by changes in different crops or combinations of crops.

Although the contributions of the green revolution to increased food production are considerable and highly significant, they are nonetheless modest in comparison with the magnitude of present global needs. The greatest obvious achievements are the rapid increase in cereal production during the past three years and the generation of a climate of confidence in the developing nations with regard to their capabilities of achieving food self-sufficiency. Perhaps even more significant, however, is the change in organizations and attitudes which has accompanied the increases in cereal production.

The All-India Coordinated Wheat Improvement Program, which is largely responsible for the wheat revolution in India, has developed one of the most extensive and widely

India equals the best in the world. The breeding program is huge, diversified, and aggressive; already it has produced several varieties which surpass those originally introduced from Mexico in 1965. The first group of new Indian varieties, already in extensive commercial production, were derived from selections made in India from partially selected materials received from Mexico. A second group of varieties, now being multiplied, are selections from crosses made in India between Indian and Mexican varieties. The rapidity of creation and distribution of these new varieties has already diversified the type of resistance to diseases and therefore minimizes the menace of destructive disease epidemics if and when changes occur in parasitic races of the pathogens.

Contrary to a widespread and erroneous opinion, the original dwarf wheat imported from Mexico definitely carried a wider spectrum of disease resistance than the local Indian types that they replaced. But the newer Indian varieties are even better in resistance and of a different genetic type than the original introductions. This greater diversity reduces the danger from disease epidemics but cannot completely eliminate the dangers of disease epidemics, as has become vividly evident from the unexpected and destructive epidemic of southern leaf blight of maize over vast areas of the U. S. A. during the summer of 1970. The only protection against such epidemics, in all countries, is through resistant varieties developed by an intelligent, persistent, and diversified breeding program, such as that being currently carried on in India, coupled with a broad disease-surveillance system and a sound plant pathology program to support the breeding program. From such a program a constant flow of new high-yielding disease-resistant varieties can be developed to checkmate any important changes in the pathogens. The Indian program is also developing competence in research on the biochemical, industrial, and nutritional properties of wheat.

Perhaps the most important contribution of all is that the methods and tactics used so successfully in making the production breakthrough in wheat, first in Mexico and now in India and Pakistan, can serve as a model for production programs with many other crops and in many other countries.

West Pakistan has already used the wheat model to revolutionize its rice production. Although the Indian rice program has not yet achieved a nationwide breakthrough in production, rapid progress is now being made in several areas, and it seems probable that the area sown to the new seed and technology will be large enough to produce a strong impact on national production within another year. Varieties and new technology

Africa, and Latin America. What is still needed is the will and commitment of governments to support national production campaigns, both politically and financially, and the services of a few competent and dedicated agricultural scientists as leaders.

The quality of scientific leadership is certainly a vital factor in the success of any production campaign. It is deplorable but true that many agricultural scientists in some advanced countries have renounced their allegiance to agriculture for reasons of expediency and presumed prestige. And some institutions have furnished them a curtain behind which to hide. Some educational and research institutions have even restricted the amount of basic research that can be done under the aegis of its agricultural departments, however basic these researches may be to progress in increasing and insuring food production. Let the individuals live with their own motivations; let them serve science and themselves if they wish. But the institutions have the moral obligation to serve agriculture and society also; and to discharge that obligation honorably, they must try to help educate scientists and scientific leaders whose primary motivation is to serve humanity.

I want to reiterate emphatically that there now are available materials and techniques of great potential value for expanding the green revolution into additional fields of agriculture. But to convert these potential values into actual values requires scientific and organizational leadership. Where are those leaders? Where are the leaders who have the necessary scientific competence, the vision, the common sense, the social consciousness, the qualities of leadership, and the persistent determination to convert the potential benefactions into real benefactions for mankind in general and for the hungry in particular? There are not enough of them now; therefore we must try to identify and develop them in our educational systems and we must utilize them in our campaigns for food production. We need them and need them badly, for it is tragic to let potential values languish for want of leadership in capitalizing the potential. This is not theory; this is reality, as illustrated by the fact that the leadership has been the determining factor in the relative success of parallel but different crop production programs within the same country.

But let no one think that we can relax our efforts in research. All successful action programs must be preceded and accompanied by research. It has been pointed out that the rapid change in wheat production in both India and Pakistan was in part made possible by two decades of research in Mexico. How did this come about?

was launched in Mexico. This was a pioneer cooperative project between the Mexican Ministry of Agriculture and the Rockefeller Foundation, initiated at the request of the Mexican government for assistance in increasing the production of maize, wheat, and beans.

At that time Mexico was importing more than fifty percent of the wheat that it consumed, as well as a considerable percentage of its maize. Wheat yields were low and static, with a national average yield of 750 kilos per hectare, even though most of the wheat was grown on irrigated land. This situation was very similar to that in India and Pakistan before the recent advent of the green revolution. Mexican soils were impoverished and chemical fertilizer virtually unknown.

Mexico's need was urgent, and so a simple research program was started to increase production. The philosophy of the Rockefeller Foundation was "to help Mexico to help itself" in solving its food production problems, and in the process work itself out of a job. I have had the privilege and good fortune to have been associated with the wheat program almost from the beginning, and have remained a part of it for the past twenty-six years. From the outset all factors limiting wheat production were studied; consequently, there were interdisciplinary researches between genetics and plant breeding, agronomy, soil fertility, plant pathology, and entomology. Cereal chemistry and biochemistry were added later.

After preliminary work in 1943, plant breeders, soil scientists, plant pathologists, and entomologists working as a team, began a concentrated attack on the various aspects of wheat production in 1944.

An in-service (intern) training component was added to the research program to train a new generation of Mexican scientists while they were assisting with the development of the research program. Provision was also made for fellowships to enable the most promising of these young scientists to study abroad for advanced degrees, hopefully in preparation for positions of leadership in Mexican agriculture.

Research from the outset was production-oriented and restricted to that which was relevant to increasing wheat production. Researches in pursuit of irrelevant academic butterflies were discouraged, both because of the acute shortage of scientific manpower and because of the need to have data and materials available as soon as possible for use in the production program.

twenty-eight degrees north latitude in the fall when the days were progressively shorter; the second was sown near Toluca, at eighteen degrees latitude and 2,500 meters above sea level during the summer when days were progressively longer. Through the use of this technique, we developed high-yielding, day-length-insensitive varieties with a wide range of ecologic adoption and a broad spectrum of disease resistance – a new combination of uniquely valuable characters in wheat varieties.

These characters were valuable in increasing wheat production in Mexico and neighboring countries, but were to prove even more valuable twenty years later when the Mexican varieties were introduced into Pakistan and India. Without this combination of characters the successful transplantation of the Mexican varieties into Pakistan and India would have been impossible; and the advent of the green revolution would almost certainly have been delayed many years.

In Mexico, as soon as significant improvements were made by research, whether in varieties, fertilizer recommendations, or cultural practices, they were taken to farms and incorporated into the production programs. We never waited for perfection in varieties or methods but used the best available each year and modified them as further improvement came to hand. This simple principle is too often disregarded by scientific perfectionists who spend a lifetime searching for the unattainable in biological perfection, and consequently during a lifetime of frustration contribute nothing to increasing food production.

Farm demonstrations of new varieties and technology were made by the research scientists who had developed them. Indeed, the revolution in wheat production in Mexico was accomplished before the extension service came into being. This forced the research scientists themselves to consider the obstacles to production that confronted the farmers. The same philosophy and tactic were used effectively to bring researchers in contact with the farmers' problems in the early years of the wheat improvement programs in India and West Pakistan. Later, however, the extension services were brought into the production programs in both countries.

Mexican wheat yields began to climb by 1948 and have continued their upward trend to the present time. During the past twenty-six years, the national average has risen from 750 kilos per hectare to only slightly less than 3,000 kilos during the past harvest, approximately a fourfold increase. During the same period, total production has increased sevenfold. Mexico became self-sufficient in wheat production for the first time

Pakistan a decade later.

As the use of fertilizer increased and yields climbed to four and a half thousand kilos per hectare, lodging (falling over of the plant) began to limit further increases in yields. A search was therefore made among wheat from different areas of the world to locate a suitable source of genetic dwarfness to overcome this barrier. Norin 10, an extremely dwarf wheat from Japan, proved to be a suitable source. Through a series of crosses and re-crosses begun in 1954, dwarfness was incorporated into the superior, new-combination Mexican types, finally giving rise to a group of so-called dwarf Mexican wheat varieties. With this new development, the potential yield of the new varieties, under ideal conditions, increased from the previous high of four and a half thousand kilos per hectare to nine thousand kilos per hectare. The dwarf Mexican wheat were first distributed in Mexico in 1961, and the best farmers began to harvest five, six, seven, and even eight tons more per hectare, and within seven years the national average yields doubled. It was these same dwarf Mexican wheat from the quiet revolution that served as catalysts to trigger off the green revolution in India and Pakistan.

From the outset the Mexican Agricultural Program was watched with interest by many other countries. As progress became evident, the Rockefeller Foundation was besieged by requests from many countries for assistance in agricultural improvement programs. The Cooperative Mexican Agricultural Program had become a model. The Cooperative Colombian Agricultural Program, devoted largely to maize, wheat, potatoes, forage, and livestock, was established in 1950. Similarly, the Cooperative Chilean Agricultural Program was established in 1955 to work on wheat and forage. The Cooperative Indian Agricultural Program was established in 1956 to improve maize, sorghum, and millet production and to assist in the development of postgraduate agricultural education. Each of these programs subsequently played an important role in improving agricultural production and education in different parts of the world.

Meanwhile, back in Mexico, the program that had originally been confined to maize, wheat, and beans, and soon thereafter potatoes, was expanded to include many other crops. Larger numbers of young Mexican scientists were added to the research and training programs. Progress in research was generally good, and the training program also bore fruit. Between the years 1943-1963, a total of 550 interns participated in the overall agricultural research and training programs, of whom about 200 received a Master of Science degree and about thirty the Doctor of Philosophy degree while on fellowships for study abroad. With this corps of trained scientists a new National

The Mexican experience indicated that one of the greatest obstacles to the improvement of agriculture in the developing countries is the scarcity of trained people. This experience indicated clearly that training is a slow process. Where no corps of trained scientists exists, as was the case in Mexico twenty-seven years ago and remains the case in many countries of Asia, Africa, and Latin America today, it requires eighteen to twenty-five years to develop enough competent research scientists and educators to meet a country's needs. So great is the urgency of the food shortage in many underdeveloped and emerging countries that there is not enough time to develop an adequate corps of scientists before attacking food production problems. A shortcut and organizational change had to be invented to meet the needs. And so was born the first truly international research and training institute, the International Rice Research Institute (IRRI) at Los Baños, the Philippines, in 1960, to work exclusively on the regionally all-important but too-long-neglected rice crop. The institute was jointly financed by the Ford and Rockefeller Foundations in collaboration with the government of the Philippines.

The research activities on wheat, maize, and potatoes in Mexico were informally internationalized in 1959 and organized as a second international center in 1963. This International Center for Maize and Wheat Improvement (CIMMYT) is supported also by the Ford and Rockefeller Foundations in collaboration with the government of Mexico. More recently, additional financial support has been provided by the U.S. Agency for International Development (U.S.AID), United Nations Development Program (UNDP), and the Inter-American Development Bank (BID).

A third center, the International Center of Tropical Agriculture (CIAT) in Colombia, and the International Institute of Tropical Agriculture (IITA) in Nigeria, the most recent, have been established to study problems and stimulate production of certain tropical crops and animal species, as well as to help train scientific specialists. CIAT is financed by the Ford, Rockefeller, and W. K. Kellogg Foundations in cooperation with the government of Colombia. The Ford and Rockefeller Foundations and the Canadian International Development Agency (CIDA) are supporting IITA in collaboration with the government of Nigeria.

These four international institutes represent a significant but modest start toward the construction of a worldwide network of international, national, and local research and

The impact of such an integrated approach is already evident in the green revolution. New varieties and the new technologies that make them highly productive have been the thrust behind the green revolution. In the Philippines, Ceylon, Malaysia, and West Pakistan, it was IR8 rice, developed at the International Rice Research Institute. The dwarf Mexican wheat, partly produced by CIMMYT, have provided the thrust in India and Pakistan, and this is now spreading to Turkey, Afghanistan, Iran, Morocco, and Tunisia. Contributing equally, or perhaps even more, to the evolution of the green revolution was the talented supporting leadership that has been provided by the centers to the national programs through temporary assignments of mature scientists skilled in organizing crop production programs to assist in the development of the national production campaigns.

The international centers were developed to supplement national agricultural research, production, and training programs, not to replace them. The centers are but one link in the worldwide network of organizations attacking basic food-crop production problems on a worldwide, regional, national, and local level. The backbone of this network is now and must continue to be the national programs. These must be given greater financial support and strengthened staff-wise to meet the challenge of rapidly expanding food needs for the future.

The international centers, however, are in a unique position to assist the national programs. They are independent, nonpolitical international organizations, which, although originally funded by private foundations, now receive support from many diverse sources. Their scientific staffs are also international and comprise outstanding scientists representing the various scientific disciplines affecting crop production. Included on their staffs are a number of crop production experts who have the scientific competence and broad experience to assist national agencies in organizing and launching crop production programs.

The centers collaborate not only with the national agencies from many different countries but also with other international organizations such as the Food and Agriculture Organization (FAO) of the United Nations, the United Nations Development Program (UNDP), and international development banks. Each year the centers have been collaborating with an increasing number of countries of all political spectra.

food production. We must all strive to strengthen this bond in the spirit of Alfred Nobel "to promote brotherhood among the nations".

The international centers are uniquely equipped to do fundamental, longtime researches of worldwide importance. For example, the opportunity for plant breeders, pathologists, and entomologists to operate on a worldwide basis permits them to develop well-conceived, diverse gene pools of the important crop species. The final crop varieties are not currently generally selected at the centers but sent to collaborators in national programs in many parts of the world, who in turn make the selections that best suit their needs; and many eventually become commercial varieties. Similarly, the centers prepare a series of international crop yield tests, which include representatives of the best commercial varieties from the world and a few of the most promising experimental lines from collaborators. These are sent to collaborators in thirty-five countries for growing at eighty locations. The data from collaborators are returned to CIMMYT for summarizing and for subsequent distribution to scientists in all parts of the world. The data obtained on yield, adaption, disease, and insect resistance in one year in such tests are often more meaningful and valuable to scientists engaged in crop research and production programs than data obtained by independent testing at one location for a period of ten or fifteen years.

The international centers also are in a unique position to contribute to practical or internship type of training in all of the scientific disciplines affecting crop production. This type of training is particularly valuable for young scientists from the developing countries because it prepares them for initiating research work upon return to their native country and will also be of value if they subsequently continue their education at the graduate level.

In summarizing the accomplishments of the green revolution during the past three years, I wish to restate that the increase in cereal production, rice, maize, and wheat, especially in wheat, has been spectacular and highly significant to the welfare of millions of human beings. It is still modest in terms of total needs. Recalling that fifty percent of the present world population is undernourished and that an even larger percentage, perhaps sixty-five percent, is malnourished, no room is left for complacency. It is not enough to prevent the currently bad situation from getting worse as population increases. Our aim must be to produce enough food to eradicate all present hunger while at the same time striving to correct malnutrition. To eliminate hunger now in the developing nations, we would need to expand world cereal production by thirty percent.

rapidly by expanding it in the United States, Canada, Australia, Argentina, and Russia. But this would not necessarily solve the hunger problem of the developing world because their weak economies will not permit them to expand their food imports by thirty percent. Worse still, even if present production could be expanded rapidly by thirty percent in the developing countries – which I believe is possible based on recent progress of the green revolution – so as theoretically to eliminate hunger, the hunger problem as it now exists still would not be solved. There remains the unsolved social-economic problem of finding effective ways to distribute the needed additional food to the vast underprivileged masses who have little or no purchasing power. This is still the great unsolved problem with which the economists, sociologists, and political leaders must now come to grips.

I am convinced that if all policymakers would take sufficient interest in population control and in aggressively employing and exploiting agricultural development as a potent instrument of agrarian prosperity and economic advancement, many of the social ills of the present day could soon become problems of the past. The tropics and subtropics have abundant sunlight and other great biological assets, and it will be criminal to delay further the conversion of these assets into wealth meaningful to the poor and hungry.

Some critics have said that the green revolution has created more problems than it has solved. This I cannot accept, for I believe it is far better for mankind to be struggling with new problems caused by abundance rather than with the old problem of famine. Certainly, loyalty to the status quo in food production – when being pressured by population growth – cannot break the chains that have bound the peasant to poverty and hunger. One must ask: Is it just to criticize the green revolution, with its recognized accomplishments, for failure to correct all the social-economic ills of the world that have accumulated from the days of Adam and Eve up to the present? Change we must, or we will perish as a species, just as did the dinosaurs in the late Cretaceous.

The green revolution is a change in the right direction, but it has not transformed the world into Utopia. None are more keenly aware of its limitations than those who started it and fought for its success. But there has been solid accomplishment, as I have already shown by concrete examples. I have also tried to indicate the various opportunities for capitalizing more fully on the new materials that were produced and the new methods that were devised. And, above all, I cannot emphasize too strongly the fact that further progress depends on intelligent, integrated, and persistent effort by government leaders, But progress is continuous, and we can and must make continuous progress. Better varieties of wheat and other cereals with not only higher yield potential but also with higher content of protein are already in the process of creation.

We need also to explore more fully the feasibility of producing new manmade cereal species with greater production potential and better nutritional quality than those now in existence. Triticale, a man-made species, derived from a cross between wheat and rye, now shows promise of becoming such a crop.

During the past six years, the International Corn and Wheat Center in Mexico, cooperating with the University of Manitoba, has developed a large breeding program to improve Triticale. Within the past three years we have developed highly fertile lines, and the results up to the present indicate the possibility of combining the desirable characteristics now present in different lines into a single line, thereby creating a new kind of cereal that is superior to wheat in productivity and nutritional quality.

The rapid progress achieved in Triticale improvement suggests the desirability of initiating basic studies to determine the feasibility of developing other cereal species from wide crosses between different existing species or their wild relatives. Recent improvements in individual cell, tissue and embryo-culture techniques, in the development of culture media with additions of hormones and nutrients that foster cell and tissue differentiations, in achieving hybridization between somatic cells, and in the methods of inducing polyploidy and mutations, offer many fascinating possibilities of achieving crosses between species that were formerly uncrossable. Even the possibility of using protoplasmic and cell hybridization, followed by manipulation to promote cell differentiation for plant improvement, appears to be nearer.

I propose therefore that a bold program of wide crosses be initiated to improve both cereals and legumes (pulses). It should include attempts to make numerous intergeneric crosses among cereals, employing all of the modern techniques to consummate fertilization, and propagate the hybrids. If a series of new combinations can be made and doubled, as, for example, between maize and sorghum, wheat and barley, or wheat and rice, it would open the door to the possibilities for vast subsequent improvement by conventional methods.

health. Protein malnutrition is widespread, especially among children, and many of its victims die or are maimed both physically and mentally for life.

Although food supplements can alleviate this situation, the development of high-yielding varieties of cereal grains that have high levels of protein and better amino acid balance would be the ideal solution, since this would not involve added expense or special educational efforts, and there are good possibilities of producing them. The now famous opaque-2 gene in maize doubles the production of the amino acid lysine which is essential to growth and health in man and many other animals. Similarly, an Ethiopian strain of barley, and some lines of Triticale have genes for extraordinary production of essential nutrient materials. Plant breeders are trying to combine such genes with the best genes now available for productivity and other desirable characters, thus increasing not only the tonnage of food, but also its essential nutrient quality. As we are now striving to emancipate ourselves from dependence on artificial food supplements, I have a dream that we can likewise emancipate ourselves to some extent from our dependence on artificial nutrients for the cereal plants themselves, thus lightening the financial burden that now oppresses the small farmer and handicaps his efforts to participate fully in the new technologies.

In my dream I see green, vigorous, high-yielding fields of wheat, rice, maize, sorghums, and millets, which are obtaining, free of expense, 100 kilograms of nitrogen per hectare from nodule-forming, nitrogen-fixing bacteria. These mutant strains of *Rhizobium cerealis* were developed in 1990 by a massive mutation breeding program with strains of *Rhizobium* sp. obtained from roots of legumes and other nodule-bearing plants. This scientific discovery has revolutionized agricultural production for the hundreds of millions of humble farmers throughout the world; for they now receive much of the needed fertilizer for their crops directly from these little wondrous microbes that are taking nitrogen from the air and fixing it without cost in the roots of cereals, from which it is transformed into grain...

Then I wake up and become disillusioned to find that mutation genetics programs are still engaged mostly in such minutiae as putting beards on wheat plants and taking off the hairs.

If we are to capitalize fully on the past biological accomplishments and realize the prospective accomplishments, as exemplified in my dream, there must be far greater investments in research and education in the future than in the past.

annual return of 750 percent. This study was made prior to the full impact of dwarf wheat on the national production. If the benefits were calculated now, with the inclusion of the returns from the increased wheat production in Pakistan, India, and other Asian and African countries, they would be fantastically high.

Nevertheless, vast sums are now being spent in all countries, developed and developing, on armaments and new nuclear and other lethal weapons, while pitifully small sums are being spent on agricultural research and education designed to sustain and humanize life rather than to degrade and destroy it.

The green revolution has won a temporary success in man's war against hunger and deprivation; it has given man a breathing space. If fully implemented, the revolution can provide sufficient food for sustenance during the next three decades. But the frightening power of human reproduction must also be curbed; otherwise the success of the green revolution will be ephemeral only.

Most people still fail to comprehend the magnitude and menace of the "Population Monster". In the beginning there were but two, Adam and Eve. When they appeared on this earth is still questionable. By the time of Christ, world population had probably reached 250 million. But between then and now, population has grown to 3.5 billion. Growth has been especially fast since the advent of modern medicine. If it continues to increase at the estimated present rate of two percent a year, the world population will reach 6.5 billion by the year 2000. Currently, with each second, or tick of the clock, about 2.2 additional people are added to the world population. The rhythm of increase will accelerate to 2.7, 3.3, and 4.0 for each tick of the clock by 1980, 1990, and 2000, respectively, unless man becomes more realistic and preoccupied about this impending doom. The ticktock of the clock will continually grow louder and more menacing each decade. Where will it all end?

Malthus signaled the danger a century and a half ago. But he emphasized principally the danger that population would increase faster than food supplies. In his time he could not foresee the tremendous increase in man's food production potential. Nor could he have foreseen the disturbing and destructive physical and mental consequences of the grotesque concentration of human beings into the poisoned and clangorous environment of pathologically hypertrophied megalopoles. Can human beings endure the strain? Abnormal stresses and strains tend to accentuate man's animal instincts and

We must recognize the fact that adequate food is only the first requisite for life. For a decent and humane life we must also provide an opportunity for good education, remunerative employment, comfortable housing, good clothing, and effective and compassionate medical care. Unless we can do this, man may degenerate sooner from environmental diseases than from hunger.

And yet, I am optimistic for the future of mankind, for in all biological populations there are innate devices to adjust population growth to the carrying capacity of the environment. Undoubtedly, some such device exists in man, presumably *Homo sapiens*, but so far it has not asserted itself to bring into balance population growth and the carrying capacity of the environment on a worldwide scale. It would be disastrous for the species to continue to increase our human numbers madly until such innate devices take over. It is a test of the validity of *sapiens* as a species epithet.

Since man is potentially a rational being, however, I am confident that within the next two decades he will recognize the self-destructive course he steers along the road of irresponsible population growth and will adjust the growth rate to levels which will permit a decent standard of living for all mankind. If man is wise enough to make this decision and if all nations abandon their idolatry of Ares, Mars, and Thor, then Mankind itself should be the recipient of a Nobel Peace Prize which is "to be awarded to the person who has done most to promote brotherhood among the nations".

Then, by developing and applying the scientific and technological skills of the twentieth century for "the well-being of mankind throughout the world", he may still see Isaiah's prophesies come true: "... And the desert shall rejoice, and blossom as the rose... And the parched ground shall become a pool, and the thirsty land springs of water..."[7]

And may these words come true!

* The laureate delivered this lecture in the auditorium of the Nobel Institute. The text, which in actual delivery was considerably shortened, is taken from *Les Prix Nobel en 1970*.

1. In what is now West Iran.

3. Joel 1:17, 20.

4. Genesis 41:54.

5. Isaiah 8:21.

6. Lord John Boyd Orr (1880-1971), recipient of the Nobel Peace Prize for 1949.

7. Isaiah 35:1, 7.

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