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Wheat Breeding and its Impact on World Food Supply

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PUBLIC LECTURE

Wheat Breeding and its Impact on World Food Supply

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It is a pleasure for me to have this opportunity to visit Australia for the first time and to attend the Third International Wheat Genetics Symposium. It is a special privilege to have an opportunity to visit Canberra and environs, the site where WILLIAM FARRER worked and laid the basis for today's scientific wheat breeding programmes. There have been close bonds between the Australian and Mexican wheat breeding programmes over the past two decades, both as the result of visits by many Australian scientists to Mexico, as well as from the fact that Australian varieties have been used extensively as progenitors in the Mexican breeding programme. Moreover, I have for many years admired the research by Australian scientists on soil nutrients – superphosphate and minor elements — and especially the development of improved pasture, built around the selection of subterranean clovers, medics and grasses, and their use in rotation with wheat. These discoveries have revolutionized both wheat and sheep production, and have transformed millions of acres of waste lands into productive food producing areas. I hope to live to see the day when the knowledge and management skills you have developed to greatly expand wheat, wool and mutton production in the Mediterranean-type climate zones of Australia, are transplanted back to the Mediterranean climate zones of North Africa and the Near and Middle East where they are so badly needed.

My presentation tonight will not retrace historically the many milestones of wheat genetics and breeding upon which modern wheat production is based. Rather I will confine my remarks to the development of the Mexican Wheat Improvement Programme, and its subsequent impact on the development of wheat production in a number of other food deficit countries.

Twenty-five years ago when the Rockefeller Foundation launched its first co-operative programme in agricultural science in Mexico, at the invitation of and with collaboration from the Mexican Ministry of Agriculture, world opinion reflected no concern over food production and population growth. Indeed, at that time, most political leaders of emerging nations instead gave major emphasis to industrialization in their development programmes while largely ignoring such mundane projects as the improvement of their inefficient traditional agricultures. Without exception these short cuts to industrialization and a higher standard of living failed miserably. Leaps forward became strategic retreats.

Within the past decade the attitude of world leaders has begun to change. This change has come about as country after country found its population growing at a rate that was greater than the increase in food production. Famine has stalked. The phenomenal reduction in death rates, as the result of effective public health programmes during the past two decades in the developing countries, has precipitated the population crisis and given urgency to expanding food production.

Within the past five years the pendulum has swung to the other extreme. Currently, many scientists, demographers and political leaders are predicting doom for the human race because of the growing imbalance between food production and population growth (BROWN, 1963, 1965; NOTESTEIN, 1965; PADDOCK, 1967; PADDOCK and PADDOCK, 1967; REVELLE, 1966).

I would now like to indicate some of our experiences in wheat research and production that bear on the world food and population problems.

THE MEXICAN AGRICULTURAL PROGRAMME

Wheat culture was introduced into Mexico in the early 1520's by the Spaniards, shortly after the Conquest. Nevertheless, maize which was already extensively cultivated by the Indians when the Spaniards arrived, remained the only important "bread grain" until recent decades. The *tortilla,* which is the daily bread of the Mexican people, is principally made from maize. Within the past two decades, however, the consumption of wheat has increased to a point where it is now about one-third that of maize.

Wheat today is consumed largely in the form of hard rolls known as *bolillos.* Pan type bread has grown in popularity within the past ten years especially in the larger cities. Similarly there is now a rapidly growing demand for pastas (*i.e.* macaroni, spaghetti) and pastry products. The *tortilla* of northern Mexico is, however, made of wheat not maize. It is similar to the *chapatti* of the Near and Middle East, except that it is made from white flour rather than *atta* (whole meal).

The Problem

When the Co-operative Mexican Agricultural Research Programme was initiated in 1943 to increase the production of basic food crops, it was clear that wheat was one of the crops on which a concerted research effort should be made. At that time more than 275,000 tons (10,175,000 bushels), representing approximately 55 percent of the total consumption, were being imported. The importation costs, approximately 100,000,000 pesos (21 million dollars) was by far the greatest expenditure for food imports, and also represented a serious drain on limited foreign exchange. There were indications that the demands for wheat would grow as the population increased and as a greater proportion of the population acquired a taste for bread and pastry products (BORLAUG, 1954, 1958, 1965).

What was the situation with respect to wheat production when the research programme was initiated? Wheat was grown primarily as a winter irrigated crop. It was planted from September through December and harvested from April through June, depending upon both variety and elevation. The varieties were all of spring habit and were of unknown origin with the exception of two varieties, Ramona and Baart, introduced from California into the State of Sonora. Varieties, in the ordinary sense of the word, did not exist but were mixtures of many different types. All varieties were susceptible to stem, stripe and leaf rust. In years when ecological conditions were favourable for the stem rust pathogen, as was the case in Sonora in 1939, 1940 and 1941 and in the central Bajio region in 1948, devastating epidemics brought economic ruin to the wheat farmer. Cultural practices were primitive in every area except Sonora which was mechanized. In all other areas the Egyptian wooden plough, pulled either by oxen or mules, was the only implement used in land preparation and planting operations. In all areas, except Sonora, harvesting was done with a hand sickle and the threshing was done with small stationary threshers or more commonly by treading out by oxen and mules, and the grain was cleaned by winnowing. Yields were low and stagnant, with a national average yield of 750 kilos per hectare (11 bushels per acre). Soils were impoverished and fertilizers unknown.

When the programme was established there were only a very few qualified agricultural scientists in Mexico. A wheat breeding programme was non-existent. Only one qualified scientist was available for wheat breeding but, because of other responsibilities, he spent only about ten percent of his effort in wheat research. No soil fertility or agronomic research of any type was being done. Nothing was being done on research to control losses from diseases, insects and weeds.

The Approach

At the time the programme was initiated no preconceived ideas were available about how to launch an agricultural revolution. Mexico had no grandiose plans nor did it have a hierarchy of planners to guide its agricultural and industrial development — such as I have subsequently encountered in many countries in which I have worked in recent years. The Mexican Minister of Agriculture simply told us to see what we could do about increasing wheat production. He backed the programme faithfully, but openly stated that he did not expect miracles. The belief was widespread that Mexico had neither the soil nor climate to become self-sufficient in wheat production.

1. *Programme philosophy.* From the outset the philosophy of the Rockefeller Foundation programme was "to help Mexico to help itself solve its food production problems". Moreover, it became our policy as wheat scientists, "to work ourselves out of a job as soon as possible". From the beginning it was established

that Rockefeller Foundation agricultural scientists would be "working scientists not consultants". They would participate on an equal basis with scientists from the host country in all research activities. One of the first lessons that we taught was that "there could be dignity in physical work and sweat of the human brow even when done by scientists". This idea is in direct conflict with the concept widely held by scientists in under-developed and developing countries even today.

All three of the aforementioned concepts subsequently have become basic parts of the philosophy of co-operative wheat programmes in other countries where we have worked.

One other dimension was added to our programme philosophy from later experiences. This is the importance of continuity of scientific personnel. Little can be accomplished without long time continuity of programme personnel. Staff members who stay with a programme only two years, leave little or no impact. This is a common weakness of most foreign technical assistance programmes. In our programme it has become clearly evident that programme vigour and success is strongly dependent on the long-term continuity of the foreign participating scientists (BORLAUG, 1965).

2. *Organizing the research efforts.* An analysis of the causes of low yields and lack of interest by Mexican farmers in wheat production was made in the early phases of the programme. Research was designed to develop information that would overcome all of the production bottlenecks. Manipulation of all factors affecting production was recognized as absolutely necessary from the outset. The breeding of improved varieties was recognized as only one aspect of needed change. Thus a co-ordinated inter-disciplinary research and production approach has become part of all of our efforts in co-operative wheat programmes in all other countries in which we have worked. From the beginning most of our research effort was production orientated. This has continued to be our policy in wheat research and production elsewhere.

When the Mexican programme was launched it had a two pronged attack. Firstly, to develop a research programme on all factors limiting yield and production, and secondly, to train a corps of young wheat scientists, in all scientific disciplines related to production. The young scientists would learn research techniques by participation, but would simultaneously contribute to the development of the research programme. Subsequently the most capable and best motivated young trainees would be awarded fellowships to study for advanced degrees.

The research effort was designed to develop:

(1) improved high yielding, disease resistant varieties with agronomic characteristics making them responsive to improved agronomic practices, *i.e.* the use of fertilizers, better soil moisture management and mechanization;

(2) basic information on plant nutrient requirements for each of the principal soil types where wheat was grown, and with this information, formulate

suitable fertilizer recommendations and rotation practices to permit increased yields;

(3) the needed agronomic data to increase yields, *i.e.* best rates, dates and methods of sowing, etc.;

(4) the proper irrigation and soil moisture management practices needed to efficiently utilize the benefits expected from the use of improved varieties and fertilizer practices;

(5) the basic pathological and entomological, and weed control information, to guide the breeding and production programme;

(6) improved economical methods for land preparation, planting, and harvesting, which are all important considerations in increasing grain yield, preventing losses, and reducing production costs.

Plant breeders, soil scientists, agronomists, plant pathologists and entomologists began a concentrated attack on these various aspects of the wheat problem in 1944 and 1945.

The Results

The Mexican Wheat Research and Production Programme from the time of its initiation has not only been production orientated, but also characterized by a spirit of urgency and enthusiasm. Short cuts to save time and increase efficiency have been used wherever possible.

1. *Varietal improvement.* The Mexican breeding programme has given primary emphasis to

(1) breeding varieties with high yield potential,

(2) developing varieties with good resistance to stem, stripe and more recently leaf rust,

(3) developing varieties with resistance to lodging which will permit heavy fertilization and high yield,

(4) developing varieties with broad adaptation to minimize the problem of seed multiplication and extension, and,

(5) once self-sufficiency was obtained to developing varieties with improved milling and baking characteristics.

The first improved commercial varieties that were developed by the Mexican programme were strongly influenced by three varieties, namely, Mentana, Marroqui (Florence-Aurore) and Gabo. Subsequent varieties have been selected from the very diverse and large gene pool that currently characterizes the Mexican programme.

The Mexican programme pioneered on an extensive basis the growing of two generations of all breeding materials each year. This was accomplished by growing the segregating populations during the winter — the commercial wheat crop season — near Ciudad Obregon, Sonora, at about 28° latitude on the coastal strip only a few feet above sea level. A second generation was obtained by planting during mid-May at 8,500 feet and 18° latitude near Toluca. The Toluca site is characterized by heavy rainfall throughout the growing season (average 1,000 to 1,200 m.m.) and cool temperatures. Consequently, severe epidemics of both stem and stripe rust develop every year.

By growing two generations each year as the result of moving the lines back and forth between these two very different environments, it became possible to develop a new variety in a period of three to three and a half years. The early phases of seed multiplication of a new variety are also carried out at an accelerated rate by growing one crop on the coast during the commercial crop season and the second in the high valleys of the Central Plateau during the summer.

The breeding programme has developed and released more than twenty varieties over the past 25 years. These have served Mexican needs well. Each new variety has shown progressive improvement in one or more characters.

Increased yield has been a primary consideration in breeding. With the best long strawed varieties, such as Nainari 60, Lerma Rojo and Huamantla Rojo, yields on farmers' fields, however, never exceeded 4.5 tons per hectare, because of the effects of lodging at rates of nitrogen fertilization of 80 kilos or more per hectare.

We had recognized the barriers on yield imposed by lodging as early as 1948, but we had been frustrated in our search for a useable form of dwarfness to overcome this problem until the discovery of the so-called Norin dwarfs. In 1953 we received a few seeds of several F_2 selections from the cross Norin 10 x Brevor from Dr. ORVILLE VOGEL. Our first attempts to incorporate the Norin 10 x Brevor dwarfness into Mexican wheats in 1954 were unsuccessful, since these lines were used as the female parent and being highly susceptible to all three rusts they were killed outright without producing viable seed. A second attempt in 1955 was successful, and immediately it became evident that a new type of wheat was forthcoming with higher yield potential. Not only was dwarfness of stature introduced from the Norin 10 x Brevor lines, but simultaneously this cross introduced a group of genes, perhaps partially linked, that increased the number of fertile florets per spikelet, and also increased the numbers of tillers per plant.

The introduction of the Norin 10 genes into the Mexican programme has resulted in the development of the Mexican semi-dwarf and dwarf varieties Pitic 62, Penjamo 62, Sonora 63, Sonora 64, Mayo 64, Lerma Rojo 64, Inia 66, Tobari 66, Ciano 67, Norteno 67 and Siete Cerros, all of which are bread wheat types.

We have also transferred the full complement of Norin 10 dwarfing genes from the bread wheat varieties to *Triticum durum*. The Mexican durum variety Oviachic 65 is a product of this programme.

In making the transfer of dwarfness from the dwarf bread wheats to *T. durum* through backcrossing, it was clearly established that the Norin dwarfing genes are located on the A and B genomes, since the full complement of dwarfing was recovered in the durum types.

The development of the dwarf bread wheat varieties broke the 4½-ton yield barriers, where Mexican yields had stagnated because of lodging. The semi-dwarf varieties Pitic 62 and Penjamo 62, which were first released to farmers in 1961, did not begin to make their impact on production until 1963 (Table 1). Nevertheless, with their introduction individual farmers immediately began to break yield records. The best farmers began to harvest 5, 6, 7 and even 8 tons per hectare on commercial areas. Demand for seed of dwarf varieties was brisk and for two years black markets flourished.

TABLE 1. The impact of research on Mexican wheat production.

Year	Cultivated Area 10^3 hectares	Yield kg/hectare	Production 10^3 metric tons
1945	500	750	330
1946	520	800	390
1947	550	820	430
1948	590	850	500
1949	600	880	560
1950	625	900	600
1951	635	920	640
1952	650	940	710
1953	670	960	770
1954	680	980	800
1955	790	1100	850
1956	780	1200	1200
1957	770	1352	1200
1958	840	1592	1337
1959 (a)	937	1351	1265
1960	840	1417	1200
1961	816	1700	1373
1962	777	1800	1400
1963	787	2200	1800
1964	846	2600	2200
1965	668	2368	1565
1966 (b)	723	2250	1627
1967	860	2790	2400

(a) A year with heavy losses from infestations of the English grain aphid.
(b) Considerable loss from frosts and severe leaf rust.

The semi-dwarf and dwarf varieties Penjamo 62, Pitic 62, Lerma Rojo 64, Sonora 64 and Siete Cerros (and various other selections of 8156) have been the varieties responsible for a yield breakthrough in Pakistan, India, Turkey, Afghanistan and Tunisia.

The process used in the Mexican programme of moving segregating populations over ten degrees of latitude and from near sea level to 8,500 feet elevation, and its reverse, not only reduced by half the time required to develop a new variety, but also simultaneously permitted the identification of lines and the development of varieties with wide adaptation. We now know that this, at least to a large extent, is the result of the selection of lines that are insensitive to changes in day length and date of planting, and hence are broadly adapted. Other selection pressures also are undoubtedly acting under the very diverse conditions that prevail at these two nursery sites.

During the past ten years the Mexican varieties in co-operative yield tests, organized and co-ordinated through CIMMYT, have exhibited uniquely broad adaptation in many different countries of the world (KRULL *et al.* 1968). Some have shown outstanding performance under both fertilized and non-fertilized, irrigated and rainfed conditions. Breadth of adaptation which was sought to minimize and circumvent seed multiplication and extension problems in Mexico, has simultaneously resulted in the development of varieties with surprisingly broad adaptation that now makes these varieties valuable for direct commercial use in many other countries of the world.

It is this unusual breadth of adaptation, combined with high yield potential, a strong responsiveness to fertilizers and a broad spectrum of rust resistance, that has made the Mexican dwarf varieties the powerful catalyst that they have become for triggering off a revolution in wheat production in Pakistan and India.

The difficulties of maintaining rust resistance in the commercial varieties has been a continuing one. At least six new virulent races of the stem rust organism *Puccinia graminis tritici*, five of the leaf rust organism *P. triticina*, and one of the stripe rust organism *P. glumarum* have appeared in the past 25 years. The appearance of many of these new races have terminated the useful lifetime of a commercial variety. The lifetime of most Mexican varieties has been short, generally five years or less. There are four exceptions. The variety Lerma Rojo had a commercial lifetime of eleven years. Three others, Yaqui 50, Chapingo 52 and Chapingo 53 retained their resistance until they were displaced from commercial production by higher yielding varieties. The rust reaction of these three varieties today, in experimental plots, is the same as it was when they were first distributed (BORLAUG, 1954; 1965).

Despite the appearance of new races, severe losses from rusts have been avoided by the timely multiplication and distribution of newer varieties with other types of resistance. Nonetheless, the constantly changing pattern of rust races continues to absorb much of the research effort and consequently slows progress in improving other characters. We are not satisfied with the present longevity of rust resistance in commercial varieties.

2. *Soil fertility.* Soil infertility is the most limiting factor in crop production throughout the world. Improved wheat varieties with high yield potential are of little significance unless they are grown on soil that is properly fertilized (PARKER and NELSON, 1966).

In Mexico the national average yield of wheat was about 750 kilos per hectare (11 bushels per acre) when the programme was begun. We found in extreme cases in the Bajio region unfertilized check plots which yielded no more than 180 kilos per hectare (2.7 bushels per acre), despite the use of the best variety and best cultural practices then known. The yield of the best fertilizer treatment under those circumstances produced yields of 4,200 kilos per hectare. Had these experiments been conducted when the dwarf varieties became available the fertilized plots would have produced yields of 6,500 kilos or more per hectare.

Soil fertility studies were initiated on wheat in 1944 and a large amount of data were collected from fertilizer experiments conducted on farms between 1944 and 1955, despite lack of continuity of personnel in the soil science programme. It soon became evident that nitrogen deficiencies occurred throughout the wheat growing area. Phosphate response was variable and in the early years economical responses to applications were obtained on only one of the major soil types where wheat was grown. Within about four years after heavy nitrogen fertilization had been introduced, phosphate responses became widespread in the black soil type of the Central Bajio region. The soils of the coastal plain of Sonora did not begin to respond to phosphate until ten years after the introduction of heavy nitrogen fertilization. Wheat does not respond to applications of potassium nor to micro-elements in Mexico.

The fertilizer recommendations for wheat in Mexico evolved slowly as research information and experience became available. The original recommendations in 1950 were 40-0-0, or 40-40-0 and evolved to 80-40-0 or 100-40-0 by 1958. They remained at this level because of the limiting factor of lodging until the introduction of dwarf strawed varieties. When dwarf varieties became available the recommendations were increased to 120-40-0, or 140-40-0, where they remain. Lodging of the double dwarf varieties now again limit yield, and the development of triple dwarf varieties is needed before further increased fertilizer dosages can be utilized economically.

When change of one factor affecting crop production is introduced it is necessary to manipulate many other factors in order to capitalize on the potential breakthrough in yields. The introduction of high yielding varieties and proper fertilization requires better utilization of moisture to maximize yield increases. Research to determine the proper timing and total irrigation requirements was essential, and was developed.

Weeds, which are little problem on the soils of extremely low fertility, become aggressive when fertilized. Control measures must be developed to make certain that most of the added nutrients are used to produce more wheat rather than more weeds.

In Mexico there were no known insect problems on wheat when the programme was begun. With the introduction of heavy dosages of fertilizer and adequate irrigation, dense stands of wheat developed, where only sparse stands developed before. The micro-climate in the grain fields became more favourable for diseases and pests. Conditions for rust development became very favourable, but rusts were held in check by the resistance of the improved varieties. In the case of insects, however, the English grain aphid (*Macrosiphum granarium*), which had never before been a pest of economic importance, became aggressive and caused severe losses whenever climatological conditions acted adversely on its normal predators. It was necessary to develop satisfactory control measures, utilizing the proper insecticides for use in those years when the predators were ineffective control agents because of adverse temperatures.

THE RESULTS OF APPLYING THE RESEARCH INFORMATION TO MEXICAN WHEAT PRODUCTION

The production of research information, data and materials does not necessarily mean an increase in food production. Most research scientists fail to comprehend this point. Someone must fit the research data into a meaningful plan to bring them to bear on food production problems, before human needs are met.

There was neither a seed multiplication organization nor an extension service in existence in Mexico when the breakthrough in wheat production was achieved. These two organizations evolved later. The research scientists supervised the multiplication of new varieties on farms, and invariably used all of the newest information on fertilizer and agronomic practices in such operations. By so doing seed multiplication also became a valuable extension tool.

Initially, the farmers, almost without exception, were hostile. They had no confidence in science and scientists. Scientists were considered synonomous with bureaucrats and social parasites. Farmers always insisted that their varieties were better than the new ones, and that the use of fertilizer was uneconomical. Progress from 1948 to 1952 was slow and painful, and often discouraging.

Only 25 people attended the first farmers' field day which we organized at the experimental station in Ciudad Obregon, Sonora, in 1948. There were only five *bona fide* farmers among the group. By 1951, however, the new varieties had won their acceptance. Farmers' attendance at field days had rapidly climbed to 200, then in successive years to 400, 800, 1,000, 2,000, 3,000 and to so many it became impossible to handle them properly. The farmers' acceptance of fertilizer was unnecessarily slow, we now know, because of the lack of demonstration of spectacular yield differences. We were too conservative in these demonstrations. This was something we learned and corrected before launching the production programmes in Pakistan and India.

Through the organization of farmers' meetings prior to each planting season during the 1953, '54 and '55 season, thousands of wheat farmers were contacted directly, and many more by radio, to provide them with the newest recommendations.

By 1954 (Table 1) yields began to increase at an accelerated rate. The dwarf wheat varieties made their first great impact on production in 1964, when the average national yields increased in a single year by 400 kilos per hectare. By 1967 the national average yield had climbed to 2,790 kilos per hectare (42 bushels per acre). Research and scientists had become respectable. Sonora farmers in 1968 are pouring 400,000 dollars of voluntary contributions into supporting CIANO — The North West Regional Research Center. Their financial support is five times that received from State and Federal funds.

Mexico became self-sufficient in wheat production for the first time in 1956, and has remained so since. It has the potential to produce the wheat it needs for the next several decades if aggressive research is maintained.

Twenty-five years ago there were no opportunities for employment in technical agriculture in Mexico. Today there is a big shortage of scientists despite the fact that in the process of achieving self-sufficiency in wheat and maize production several hundred scientists have been trained. Two graduate faculties have recently developed which now offer advanced degree training. Most of the staff of these faculties obtained their early training in the co-operative research programme.

The leadership of the Mexican Wheat Improvement Project was assumed by Dr. IGNACIO NARVAEZ in 1958, at which time I had an opportunity to begin to examine wheat research and production needs in other food deficit areas.

A TRANSPLANT OF AGRICULTURAL SCIENCE AND TECHNOLOGY OF PROFOUND SOCIAL SIGNIFICANCE

One of the greatest obstacles to both agricultural and industrial development in the underdeveloped and emerging countries is the scarcity of trained people. The Rockefeller Foundation has been involved for more than two decades with the training of young agricultural scientists from many different countries. It is a slow process. Where no corps of trained scientists exists, which was the case in Mexico twenty-five years ago and which remains the case in many countries of Asia, Africa and Latin America today, it requires 18 to 25 years to develop an organization of well trained research scientists and educators, with sufficient depth in numbers to meet the countries' needs. The urgency of the food shortage in many underdeveloped and emerging countries is such that there is not time enough to wait to develop such a corps of scientists before attacking food production problems. A short cut must be found.

As late as 1964 I was pessimistic about the ability of the hungry nations of the world to even temporarily solve their food production problems (BORLAUG, 1965). Today I am optimistic about the outlook of food production in the emerging countries for the next two to three decades. We have demonstrated the feasibility of short cuts to increased production, if such attempts are properly organized and executed by skillful and courageous scientists.

Within the past few months we have seen a breakthrough in wheat production in Pakistan and India. A revolution in wheat production is also beginning in Turkey and Afghanistan and there are encouraging signs of the possibilities of a breakthrough in Tunisia and Morocco.

The wheat production revolutions in Pakistan and India are not accidents of nature. They did not just happen, but rather are the result of a five-year struggle, which culminated during the last three years in the development of accelerated wheat production programmes aimed specifically at revolutionizing production in both countries. It involved the transplanting of both the high yielding Mexican wheat varieties and the technology under which they are grown, into Pakistan and India. The success of this transplant is an event of great social significance.

THE REVOLUTION IN WHEAT PRODUCTION IN PAKISTAN

The seeds for change in wheat production goes back to 1961 and 1962 when young Pakistani wheat scientists who had received practical training in Mexico brought back to Pakistan many small samples of the high yielding Mexican dwarf wheats. They also brought back with them the basic knowledge of the fertilizer and cultural practice requirements needed to make the Mexican varieties highly productive. Research was conducted during 1961 and 1962 with these seeds, and in the spring of 1963 I had an opportunity to observe these materials in Pakistan, as well as similar materials growing in Egypt and to a lesser extent in India. It was obvious that they were very well adapted. One hundred kilo lots of seed of two varieties consequently were flown to Pakistan from Mexico in the summer of 1963. The seed was increased for testing on farms during the 1964-65 season. Results were again very encouraging and on the basis of these 350 tons of seed of Lerma Rojo 64 and Penjamo 62 were imported from Mexico. The chronology of the seed importation of Mexican varieties and the area sown to each of these varieties is indicated in Table 2.

TABLE 2. The transplant of high yielding, fertilizer-responsive, semi-dwarf Mexican wheat varieties, together with new technology into the Near and Middle East countries to revolutionize wheat production.

Country	Collaborating Foreign Technical Assistance Agency	Seed Imported from Mexico in Metric tons* (or grams or kilos)	Estimated Acreage Planted to Mexican Varieties with New Technology** During crop years:	
West Pakistan	Ford Foundation via Grant to CIMMYT	1961 Experimental samples (grams) via trainees	——	
		1962 Experimental samples (grams) via trainees	——	
		1963 Experimental samples (200 kilos)	——	
		1964	1964-65	10
		1965 — 350 (tons)	1965-66	11,000
		1966 — 50 (tons)	1966-67 ±	600,000
		1967 — 42,000 (tons)	1967-68 ±	3,000,000
India	Rockefeller Foundation and CIMMYT	1963 Experimental samples (grams) (and 400 kilos)	——	
		1964 ——	1964-65	15
		1965 — 250 (tons)	1965-66 ±	7,000
		1966 — 18,000 (tons)	1966-67 ±	700,000
		1967 ——	1967-68 ±	6,000,000
Turkey	US AID	1964 Experimental samples (grams)	——	
		1965 Experimental samples (kilos)	——	
		1966 — 60 (tons)	1966-67	1,500
		1967 — 22,500 (tons)	1967-68 ±	600,000
Afghanistan	US AID	1966 — 170 (tons) (from Pakistan)	1966-67	3,000
		1967 ——	1967-68	65,000

*During 1966 and 1967 Mexico exported 81,000 tons (3,000,000 bushels) of seed wheat to Near and Middle East countries, including 18,000 tons to India (July 1966); 22,000 tons to Turkey (July 1967), and 42,000 tons to Pakistan (August, 1967).

**The major part of this acreage is heavily fertilized.

It was not only the seed that was imported from Mexico which set the stage for the breakthrough in production, but also the introduction of a whole new technology that made these varieties highly productive under Pakistan conditions. Perhaps 75 to 80 percent of the research done in Mexico on cultural practices and fertilizers was valid in Pakistan. Research undertaken in Pakistan while the imported seed was being multiplied provided the necessary information to cover those gaps where the Mexican data were not valid.

Many years of time were saved by drawing on the Mexican experience. For example, no experimental data were available in Pakistan before 1964 on the performance of dwarf varieties under high levels of fertilization. Results of fertilizer tests conducted with tall strawed Pakistani varieties previously had shown clearly that there was no yield response above an application of 50 kilos of nitrogen per hectare, because of the adverse effects of lodging. Consequently there were no data available on fertilizer responses above 50 kilos of nitrogen. In 1964 a considerable number of exploratory fertilizer experiments were conducted on farms, employing 40, 80 and 120 kilos of nitrogen per hectare (with phosphate), and in these tests the full yield potential of the Mexican varieties became evident. Favourable results in 1964 set the stage for the importation of commercial quantities of seed.

In 1965, the Ford Foundation, via a grant through CIMMYT, provided technical assistance to launch an All Pakistan Accelerated Wheat Research and Production Programme. It visualized making Pakistan self-sufficient in wheat production during the 1970 harvest. Extremely valuable administrative guidance was given to the programme by Mr. HALDORE HANSON of the Ford Foundation during the first two critical years of its existence. Dr. IGNACIO NARVAEZ, of the Mexican Ministry of Agriculture, an outstanding all-round wheat scientist, became the "visiting-quarterback" or joint co-ordinator. He has teamed up with Pakistani co-ordinator, Dr. S. A. QURESHI, and a large number of other Pakistani scientists, too numerous to mention by name, who have made this programme extremely successful.

The harvest just completed is estimated at 7 million metric tons. This compares with a harvest of 4.3 million tons last year, 3.9 million tons in 1966 and the previous highest of 4.6 million tons harvested in 1965, which was a favourable year and similar to the current crop season from a rainfall standpoint.

It is estimated that the dwarf varieties were grown and new technology applied on approximately three million acres, or 20 percent of the total area sown to wheat during the current crop cycle. The area in dwarf varieties and new technology is estimated to have produced about 43 percent of the total harvest. Many farmers harvested yields of five tons per hectare, and a few surpassed seven tons. The national average yield rose from 802 kilos per hectare last year to 1,167 kilos per hectare during the current harvest. These changes are shown graphically in Figure 1.

Pakistan has achieved self-sufficiency in wheat production with this harvest. Moreover, it has the thrust, scientific knowhow and technology to maintain self-sufficiency for the next decade if aggressive leadership and sound fiscal policies are followed. Pakistan achieved self-sufficiency three years after launching its accelerated wheat production programme, whereas it took Mexico thirteen years to achieve this result. Experience gained in Mexico permitted bolder action in Pakistan and many of the pitfalls encountered in Mexico were avoided.

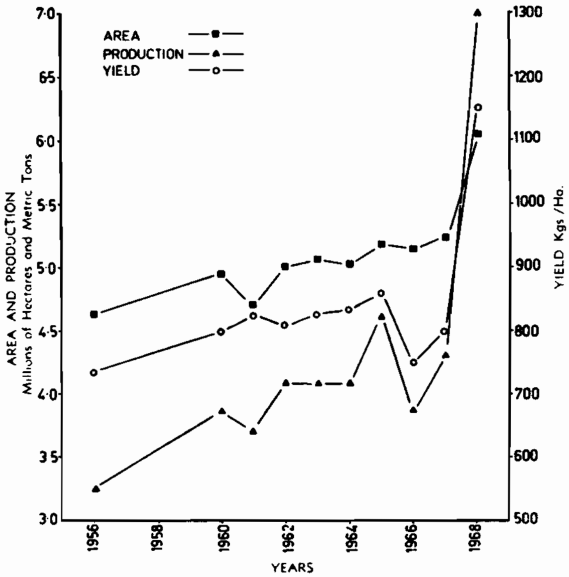

Fig. 1. Cultivated area, production and yield of wheat in West Pakistan.

INDIAN REVOLUTION IN WHEAT PRODUCTION

A revolution in wheat production has also occurred in India during the past crop season. The result came as no surprise to wheat scientists who had been close to these developments, but its progress had escaped the attention of the general public because of the masking effect of two years of devastating droughts (CANNON, 1967).

India's experience with dwarf wheats dates back to 1962 when a considerable number of Mexican dwarf lines were included in the International Spring Wheat Rust Nursery which was grown in New Delhi. Dr. M. S. SWAMINATHAN visualized these lines as possible tools for breaking the yield barrier, that was fixed by lodging at about 3,500 kilos per hectare (53 bushels per acre). I was invited to India in March of 1963 to make a survey of Indian wheat production problems, and to attempt to determine whether Mexican dwarf varieties might be of value in India. The limited observations on dwarf varieties growing in experimental plots at three locations in India, strengthened by the observations made in Pakistan and Egypt while en route back to Mexico, indicated clearly the possibility of revolutionizing wheat production by the aggressive intensive cultivation of dwarf varieties. Consequently, more than 600 lines from the Mexican programme, and 100 kilos each of the four commercial varieties Sonora 63, Sonora 64, Mayo 64 and Lerma Rojo 64 were flown to India in time for the 1963 plantings. The subsequent chronological development of the use of dwarf wheat in India is indicated in Table 2.

The introduction of Mexican dwarf wheats immediately indicated the possibility of a yield breakthrough under conditions of intensive management. The highest yielding Indian varieties, such as C306, produced maximum yields of about 3,500 kilos per hectare with applications of 50 kilos of nitrogen per hectare, but beyond that point showed no further increase in yield with higher rates of fertilization because of lodging. Sonora 64 and Lerma Rojo 64, however, showed progressively higher yields with increasing rates of fertilizer application up to 160 kilos of nitrogen per hectare, when other production factors such as adequate irrigation and improved cultural practices were used. These large differences in varietal response are indicated in Figure 2 (WRIGHT, 1968). With these developments it became possible under intensive management to increase yields by two to two and a half times of that obtained with the best tall-strawed Indian varieties.

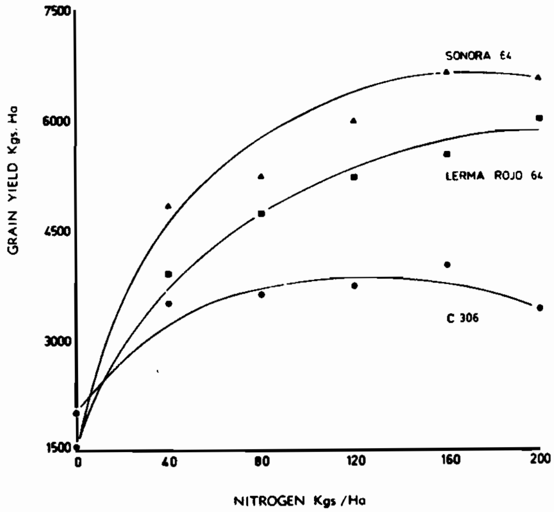

Fig. 2. Differential nitrogen response curves for two Mexican dwarf wheats compared to one of the best tall-strawed Indian varieties C 306, at the Uttar Pradesh Agricultural University, Pantanagar, India, in 1966.
Data by K. C. SHARMA, D. MISRA and B. C. WRIGHT.

From the outset the wheat production campaign in India, as well as in Pakistan, was built around the strategy of demonstrating very large increases in yield. Experience in Mexico had shown that traditional farmers readily accepted practices that resulted in yield increases of 100 to 200 percent but were slow to adopt practices which produced an increase of only 10 to 20 percent. One of the key decisions in both India and Pakistan during 1965 and 1966 was to apply heavy fertilizer dosages, *i.e.* 120-40-0, to all of the areas sown to dwarf Mexican varieties. The object was to produce maximum yields, 5 to 6 tons per hectare or higher, wherever possible, and thereby produce "cultural shock" and provoke the peasant farmer to break with his traditional methods and practices. Time and again we were forced to justify and defend the use of 120 kilos of nitrogen per hectare (where fertilizer is in short supply) on a limited area rather than apply 40 kilos of nitrogen on three times as much area. The economists and politicians originally failed to recognize the importance of the psychological factor in igniting an agricultural revolution. We stood fast by our decision and won. By so doing, the breakthrough in wheat production that has appeared in 1968, was achieved in three years, whereas it would perhaps have required ten years had we initiated the production campaign with recommendations of 40 kilos of nitrogen per hectare. As a result, millions of farmers today have faith in the use of chemical fertilizer and are demanding more. Black markets in fertilizers flourish and politicians tremble. If these demands are not met there will be angry voices from the villages and politicians will fall.

During 1963 and 1964 agronomic research was conducted on experimental stations and farms to determine the proper practices for cultivating the Mexican varieties. In 1964, Dr. R. G. ANDERSON joined the Rockefeller Foundation staff in India and began to assist the Indian Co-ordinator, Dr. S. P. KHOLI, and his many colleagues, with the incorporation of the Mexican dwarf varieties and new technology into the All Indian Wheat Improvement Project. Results were promising during the 1965 harvest and these results culminated in the importation of 250 tons of Sonora 64 and Lerma Rojo 64.

In contrast to Mexico which had no extension service when the wheat revolution took place, both Pakistan and India had large extension service organizations. Both, however, were ineffective and largely non-functional, and their activities were largely those of office work and reports. The wheat research scientists, therefore, assumed the role of demonstrating the proper methods of cultivating these new wheats on hundreds of farms during the 1965-66 crop season. This decisive action and its favourable results provoked enthusiasm among the farmers, research scientists and government officials. Mr. C. V. SUBRAMANIAM, then Minister for Food and Agriculture for India, took bold and aggressive action to import 18,000 tons of seed of Mexican dwarf wheats, even before the harvest was completed. This decisive action set the stage for the revolution in production which is now well advanced.

During the harvest just completed it is estimated that India harvested somewhere between 17 and 19 million tons, contrasted to harvests of 11.5, 10.4 and 12.3 for 1967, 1966 and 1965 respectively. The 1965 crop season, like the present one, was favourable from a moisture (rainfall) standpoint. In 1968 approximately

6 million acres or 18 percent of the total area sown to wheat was grown to high yielding dwarf varieties under intensive management practices. This area probably produced approximately 40 percent of the total harvest. Many farmers harvested five tons per hectare. A few harvested 7 to 8 tons. One farmer harvested a yield of 10 tons per hectare on a small field. The average national yield per hectare increased spectacularly from 889 kilos last year to 1,286 kilos during the current harvest. The changes are shown in graphic form in Figure 3.

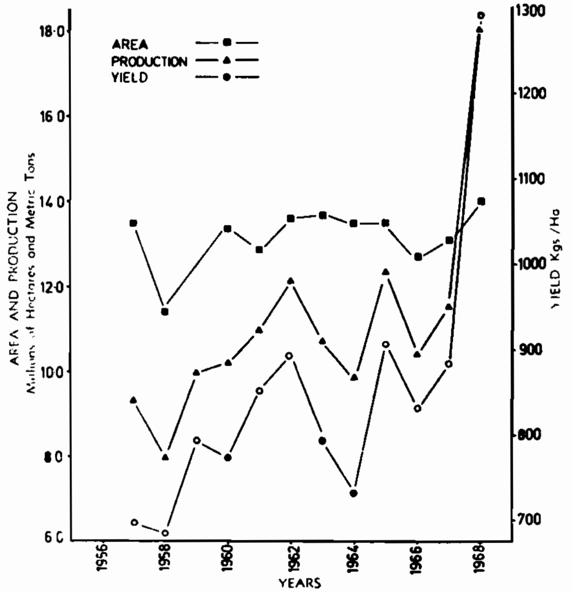

Fig. 3. Total area, production and yield of wheat in India.

India has not yet achieved self-sufficiency in wheat production but it has taken a giant stride toward this objective. Action to extend the new technology to additional areas will be forthcoming. India must now also take aggressive action to develop its vast subterranean water resources, which would then serve as a buffer to maintain production when the monsoon and winter rains fail. Moreover, it must now develop a research programme to increase yield and production on the *barani* (rainfed) areas. If this is done, India can become self-sufficient in wheat production by 1972.

In reflecting on the many difficulties that were overcome to achieve the breakthrough now evident in Pakistan and India, one can only assume that both God and "Lady Luck" have been co-pilots. Even while acknowledging their assistance one must give primary credit to the courageous, skilled "scrambling quarterbacks", that I have mentioned above. The programmes were beset by the following incidents:—

(1) The original seed (1965) destined from Mexico to Pakistan and India only reached ship-side in Los Angeles a few hours before the scheduled departure of the freighter. The truck-convoy from Mexico had become hopelessly entangled in traffic tie-ups in the Los Angeles area, as a result of the Watts' racial riots.

(2) The seed for both countries was at sea on the same freighter when war broke out between Pakistan and India. It arrived late in both countries after trans-shipment.

(3) The seed upon arrival in both countries had poor germination; and

(4) Two consecutive years of the worst drought in recent times were encountered when the new seed and technology was being introduced.

Despite these many frustrating difficulties the aforementioned revolution has been achieved. The breakthrough must now be aggressively exploited to attain sustained production increases.

The breakthrough in wheat production that is now well advanced in Pakistan and India is also advancing rapidly in the spring wheat areas of Turkey. Drs. ORVILLE VOGEL, WARREN KRONSTAD and T. JACKSON have provided the scientific guidance in this country. The spark for change has also been lit in Afghanistan, Tunisia and Morocco.

THE INDIRECT EFFECTS OF THE WHEAT REVOLUTION IN PAKISTAN AND INDIA

The revolution in wheat yields and wheat production has had many indirect or side effects on the governments and economies of both India and Pakistan.

1. *Attitudes*

Enthusiasm has displaced despair in a short period of three years. It has affected farmers, government officials, scientists and even the bureaucrats.

The peasant farmer, who has always been accused of being ultra-conservative and non-receptive to new methods, has shown clearly that this is not true. If he is shown how to make a change in methods, and if this new method produces increased income which more than compensates for increased financial risks, he will rapidly discard his traditional methods.

Government policy makers now realize that the revolution in wheat production is providing additional purchasing power for millions of farmers. It is resulting in increased demands for fertilizer, insecticides, machinery, transport, storage and even "luxury items—such as transistor radios and bicycles" which formerly have been outside the reach of the peasant farmer. The politicians are suddenly becoming aware that their own survival depends upon meeting the demands of the villagers. Members of parliament suddenly begin to appear in large numbers at farmers' field days at the experiment stations. The extension staff suddenly find it has something worthwhile to extend and many are beginning to abandon their "paper piling" activities to teach the farmers the new technology. The research scientists have suddenly realized that they have a great responsibility for transforming their agricultures. They now realize that theory alone will not produce food and are busily reorientating their researches. Change is even beginning to come over the bureaucrats who in the past have confined most of their energies to showing scientists why they could not implement a certain change rather than helping them find a way to implement it. The impatient and angry voices from the villages are now beginning to sift down to provoke changes in the immutable bureaucrat.

The change in attitudes will be a potent force in keeping the agricultural revolution moving forward in both Pakistan and India in the years ahead. This new hope and attitude is contagious and is already spreading to many food-deficit neighbouring countries.

2. *Effect on Other Crops*

The revolution in wheat production which is now well advanced is provoking rapid changes in rice, sorghum, maize and millet production. The lessons learned by a farmer in handling fertilizer, improved cultural practices and improved seed in wheat are readily adapted to the other cereal crops he grows. The research and extension workers can now much more easily and effectively approach the farmer and assist him with the solution of problems, such as insect control, that are of little importance in wheat production but which are primary factors limiting yields in maize, rice and sorghum.

The rate of spread of the new technology to rice is clearly evident in West Pakistan. Last year there were 10,000 acres of the high yielding dwarf rice variety IRRI 8 grown. Yields were spectacular. During the current monsoon season there are more than 1,000,000 acres sown to this variety under intensive management. Last year there were 200,000 acres sown under intensive management to a new synthetic maize variety, this current season 700,000 acres have been sown. These two developments together with the breakthrough which has already resulted in self-sufficiency in wheat, will likely result in Pakistan becoming self-sufficient in all cereals by December of 1968.

Similar developments are under way in India and promise self-sufficiency in all cereals in that country within the foreseeable future if adequate quantities of fertilizers are available, and if a fiscal policy is maintained which will make food production economically rewarding to the farmer.

3. *Multiple Cropping*

The introduction of high yielding, early maturing fertilizer responsive varieties, together with heavy fertilizer applications has greatly increased cropping intensity. India and Pakistan have climates where growing conditions prevail throughout the year. Double cropping with wheat and rice, or with wheat and maize, or wheat and sorghum, is now becoming a general practice wherever irrigation is available. Ingenious farmers are now beginning to fit in a third short season crop, *i.e.* mung beans, between the wheat and rice crop, or potatoes between the maize and wheat crops. A few·even squeeze in four crops per year. The lack of adequate mechanization now is the factor that most limits the production of more than two crops on irrigated land.

4. *Negative Effects on Other Crops*

Not all effects of a breakthrough in productions on cereals is beneficial. In Pakistan the revolution in wheat and rice production is exerting a negative influence on cotton production. Research in cotton has been stagnant. The currently available varieties are low yielding and non-responsive to the use of fertilizers. There is no effective insect control programme, and the insect problem is so complex that the farmer cannot solve it without proper guidance from the scientists. Yields are stagnant. Cotton culture will be driven out by the expansion of areas grown to the high yielding IRRI 8 rice (in a double crop wheat-rice rotation) unless dynamic action is now taken to promote research and improve practices in cotton production.

5. *Storage*

The increase in production of wheat in both Pakistan and India during 1968 has created havoc with storage operations. Both inadequate capacity and unsuitable facilities have added to the confusion in both countries. Markets were glutted throughout the major producing areas at harvest. Large quantities of grain remained exposed to the weather in open markets when the monsoon threatened, because of the inadequacies of the transport for moving the grain rapidly from producing areas to the centres of consumption. Emergency actions were taken in which every available building, including sports stadia and schools (which were on vacation) were temporarily used. This dilemma recalls the long years of struggle in Mexico to provide adequate storage once the crop production revolution got underway. Both India and Pakistan will be confronted with worsening problems of storage as the revolution in production gains momentum in rice, maize, sorghum and millet.

6. *Transport*

The inadequacies of transport—especially railroads—became clearly evident during the wheat harvest in both countries. Shortage of suitable railroad cars and locomotives complicated the wheat transport and storage problems and glutted local markets. It increased the instability of grain prices.

Bottlenecks caused by inadequate transport are also occurring in the distributing of fertilizer. Planners, sometimes for self-protection, conveniently confuse poor distribution of fertilizer and resulting accumulation of stocks in a few areas, with over-estimation of fertilizer requirements. In the near future increased demands for fertilizer will further aggravate the transport problem.

7. *Grain Price Supports*

Within the past two years both the government of Pakistan and India announced floor prices, that were stimulatory and encouraged the farmers to increase production. This, especially in India, was a break with the former policy of keeping the price of grain low so as to make "food cheap for the urbanites", and consequently discouraging the farmer from expanding production.

The announced floor prices were sustained amazingly well in both countries during the current harvest, despite the gluts produced in many markets by inadequate storage and transport. Nevertheless, the price of the red grained Mexican varieties, such as Lerma Rojo 64, Penjamo 62, Sonora 64, PV 18 and Indus 66, invariably sold for from 10 to 20 percent below the price of the white grained indigenous wheats or than the Mexican varieties Kalyan Sona or Mexipak 65. This price difference was a tidy profit that accrued largely to the grain merchants. Although both the Pakistani and Indian farmer nonetheless received good prices for the red grained varieties, he was not pleased to see the market discrimination against red grain. This will result in a rapid increase in the area sown to the new white grained dwarf varieties Mexipak 65, Kalyan Sona, Norteno 66, Safed Lerma and Chhoti Lerma, during the next planting season, as the farmers adjust their production to capitalize on both maximum yield and maximum grain prices. Again this rapid adjustment to economic situations clearly indicates that although many peasant farmers are illiterate they are shrewd "economists".

Pakistan has already reached a critical phase of agricultural development, where fiscal policy will determine the future rhythm of the agricultural revolution. India is fast approaching this stage. Governments who have grown accustomed to the importation of grain under the easy payment soft currency, P.L.480 contracts frequently develop schizophrenia—or split personalities.

The Ministries of Food and Agriculture must act to discontinue the importation of food grains under P.L.480 contracts as soon as grain imports are no longer needed. Unless this is done imported grain will depress the price of domestically produced grain and make the maintenance of floor prices impossible. On the other hand, the Finance Ministries invariably want to continue to import grain under P.L.480 contracts, since, by so doing, they automatically receive large quantities of credits in the local currencies, which can be reinvested in other national development projects. More than one country in Latin America has destroyed the beginning of an agricultural revolution by adopting the policy of cheap food, low prices for grain, coupled with dependence on P.L.480 type of grain imports.

8. *Fertilizer Availability*

The revolution underway in wheat production will require more fertilizer if it is to continue to advance. The spread of the new technology to other crops will further rapidly increase demands. Although both India and Pakistan are attempting to expand domestic production of fertilizers as rapidly as possible, there is no chance of their becoming self-sufficient in fertilizer production within the next eight to ten years. While planners plan and dream of self-sufficiency in fertilizer production the farmers' demand for fertilizer make their plans obsolete before plant construction begins. Meanwhile, vast sums of foreign exchange must be spent on fertilizer importations. It is estimated that 250 million dollars are currently being spent annually by India for fertilizer importations.

The greatest single deterrent to an explosion in fertilizer consumption, now that millions of farmers have become convinced of the benefits of fertilizers, is shortage of credits.

9. *Need for More and Better Machinery*

The revolution in wheat production has created new demands for machinery. The shortage of adequate machinery for both harvesting and threshing is of special concern. Virtually all of the 50 million acres of wheat, and much larger areas of rice, in the two countries are harvested with a sickle and threshed either by treading and winnowing or with primitive threshers. Hand harvesting and the use of treading or primitive threshers was essential as long as wheat straw was an important feed for animals. During the current harvest, for the first time, the peasant farmer and the scientist have discarded the horror of a pending shortage of *bhoosa*, which they feared would result from the introduction of dwarf wheat varieties. *Bhoosa* is the finely chopped wheat straw that is the principal feed for bullocks, buffaloes and cows. The heavy applications of fertilizer to dwarf-strawed varieties resulted in heavy tillering and dense stands with a resulting big increase in straw production over that of the unfertilized tall-strawed varieties. The price of *bhoosa* has crashed and with it has come a change in the farmers' attitude toward threshing equipment. We scientists have been vindicated and are no longer accused of being the enemies of the bullock, buffalo and cow as we were three years ago when dwarf varieties were being introduced. As yields double or triple the primitive harvesting and threshing methods become impossible. Local labour shortages even developed in some areas during the current wheat harvest. Vast numbers of new harvesting machines are now badly needed.

Small tractors are needed in greatly increased numbers by all who wish to intensify their cropping. Triple cropping is impossible with bullock-drawn equipment.

I anticipate that rapid changes in mechanization will sweep across India and Pakistan just as it did in the Bajio region of Mexico 15 years ago, when yields changed spectacularly. The wooden Egyptian plough, bullocks and mules disappeared from the wheat fields of the Bajio in the short period from 1954 to 1961, when yields soared. Change will come faster in Pakistan and India than most planners can visualize.

10. *Increased Demand for More and Better Scientists*

The same change that became evident in Mexico 15 years ago is now beginning to take place in both India and Pakistan. In a stagnant agriculture there are few needs for scientists and consequently few positions available. About the only opportunities for employment are in government service. A breakthrough in production, however, creates many new opportunities. Within the past few months one fertilizer company has screened 300 scientists in Pakistan, and hired 30 of the best qualified. Similar demands are appearing in many industries related to technical agriculture. There is also increasing demand for scientists with better technical preparation. Scientists with competence and motivation are rewarded with salaries in the private sector that are much higher than in the public sector.

These new attitudes usher in a new era and outstanding agricultural scientists will find challenging opportunities in the future.

THE CHALLENGES AHEAD

There are those who insist that the introduction of vast quantities of seed of Mexican varieties into India and Pakistan was scientifically unsound, because of the dangers of losses from rusts. It should be pointed out that all of the tall-strawed Indian or Pakistani varieties are susceptible to one or more prevalent strains of stem and leaf rust. The introduced Mexican varieties covered a wider spectrum of races of both organisms, including the prevalent races in both Pakistan and India. Their disease resistance remains adequate, even though the heavy use of fertilizers is rapidly making the microclimates within the grain fields much more favourable for the development of rust epidemics.

During the first three years that the accelerated wheat research and production programmes were in operation in Pakistan and India, thousands of segregating lines and advanced lines were introduced into the two countries from the diverse Mexican gene pool. These have been intimately incorporated into the two national programmes through selection, and also by crossing into Pakistani and Indian varieties. Twice each year two new transfusions, consisting of hundreds of new F_2 populations, are made from the Mexican gene pool into the Pakistani and Indian programmes.

The Indian and Pakistan wheat breeding programmes are both large, diverse and dynamic. They are both linked directly to the CIMMYT Mexican programme, and through it to the large Argentine breeding programme. This permits the evaluation of the outstanding lines from the Pakistani and Indian programmes for resistance against the genes for pathogenicity that are present in the rust organisms in North American and South American wheat producing areas.

A number of new high yielding dwarf varieties selected or bred in Pakistan and India are now being multiplied to diversify the types of resistance currently available in commercial varieties. Barring complacency on the part of the scientist, which I am confident will not occur, both India and Pakistan have the genetic material with which to protect themselves against rust epidemics.

CONDITIONS NECESSARY FOR THE ESTABLISHMENT OF A SUCCESSFUL FOREIGN TECHNICAL ASSISTANCE PROGRAMME TO ASSIST WITH REVOLUTIONIZING A TRADITIONAL AGRICULTURE

Hundreds of millions of dollars have been spent in the past 15 years by advanced nations in their attempts to help underdeveloped and emerging nations solve their food production problems. Most of this assistance has been extremely ineffective. What have we learned about the processes involved in transforming traditional agriculture from the successful breakthroughs in wheat production in Mexico, India and Pakistan? I will attempt to crystallize my experiences that bear on this problem.

There are certain prerequisite conditions that must exist or be created in order to develop a successful technical assistance programme, aimed at transforming a traditional agriculture. These include the following:

(1) The host country must have political stability. A technical revolution in agricultural production cannot be carried out when there is political and social chaos. Once political revolution and social upheaval has begun there is no opportunity for a technical assistance programme and technological improvement of agriculture, to produce a favourable impact. The destiny of the country is then—for an indeterminate period—in the hands of politicians, demagogues and militarists.

(2) The top level officials and policymakers of the host country government must enthusiastically commit themselves to an aggressive action programme aimed at revolutionizing its agricultural production. The programme must be assured of a minimum of five years' continuous support, and it must be assured of, and be provided with, a modest flexible budget.

(3) The government fiscal policy on prices for agricultural produce and inputs must be such that it will stimulate production.

(4) The government must assure the availability of the new inputs, *i.e.* fertilizers, pesticides, improved seeds, machinery, etc., as needed to modernize the agriculture.

(5) The programme should be initiated around one single food crop. It must be a crop that is important to the economy of the country.

(6) The host government must assign competent well-motivated young scientists to the programme. They will help to implement the programme, and will gain in experience while carrying out these responsibilities. Eventually they will take over full responsibility for the programme.

(7) The host country government must insofar as possible streamline administrative procedures and cut bureaucratic red tape to a minimum. Strangulation of the world by exploding well-camouflaged bureaucracies is one of the great threats to mankind.

(8) The foreign technical assistance organization, for its part, should provide the co-operative programme of the host country with a modest, flexible

supplementary matching budget and with a few (3 to 5) experienced mature foreign scientists.

A large budget, even though it might be millions of dollars, is no substitute for a few top flight scientists. These men should be outstanding in their own speciality, or they will not be accepted by the "establishment". Moreover, they should have vision, interests and experience that transcend individual scientific disciplines, and above all, they should have a crop production orientation. They must be strongly motivated, and have good health and great physical stamina. They must be courageous fighters for change. Such scientists must be able to function effectively in a "strange" or what I call, a "hostile" environment. They must be able to stimulate both young scientists and farmers. They must be "toreros" (bull fighters) who are adept at side-stepping red tape and bureaucracy. Deafness — to criticism — is also a definite attribute. The quality of the key foreign scientists rather than the number is decisive in determining success or failure of a technical assistance programme. Moreover, there must be continuity of key scientific personnel. Two-year assignments are ineffective. They confuse rather than contribute to programme development. The basic philosophy of a technical assistance programme should be to help the host country to help itself.

CHARACTERISTICS OF A TRADITIONAL AGRICULTURE

In a traditional agriculture all crop production factors are at equilibrium at a low level. Yields are stagnant at near starvation levels. Man, plant and pests are struggling for survival. They have been so for decades or even centuries. Under these conditions, until inputs are changed, the peasant farmer is an artist. He extracts a meagre subsistence living from the soil under conditions in which scientists, bureaucrats and politicians would starve.

Under these circumstances a general attitude of despair and defeatism permeates the entire society. The government generally gives up on agriculture in despair and devotes the limited funds that are available for development to some other sector of the economy.

Agricultural scientists are generally very few in number in contrast to the relative abundance of lawyers, even though words, red tape and laws do not feed people. The few scientists that are available isolate themselves in laboratories or on government agricultural experiment stations where they work on theoretical researches of minor significance, rather than trying to come to grips with the enormously difficult task of revolutionizing agricultural production. Much of this narrow approach they brought back home from the graduate schools of developed countries. Consequently there is little new experimental data being developed with which to try to launch a revolution in agricultural production.

In such a society government officials, scientists and bureaucrats openly state that the peasant farmer is ultra-conservative and will not accept new methods. Consequently it is assumed nothing can be done to improve the agriculture, except gradually over a very long period of time. At one time I believed that this was a valid hypothesis, but now I reject it outright. It was from this background that Brown's (1965) concept of "yield take-off" was postulated—which states that a long period of education (high percentage of literacy), accompanied by a gradually increasing per capita income are needed to trigger off a "yield take-off" in a traditional agriculture. I am impatient and do not accept the need for slow change and evolution to improve the agriculture and food production of the emerging countries. I advocate instead a "yield kick-off" or "yield blast-off". There is no time to be lost, considering the magnitude of the world food and population problem. President Mohammed Ayub Khan in his recent book "Friends Not Masters" expresses very clearly my own personal views for needed rapid change in food production, when he stated "I am a man in a hurry. There are so many things to do and there is so little time in which to do them. . . ."

GROUPS OF FACTORS THAT MUST BE MANIPULATED HARMONIOUSLY TO TRANSFORM A TRADITIONAL AGRICULTURE INTO A PRODUCTIVE AGRICULTURE

Three groups of inter-related factors must be manipulated astutely in order to provoke rapid change in a traditional agriculture. These are: (1) the biologic-soil factors, (2) the psychological factors and (3) the economic factors.

If a traditional agriculture is to be transformed dynamically, it is essential to manipulate each of these groups of factors opportunely and properly. Moreover, between each group as well as within each group of factors, it is absolutely necessary to give the proper order of importance to all factors limiting yield and production. This calls for dealing first with the factor that is most limiting production, then subsequently dealing with the second most limiting factor, the third factor in the third slot, the fourth in the fourth position and the tenth in the tenth slot, etc., etc. If the factors limiting production are not given their proper order and weight in manipulation, progress will be stalled and a revolution in production is unattainable. Road blocks and production bottlenecks must be anticipated and avoided or promptly removed, in order to maximize production advancements.

Perhaps because of my early years as an athlete and coach I see a close parallel between the tactics needed to build a winning athletic team, and that needed to build a national wheat production team, with the will, determination and know-how to revolutionize wheat production in an emerging country.

The Biologic-Soil Factors Affecting Crop Production

A traditional agriculture cannot be transformed into a productive agriculture without proper manipulation of the biologic-soil production factors. Revolution in both yield and production must begin here. Proper manipulation of these factors can only be learned through experimentation and research. This is a long, expensive, time-consuming process. Fortunately in two of the three case studies we have been able to transfer with high efficiency and only minor modifications, most of the knowledge and technology developed in Mexico for efficient wheat production, directly to Pakistan and India.

The biologic-soil factors which must be manipulated astutely and harmoniously to provoke this rapid change include: (WRIGHT, 1968)

1. Improvements in variety
2. Improvements in soil fertility
3. Improvements in cultural practices
4. Improvements in irrigation or moisture manipulation practices
5. Improvements in weed control
6. Improvements in disease control
7. Improvements in insect control

I have given in considerable detail a general description of this long gradual process, based upon research, which was necessary to develop the high yielding, fertilizer responsive, light insensitive, dwarf Mexican wheat varieties and the package of technological practices first used in Mexico, and now successfully being used widely in Pakistan and India to revolutionize wheat yields and production.

The Psychologic (Human) Factors—Yield Take-off versus Yield Kick-off

I am convinced that the importance of the psychological factor is almost always overlooked by planners formulating production programmes. To me it is of very great importance.

I reject the currently popular approach of a "yield take-off" as a means of changing a traditional agriculture. The world will disintegrate if we take this long slow academic approach to solving food production problems. I believe instead in approaching this transformation just as an aggressive football coach would approach building a winning combination out of a football team that has not won a game for the last hundred years, and one in which the team throughout its entire history has been playing only a passive, defensive defeatist type of game. I believe that the correct approach to revolutionizing a traditional agriculture calls for a "yield kick-off". It calls for mounting a furiously aggressive attack from the opening whistle, manipulating all production factors, while fully recognizing it will be a fight every step of the way—against superstition, tradition, ignorance and vested interests. It calls for promptly demonstrating yields that are 200 or 400 percent greater than those that have ever been seen before by the peasant farmers. This, if achieved, destroys all of their former beliefs, and with them go the peasants' "conservatism". It generates enthusiasm in the farmer, scientist and government official and an entire new spirit of aggressiveness.

This is in effect throwing the long touchdown pass or "bomb" on the first play from scrimmage. A scientist's plant materials, research data, and technology must be correct and must be formulated into a sound production programme package to achieve this breakthrough. The "scientist-quarterback" must connect on the first long "bomb" for he may never have a second chance if he fails on the first attempt.

The "scientist-quarterback" must call on all his scientific experience and resourcefulness and "scramble" when necessary, just as a veteran battle-scarred quarterback would do when entering to throw the long "pass" from behind a weak line on the first play from scrimmage. The "scientist-quarterback", to be effective, must be a playing and working quarterback, not a consultant or coach. This point is overlooked in many technical assistance programmes.

The term "consultant" too often implies superiority, which is disastrous from the standpoint of building a team spirit. "Substitute scientist-quarterback" or "participant-scientist" implies complete equality in the battle of dust, mud, heat, sweat and frustration. The difference in psychological impact is very great.

I have become convinced from my own experience in many different countries, that the peasant farmer is shrewd and receptive to change whenever changes in technology clearly demonstrate that large increases in yield are possible, provided of course that the new needed inputs are made available and that there is ample margin for reasonable profit. Dr. F. F. Hill, of the Ford Foundation, is often quoted as saying that, "although the peasant farmer may be illiterate, he can figure". This certainly applies world-wide and the peasant is anything but ultraconservative whenever he is provided with a financially worthwhile choice and he has been shown how to achieve the breakthrough.

The development of research information and of the plant materials is but the first step in revolutionizing a traditional agriculture. The second step is the formation of sound recommendations which when implemented will produce a tremendous change in yields. These recommendations should be demonstrated spectacularly on private farms as well as on government experiment stations. The peasant farmers in all countries of the world are suspicious of demonstrations conducted on government farms. When they see experiments and demonstrations conducted on their own property they feel more confident of being able to distinguish between what portion of the increases in yield is due to science and what portion is better attributable to "witchcraft". All demonstrations should be made as spectacular as possible so as to overcome the scepticism and inertia of farmers, planners, government officials and scientists. Yield increases of 15 to 20 percent will convince no-one. Demonstrations showing increases from 200 to 600 percent, *i.e.* from 10 bushels to 75 bushels per acre (700 kilos to + 5000 kilos per hectare) as have been widely demonstrated in Pakistan and India during the past two years, have caught the peasant's imagination, built a fire or set a bomb under the politician and have triggered off an agricultural revolution of fantastic potential.

The revolution in food production in India and Pakistan is also establishing mutual confidence and trust between peasant and scientist, where little or none generally existed previously. It is transforming the scientists, providing them with experience, confidence, pride and new hope. This is particularly true among the younger scientists. In the past, more often than the farmer, it has been the scientist who has been ultra-conservative. Scientists who should function as catalysts for provoking change have often functioned instead, presumably because of his relatively favoured position in the society, as a brake on progress. I am sure this is too often a universal phenomenon. This may be a luxury that can be temporarily tolerated when it occurs in an affluent society such as that of the U.S.A. where it appears to be occurring with increasing frequency. The situation is deplorable and ruinous, however, when it occurs in emerging societies, where I have often observed it. The effects are disastrous. Is this one of the negative scientific heritages that the affluent societies have passed on to emerging nations via their graduate schools and technical assistance programmes?

Economic Factors

The profit motive must be exploited in order to transform a traditional agriculture into an evolving dynamic agriculture. If rapid change is to be fostered, government fiscal policy must be such that the adoption of new methods and inputs are profitable to the farmer. The farmer must be assured of a stimulatory price for his grain. Prices must be stabilized to prevent unreasonable seasonal fluctuations.

Dr. THEODORE W. SCHULTZ (1965, 1966) has clearly indicated that unwise financial policies assumed to assure cheap food for the urban consumer have discouraged agricultural production in Chile and Colombia. Peru can be added to this list. I am convinced that unwise fiscal policy by recipient governments receiving PL.480 grains has retarded agricultural development in at least four Latin American republics, and perhaps in many other countries elsewhere, instead of fostering development as was one of the original aims of PL.480 legislation.

Six years ago it was stated that there was no yield response from the use of chemical fertilizers on wheat and maize in Argentina. Research conducted during the past six years has disproven this hypothesis. Yield responses are frequently large. Nevertheless, the use of fertilizer is stagnant because of an unfavourable economic situation. The Argentine farmer receives a low price for his wheat and must pay a high price for fertilizer. The price ratio of nitrogen (from ammonia) to wheat grain is 9·3 to 1 in Argentina contrasted to 2·8 to 1, 2·6 to 1 and 2·4 to 1 in Mexico, Canada and the U.S.A. respectively, or compared to 2·6 to 1 and 2·7 to 1 (from urea) in India and Pakistan. Is there any wonder why the Argentine farmer does not fertilize when he has to sell 9·3 kilos of grain to pay for 1 kilo of nitrogen?

During the past three years fiscal policies toward agriculture have been favourable in both India and Pakistan. They are currently stimulatory. Although unwise fiscal policy can prevent the evolution of a traditional agriculture, an enlightened stimulatory financial policy alone can only contribute moderately to increasing crop yields. Aggressive manipulation of both the psychologic and economic factors alone will only lead to frustration and yield increases of 10 to 20 percent. Proper manipulation of the biologic-soil factors are therefore absolutely necessary before a breakthrough can be attained in a stagnant traditional agriculture, regardless of the skill of manipulation of the economic and psychologic factors.

WORLD FOOD SUPPLIES, POPULATION PRESSURE AND THE ROLE OF THE SCIENTIST

The successful transplant of the dwarf Mexican wheats and intensive management practices into Asia, combined with increasing evidence that a revolution in rice and maize production is on the immediate horizon, convinces me that the world will not be stricken by widespread famine in 1975 (PADDOCK, 1967; PADDOCK and PADDOCK, 1967). Nor do I believe that this will happen in 1985, nor in the year 2000. Instead it would not be surprising to see the rice-producing countries of south-east Asia, fifteen years from now, struggling with temporary problems of overproduction of rice and falling prices, just as has happened with wheat prices in the western world during the past two decades. Such dramatic developments in crop production of course assume peace and political stability in the area.

The average yield of cereal crops will be on the up-swing in many parts of the world during the next fifteen to twenty-five years. New areas will be opened to cultivation in the tropics. Deserts will be reclaimed for agriculture with irrigation water provided in some cases by desalting ocean water. Further improvements in yield of cereal grains will be forthcoming. Better amino acid balance—better nutritional quality (*i.e* high lysine)—in high yielding maize varieties is on the threshold of commercial production. Improvements in the protein quantity and quality of other cereal grains is sure to follow. New varieties of cotton with low levels of gossipol content will be developed. "Synthetic" foods of several types will undoubtedly be added to our food production potential before the turn of the century (SCRIMSHAW, 1965; 1966).

Nevertheless, I do not wish to understate the seriousness of the food production problem that faces mankind in the future (MAYER, 1964; NOTESTEIN, 1965). If complacency is banished, however, and if dynamic world-wide agricultural education, research, extension and production programmes are expanded and maintained I am confident that the aforementioned developments collectively will forestall disastrous famines for the next quarter century. Nevertheless, Reverend THOMAS MALTHUS' prediction made in 1798—that man would reproduce himself into a condition of "misery and vice" because of the growing imbalance caused by the multiplication of his own numbers by geometric progression, while his food supply was increasing arithmetically—is as valid today as when it was made. He was a visionary and saw clearly the monster of overpopulation. The only error in his prediction was one of a "few seconds on the clock of human occupancy of the earth". We, agriculturists, can buy at most a few decades of time in which to bring population growth into successful balance with food production. MALTHUS, however, may have underestimated the importance of other factors essential to continued human progress. Although I am convinced that an adequate food supply is of prime importance to man—for without it one can survive for no more than a few days at most—yet it may not be the most important problem that will confront mankind during the next quarter century.

Population Growth and Human Progress or Retrogression

Homo sapiens has apparently been busily engaged at reproducing himself as rapidly as biologically possible since shortly after Adam and Eve first inhabited the earth. The mandate given to Eve to "be fruitful and multiply" was absolutely necessary at that time. Indeed in all probability Eve and her early female descendants must have, by necessity, reproduced at their full biotic potential in order to assure the survival of the species. Undoubtedly, early man's inability to modify the hostile environment, must have more than once pushed him to the brink of extinction, because of shortages of food, inadequate shelter and the ravages of disease. A few thousand years before Christ, populations must have exploded as man temporarily gained control of his food supply through the domestication of plants and animals. He soon began to find remedies for certain illnesses. It was not, however, until about 120 years ago when he discovered the basis of modern medicine, that death rates dropped sharply and the population explosion really took off. MALTHUS had the vision to anticipate some of its horrible consequences.

A glance at the past indicates the urgency of reducing population growth (BROWN, 1963; HOAGLAND, 1964; NOTESTEIN, 1965; REVELLE, 1966). It took from the time of Adam and Eve—take your choice of a period of from several hundred thousand to several million years—for their living descendants to reach a population of 1 billion, which was attained in 1850. It doubled to 2 billion by 1930, in a period of only 80 years, and now it stands at near 3½ billion. Currently world population is increasing at about 2 percent annually, which means it will double in 35 years. The developing countries, however, are under greater pressure from the population explosion than the developed countries. Several African and Latin American nations, including Mexico, are growing at rates of 3·6 percent or more per year. This means their populations will double in 18 years (NOTESTEIN, 1965). Mexico with a population of 44 million, will have a population of 88 million by 1987.

Mexico is relatively fortunate in that it will be able to expand its agriculture to meet the food requirements, whereas many other nations may not be able to do so. But is the question of food and mere survival a goal for the future? Shouldn't life hold something better for both the present and future generations? It is doubtful that food availability alone will govern the destiny of the world's next few generations (CALHOUN, 1962; MAYER, 1964).

There is a growing unrest among the people in the underdeveloped nations of the world. They want and deserve something better than survival. Rapidly increasing numbers aspire to the benefits of a biologically enjoyable life. The same aspirations are present among the underprivileged groups in the affluent societies. It is the moral obligation of governments around the world to improve the standard of living of their citizens. Nevertheless, this is no simple task. The problem is more than population and food. Simultaneously, governments, societies and individuals must attack the octagon problem of population growth, food, health, education, employment opportunities, housing, communications and recreation.

Vast areas of the world are already overpopulated. Billions live at a very low standard of living and all too often merely exist (SCRIMSHAW, 1965). Their governments, like the people, are so economically weak that they are unable to invest sufficient capital to improve the standard of living. The situation grows progressively worse. Political instability intensifies. Wars break out and spread.

There are vast areas of the world where agricultural lands have been fragmented and splintered into non-economic units by agrarian land reforms. Many of these units are now so small that they can never provide a decent standard of living for any family. I know this from personal experience for I am the product of a 50 acre farm in an area where only one crop was possible each year. Such small farms are the bane to all agriculturists who are struggling to increase food production. Nonetheless, politicians and demagogues in many areas of the world recommend further fragmentation, instead of facing up to the real issue—overpopulation.

During the past decade family planning programmes of considerable magnitude have been launched in many countries to attempt to slow population growth and bring it into balance with the ability of the country to provide a better standard of living for all. Twenty countries have either adopted official policies aimed at reducing population growth, or have initiated large family planning programmes supported by public funds. It is still too early to be able to measure the effectiveness of most of these programmes.

Nevertheless, the adoption of these programmes indicates a rapidly growing awareness of the seriousness of the population problem. It represents a break with tradition. There are, however, still vast areas of the world and vast segments of most societies that continue to lift from context and live by the commandment "be fruitful and multiply". The Encyclical from Rome last week, immeasurably set back prospects of rapid social, economic and educational improvement for many countries, especially Latin America.

Nothing is more tragic than to see countries that have been spending 20 percent or more of their entire budget for the past two decades to expand education, losing the battle against illiteracy because of exploding populations. The U.S.A. is having problems keeping up with expanded demands for facilities for education. Imagine then the plight of many of the underdeveloped and developing countries where from 50 to 80 percent of the population is illiterate.

The number of new positions or jobs is not developing as fast as human numbers in many countries of the world. Unemployment grows worse, especially among the youth. Energies unspent in constructive work are all too often dissipated in destructive disorders. Social disorders are not unique to underdeveloped or emerging countries, but also today constitute one of the major problems of the large cities of the U.S.A. Sociologists, psychologists, lawyers, judges and politicians frequently attribute these disorders to racial conflicts, and lack of opportunities for the low income segment of society. With guilty consciences the enforcement of laws is relaxed in the name of the rights of the individual, with the hope that restlessness will subside. All too often it has flared into violent riots. As a biologist, I feel that there are also other basic causes for the unrest and disorders.

There is a growing body of evidence obtained from controlled experiments with laboratory animals, especially rats, which indicates that certain individuals in any population cannot withstand the adverse effects of crowding and stress. Such individuals exhibit abnormal behaviour patterns. These abnormalities are related to imbalances of the endocrine system provoked by stress. As the numbers of abnormals increase they adversely affect the social order of the whole colony and may lead to its disintegration (CALHOUN, 1962; HOAGLAND, 1964; MAYER, 1964).

Man is a biological entity and within any given population no two individuals are genetically identical (identical twins excluded). The vast majority are rather similar in phenotype, including general behaviour patterns. But there is a small percentage that deviates greatly from the norm in many respects, including behaviour. The boundary line between social order ("democracy") and degenerative disorder ("anarchy") in an over-crowded experimental animal cage and in some of the overpopulated slums of the large cities may have more in common biologically than any of our social scientists and politicians recognize or are willing to currently admit.

Admittedly, government and society should do all they can to remove the festering slums of the cities. However, it is becoming more and more clear that sociologists, psychologists, lawyers, judges and politicians should also begin to study something about the genetic basis of variability in biologic populations. They must recognize the differential variation in behaviour of individuals under stress, and they must take this into consideration in dealing with disorders in the streets. More fundamentally they should begin to focus on the underlying problems causing these disorders, namely the cities', nation's or world's inability or unwillingness to cope with the many facets of the basic population problem.

Scientists in Our Present Civilization

We are all aware from history and archaeology of the disappearance of one civilization after another. We know that in some of the theocracies of recent times, as the privileged caste—the clergy—lost contact with the masses their civilizations disintegrated. Time after time military dictatorships also have lost contact with the masses and their government and sometimes the entire civilization has perished.

Ours is the first civilization based on science and technology. Through the development and contributions of science and technology the present standard of living of much of the world has reached undreamed of heights. In order to assure continued progress we scientists must not lose contact with the needs of the masses of our own society nor of that of other societies of the world. Our own survival is at stake. We must recognize and meet the changing needs and demands of our fellow men. To do so we must strive for the proper balance between fundamental and applied research, and we must try our best to assist in training young scientists, from the many developing countries who study in our universities, in such a way that their training will be useful to them when they return to their homeland. Moreover, our technical assistance programmes to the developing countries should be organized so that they will be relevant to the needs of the host country. All too often the approach is much too sophisticated.

I have seen the consequences of oversophisticated approaches reflected in the research and education programmes in many developing countries. Sometimes the irrelevant research being done and the expensive gadgets and equipment that one sees standing unused is the result of ideas brought back by students—who had taken advanced degrees in foreign universities. At other times it is the result of foreign consultants or scientists from one of the advanced countries promoting impractical irrelevant research projects to unsuspecting government policy makers and with it the need for sophisticated equipment. I would like to take a few moments to indicate some of the consequences of such folly.

Twenty years ago electron microscopes appeared in underdeveloped countries, where they were not relevant to the type of research that was needed to modernize these agricultures. They mostly collected dust or were used in noble research projects best described as "the chasing of academic butterflies".

Fifteen years ago gamma reactors and X-ray equipment to promote mutation genetics and mutation breeding programmes made their appearance. This approach, with the notable exception of India where there is excellent leadership in this field, has produced little or nothing of value. Even today in several of these countries, it is much easier to obtain 500,000 dollars for this type of research than it is to obtain 5,000 dollars for supporting a summer wheat breeding nursery, even though the latter is vital to the wheat research and production effort of the country.

We are now in the era of electronic computers. These too, are making their appearance in the underdeveloped countries. Bad data are being fed into the latest models and these monsters are frequently giving the wrong answers to questions of vital importance. For example they are currently underestimating the needed fertilizer plant production capacity for Pakistan. What is obviously needed to correct this and similar situations is for some talented engineer to design a newer, more sophisticated model. The new model should have a "gadget" in its belly (or brain) containing a compound as vile-smelling as the stomach of the camel, and it should be automatically governed so that it would regurgitate in the face of the operator, programmer and scientist whenever it is fed bad data.

One often wonders how the hungry billions of the world interpret the sophisticated multibillion dollar race by the two strongest nations of the world, to land a few men on the moon. The hungry masses probably hope that these efforts will be successful, and that they will soon establish effective agricultural colonies to produce rice, wheat, maize and sorghum which can be shipped back to alleviate the suffering of the hungry overpopulated earth.

I also have my reservations over the highly specialized narrowness and lack of communication that has been creeping into our science during the past two decades. Dr. THOR HEYERDAHL in his book AKU-AKU expresses this misgiving beautifully: "In order to penetrate even farther into their subjects the host of specialists narrow their fields and dig down deeper and deeper till they can't see each other from hole to hole. But the treasures that their toil brings to light they place on the ground above. A different kind of specialist should be sitting there, the one still missing. He would not go down any hole, but would stay on top and piece all the facts together." To this thought I add: "He might even help decide where some of the digging should be done."

In closing I would like to leave this final proposal for someone who wishes to delve into fundamental research. I suggest that you direct your efforts to save our civilization through the establishment of an irradiation genetics and breeding programme designed to develop a new race of *Homo sapiens*. This new improved race of man should have the enzyme cellulase in his gut which will thereby permit him to eat, digest and grow fat on the mountains of paper and red tape which are being produced in ever increasing quantities by the world's planners, bureaucrats and the press. Moreover, let this mutant gene for cellulase production be tightly linked to the following three additional genes that are essential for the improvement of the human species: 1. a gene for compassion for his fellowman, which seems never to have existed in the wild (normal) type; 2. a gene which will provide massive doses of common sense, since the original gene for this character has been badly eroded and lost its effectiveness in the wild type, as the number and complexities of gadgets have multiplied; and 3. a gene that will assure a low level of human reproduction, again this seems to be a gene that has never existed in the wild type, for history shows that man has repeatedly bred himself into misery and famine.

Should it be impossible to identify a potent gene for a low biotic potential then we cereal breeders had better discontinue our efforts to incorporate improved nutritional quality, *i.e.* better amino acid balance, into cereals and turn our attention instead to locating and incorporating into wheat, rice, maize, sorghums and millets, a potent gene for estrogen production, which would thereby produce the same effect as the "pill" in a more acceptable form.

This project, I would imagine, would be classified as fundamental research of profound significance and would undoubtedly be funded by any one of several grant agencies.

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