THE DEVELOPMENT OF HIGH YIELDING BROADLY ADAPTED MEXICAN WHEAT VARIETIES AND THEIR EFFECT ON WORLD WHEAT PRODUCTION

From the outset in 1944 the Mexican Wheat Improvement Program, sponsored jointly by the Government of Mexico and The Rockefeller Foundation, was organized to develop high-yielding varieties with good resistance to diseases and which would be efficient in use of both irrigation water and fertilizer.

In order to shorten the time required to produce a new variety, against the advice of the experts, our program pioneered extensively in the growing of two generations of all breeding material each year. One generation was grown during the winter, the commercial wheat crop season, near Ciudad Obregon, Sonora, at about 28°N. latitude on the coastal plain only a few feet above sea level. Near Toluca a second generation was obtained by planting during mid-May at 8,500 feet and 18°N. latitude. The Toluca site is characterized by heavy rainfall throughout the growing season and cool temperatures. Consequently severe epidemics of both stem and stripe rust develop at this site every year.

The process used in the Mexican program of moving segregating populations over 10 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 (Borlaug, 1968).

During the past 7 years CIMMYT has organized and coordinated The International Spring Wheat Yield Nursery which is currently grown by collaborators at more than 80 locations in the world. The varieties included in this nursery include representatives of all of the principal spring wheat producing areas of the world. During the past 7 years the Mexican varieties have exhibited uniquely broad adaptation as measured by high grain yield in many different countries of the world. Although they were bred for use under irrigation with heavy fertilization, some have shown outstanding performance under both fertilized and non-fertilized, irrigated and non-irrigated conditions.

During the past 3 years, the Mexican dwarf wheat varieties have been the principal catalyst involved in triggering off the green revolution in Pakistan, India and Turkey (Borlaug, in press; Borlaug *et al.*, 1969). They are now opening the breach to higher yield plateaus in a number of other countries. It is the unusual breadth of adaptation, combined with high genetic grain yield potential, dwarfness, a strong responsiveness to fertilizers, and a broad spectrum of disease resistance that has made the Mexican dwarf varieties so valuable to world agriculture. This revolution in wheat production was not based, however, on the panacea of the Mexican dwarf seed alone. It involved the transplant from Mexico to Pakistan and India of a whole new production technology that makes these varieties highly productive. Perhaps 75 to 80% of the research done in Mexico in developing the package of cultural practices, including fertilizer recommendations, was valid in Pakistan and India. Adaptive research done in Pakistan, India, and Turkey while the imported seed was being multiplied provided the necessary information to cover those gaps where the Mexican data were not valid.

The impact of the high-yielding, fertilizer responsive, light-insensitive, dwarf Mexican varieties on yield and production of wheat in Mexico, Pakistan and India is shown graphically in Figures 1, 2, 3, and 4. The Mexican varieties have made Pakistan self-sufficient in wheat production and have helped India take a giant step in this direction. It is estimated that they have increased the combined gross national product (GNP) of the two countries by 1.5 billion dollars during the past two harvests, compared to the 1965 base which was a previous all-time record crop (Borlaug, *et al.*, 1969).

Amazingly although the Mexican dwarfs were bred and developed for irrigated areas, they also are proving to be highly effective under rainfed areas in many parts. Approximately 20% of the barani (rainfed) area sown to wheat in Pakistan is in Mexican dwarfs. Virtually all of the Afghanistan area sown to Mexican dwarfs and more than 80% of the Turkish area is rainfed. Next year about 20% of the entire area sown to wheat in Tunisia, virtually all of it rainfed, will be in Mexican dwarfs.

During the 1968-69 crop season, Mexican wheat varieties were grown on more than 20 million acres in foreign countries. This is more than 10 times the entire area sown to wheat in Mexico, the country for which they were bred. *Little did I realize, when we initiated the breeding program 25 years ago to assist Mexico to become self-sufficient in wheat production, that it would subsequently have a "world-wide" impact. Your forest tree breeding projects too will evolve into programs with world-wide impacts if you concentrate your efforts on valuable forest species, develop and maintain very diversified gene pools, and develop an international system of cooperative testing.*

THE MONSTER GROWS

The seriousness and magnitude of the world food problem must not be underestimated. The recent, much-publicized successes of the green revolution in increasing wheat, rice, and maize production in Asian countires only offers the possibilities of buying 20 to 30 years of time in which to bring population growth into balance with food production.

Plant breeders who look ahead must not be satisfied with maintaining the current yield plateau for our major food crop plants. Complacency can bring disaster.

The unrelentless pressure of exploding world population, with no relief in sight, should urge all of us to struggle to increase the potential yield levels of all food crops if we are to help ward off widespread world famine within the next 50 years.

I believe there is entirely too much conservatism in virtually all plant breeding programs. One of the first lessons which we learn in genetics is that maximum levels of heterosis and yield are generally obtained from crossing genetically distinct parents. This principle we promptly ignore in our breeding programs, with few exceptions. Most programs involve crossing closely related varieties or parents. Frequently this error is compounded by long backcrossing to the commercial parent. There is very little possibility of significantly increasing the grain yield potential in new varieties developed with these types of approach.

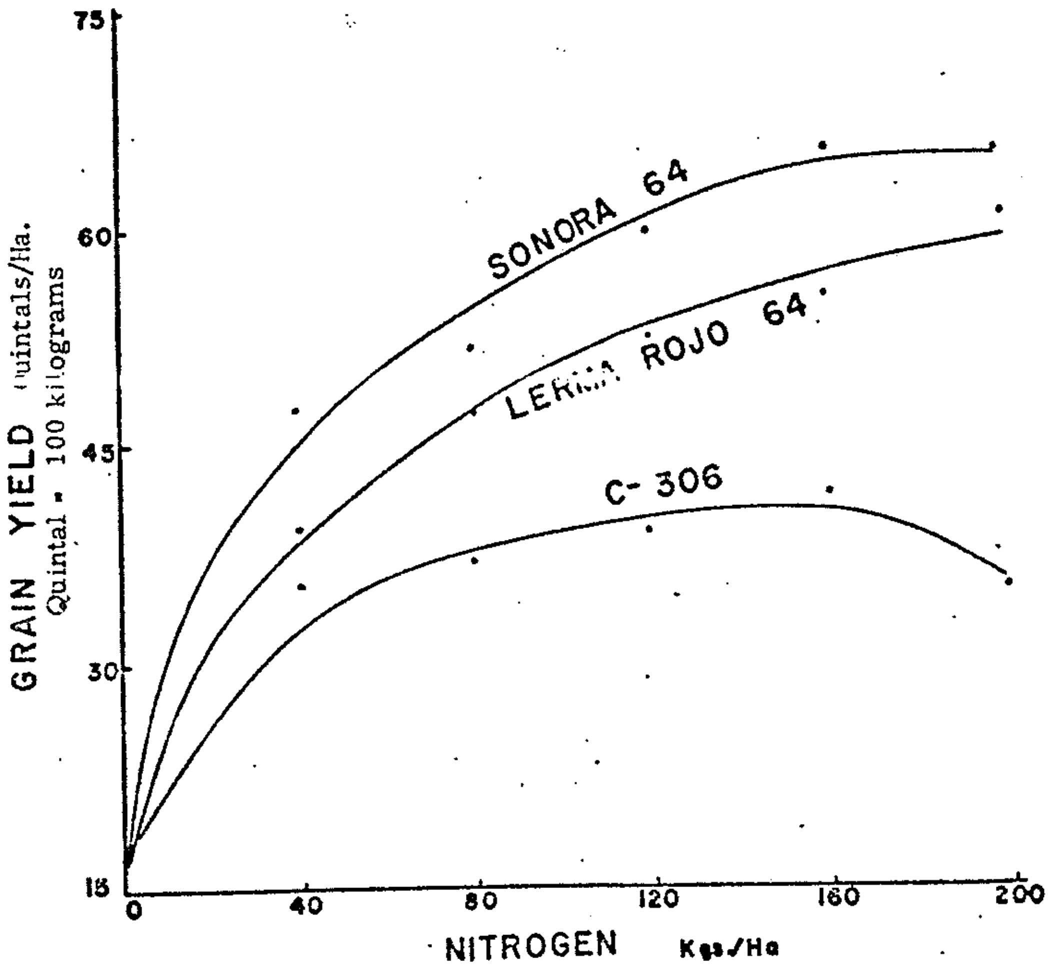

Figure 1. Differential nitrogen response curves for two Mexican dwarf wheat varieties compared to one of the best tall-strawed Indian varieties C 306, at the Uttar Pradesh Agricultural University, Pantanagar, U.P., India in 1966. Data by Drs. K. C. Sharma, D. Misra and B. C. Wright.

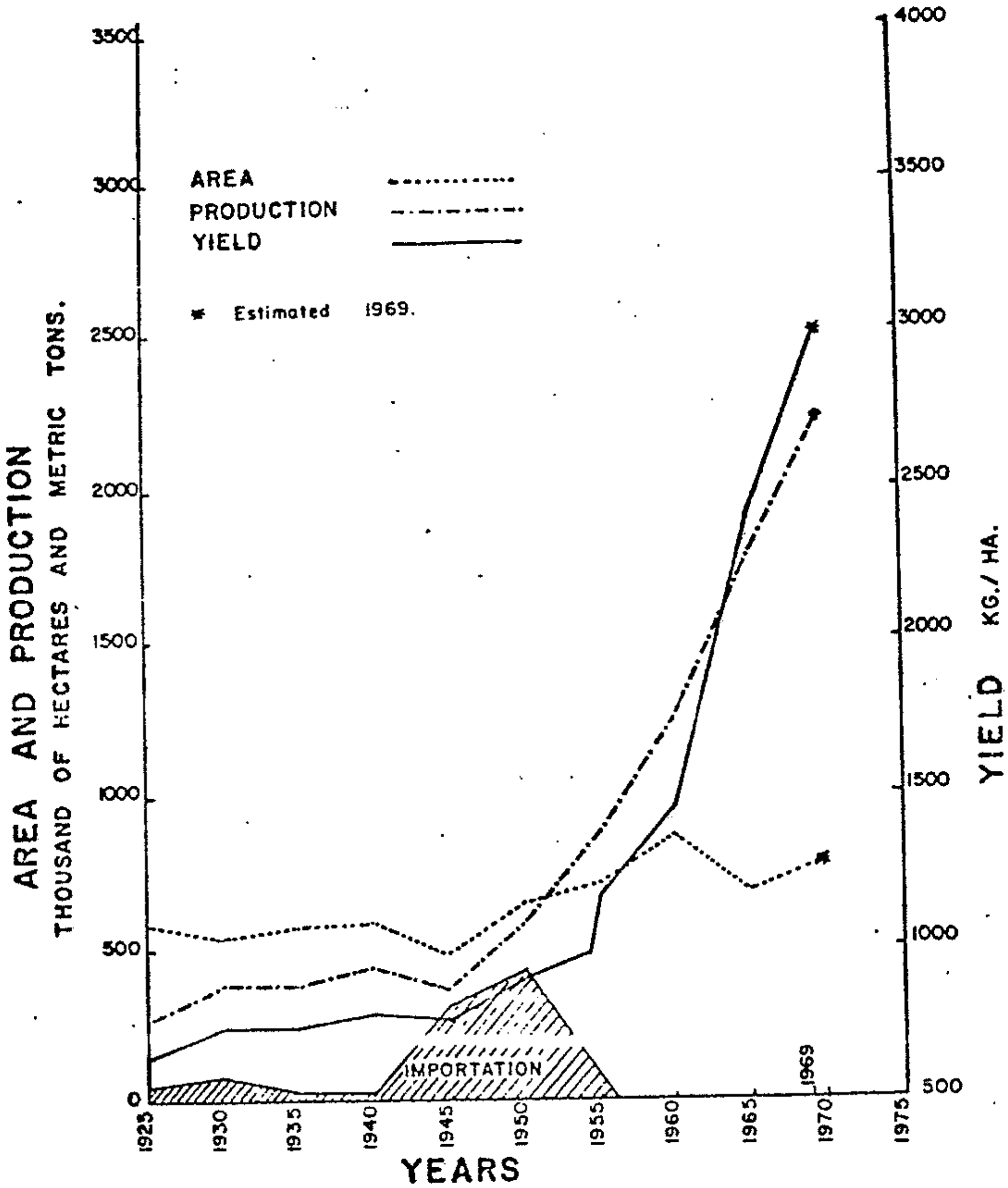

Figure 2. Cultivated area, production and yield of wheat in Mexico.

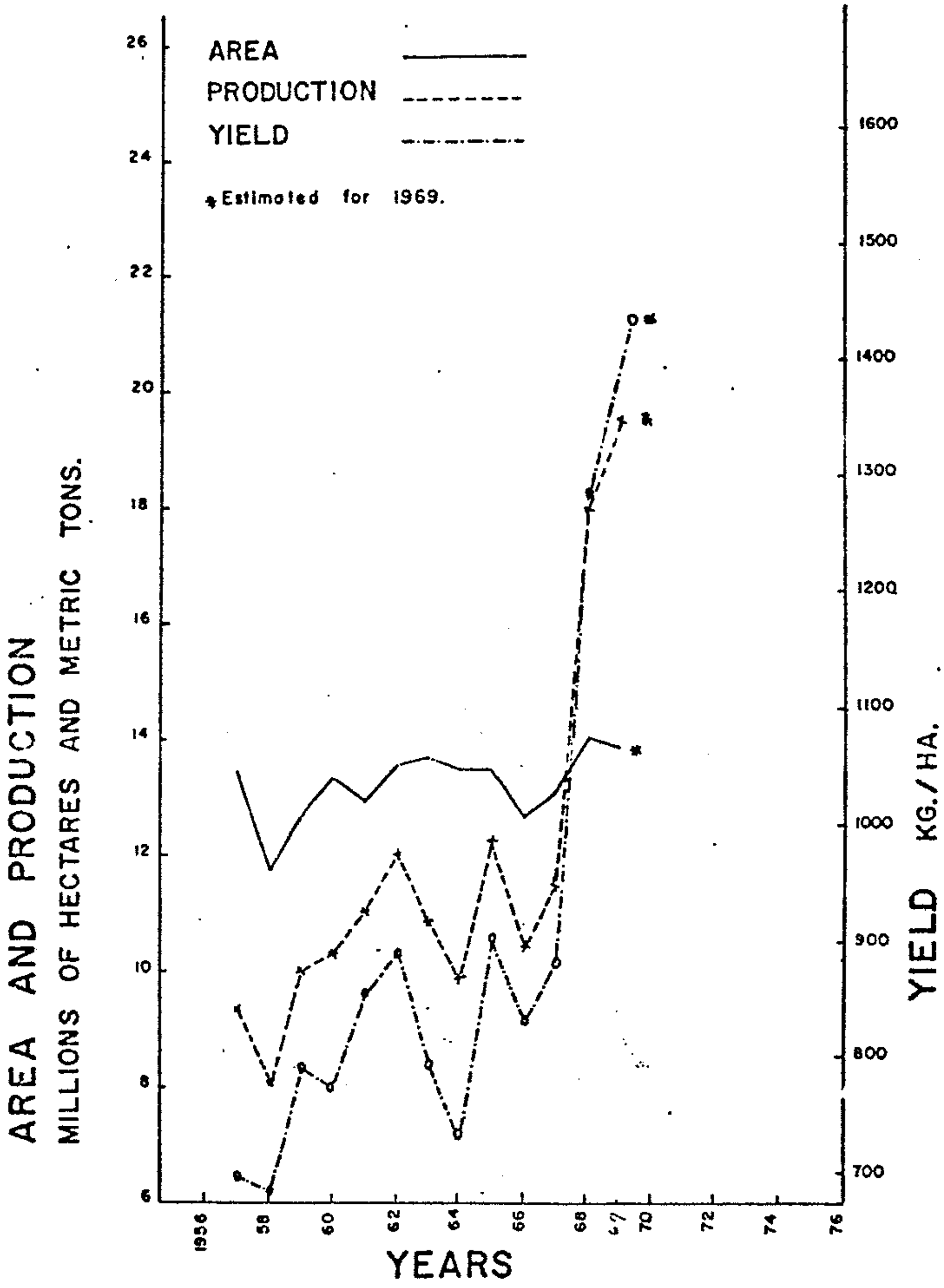

Figure 3. Total area; production and yield of wheat in India.

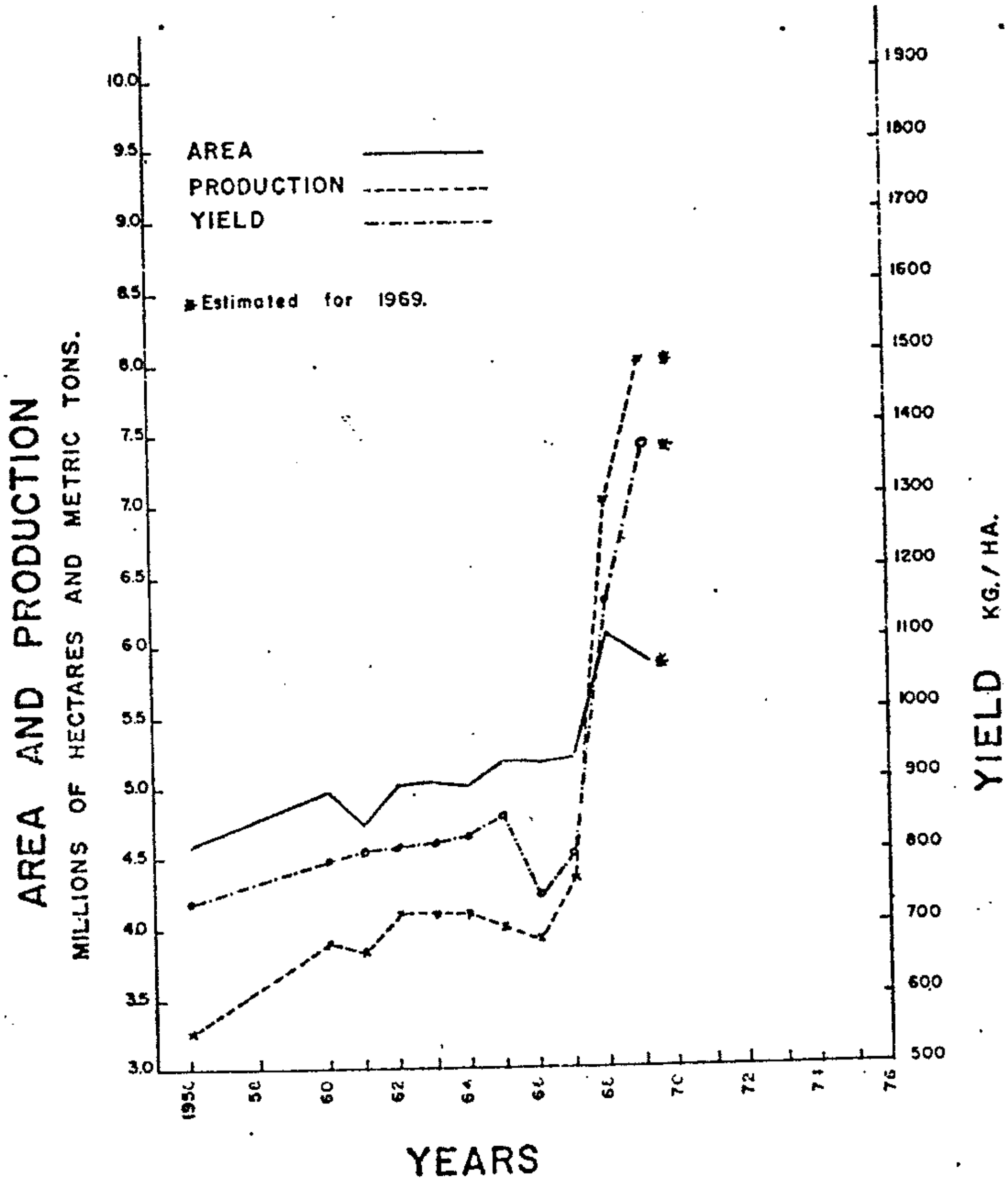

Figure 4. Cultivated area, production and yield of wheat in West Pakistan.

Rather we should be visionary and imaginative in our plant breeding programs if we hope to stay ahead of demands for food, feed, wood, and fiber. To accomplish this we must use every new approach that seems feasible, not only to improve the current crop species but also to create entirely new crop or tree species through the use of wide crosses. To illustrate my point, I would like to briefly outline our experiences on Triticale breeding during the past 4 years.

TRITICALE. THE FIRST MAN-MADE SPECIES THAT SHOWS PROMISE OF BECOMING A MAJOR CEREAL CROP

Triticales are amphiploid derivatives of a cross between wheat and rye. When such a cross is made, the hybrid seed produced gives rise to a completely sterile plant. If, however, the seedling arising from the hybrid F_1 seed is suitably treated with colchicine, the chromosomes of both the wheat and rye components of the hybrid seedling are doubled. This results in a seedling which develops into a partially fertile plant that produces seed.

Triticales have been known since 1888. However, until about 40 years ago, they were mostly academic curiosities. During the past three decades several scientists, especially Muntzing in Sweden and Sanchez-Monge in Spain, have devoted most of their professional careers to the improvement of this artificial species. In 1964 CIMMYT in collaboration with the University of Manitoba began a breeding program designed to develop Triticale varieties that would be competitive with wheat, barley, rye, and oats.

Until about 1-1/2 years ago the development of Triticales had been stymied by two main obstacles, partial sterility and shrivelled grain. In April 1967, Drs. Frank J. Zillinsky and George Varughese of our staff discovered 7 F_3 plants that were highly fertile. These subsequently have been reselected and resown 5 times under 4 widely different climatic conditions. They have remained highly fertile in all plantings. We also have crossed the fertile types to sterile and partially sterile types and have found that the first generation progeny are fertile, thus indicating that this character is heritable. During the past year we have isolated some types that have far better grain types than those that were previously available. In our program we have also developed dwarf early-maturing, daylength-insensitive lines and some types which are highly resistant to diseases. At the present time we are combining these various desirable characters, through further crossing. I am now completely convinced that Triticale varieties will be developed within the next 8 years that will be competitive, yield-wise, with the best wheat, oats, and barley varieties.

On the basis of the breakthrough in overcoming sterility, combined with very considerable improvement in grain plumpness, we have now greatly expanded our Triticale breeding program. The progress reported above has been achieved in the hexaploid Triticale types, those derived from crossing *Triticum durum* Desf. wheat with rye. We are making many new Triticales at this ploidy level involving many different durum wheat varieties and different rye varieties. We are also now making many new octaploid Triticales, derived from crossing bread wheat varieties (*T. vulgare* Vill.) with rye. We visualize developing Triticales both as a food and a feed grain. Preliminary research indicates that it should be possible to develop varieties with high levels of both lysine and total protein, which would enhance their value nutritionally (Borlaug, in press).

We in CIMMYT are now convinced that Triticale - a man-made cereal species - is on the verge of becoming a commercial crop that will compete successfully with other small grains. How soon this happens will depend largely upon the amount of research effort that is devoted to further improving this species. CIMMYT is distributing its best lines to all research organizations who are interested in working with this new crop.

WHAT ARE THE POSSIBILITIES OF DEVELOPING OTHER MAN-MADE CROPS OR TREE SPECIES?

The rapid progress now being made in the improvement of Triticales naturally stimulates one to consider the feasibility of making other wide crosses, either for the improvement of parent crop plants or for the creation of entirely new ones.

Within the past decade, as has been indicated by Dr. Ernst Schreiner, tremendous progress has been made in the basic sciences that bear on the feasibility of such undertakings. It is now possible to grow haploid plants of rice, barley, and wheat from anthers, when the proper media are employed (Nichell and Torrey, 1969). Embryo culture techniques have improved greatly. Tissue culture techniques, involving the use of hormones and many new, more efficient nutrient media, have produced spectacular results. It is now possible to isolate apparently undamaged individual protoplasts of wheat, carrot, tomato, soybeans, and other species by the use of the enzymes pectinase and cellulase. In some cases when cellulase has been removed from the system, the protoplasts have been able to resynthesize the cell wall. Fusions also have been obtained between two protoplasts within a species.

These events definitely open the door to the possibilities of using protoplasmic fusion and cell hybridization as a future tool in plant breeding. It is now possible, employing proper techniques, to begin with a single somatic tissue cell of many different plants, i.e., carrot, tobacco, endive, parsely, rice, and sugarcane, and regenerate the entire plant, including the production of seed. Hybrid seed and seedlings have been obtained from wide crosses by using Giberellic acid to facilitate the consummation of fertilization, followed by embryo culture. Using such techniques, Kruse has reported obtaining hybrid seedlings of *Hordeum* x *Secale* and more recently, tentatively, between *Avena* x *Triticum* (personal communication). To date, however, there has been no report of his having formed the amphidiploid of these hybrids.

Although I am fascinated by the eventual feasibility of using cell hybridization for plant improvement, I nevertheless feel that there are other avenues that are more immediately feasible. In light of our recent success in progress with Triticale improvement, and Dr. A. Kruse's preliminary report on successful hybridization of barley x rye, and oats x wheat, and the reported but unproven occurrences of natural hybrid seedlings of maize and sorghum, it now appears the time has come to launch an aggressive program in crop plant improvement based on wide crosses. I propose that such a program be undertaken to improve both cereals and legumes. It should include attempting to make as many crosses between different genera of cereals as possible, employing all of the most modern techniques to consummate fertilization, to cultivate the embryoes, and to form the amphidiploids. If a series of amphidiploids of diverse genetic backgrounds can be produced, this will open the door to vast further improvement through conventional breeding approaches. I feel that the time has come to undertake a major attempt to improve our crop plants or to create entirely new ones through this type of approach. I believe that one or more of the International Research Institutes can be an effective catalyst in exploring the feasibility of such an approach to plant breeding.

I personally want to live to see what happens when the amphidiploid is produced between wheat and rice. Since rice is the only small grain cereal that does not have its corresponding rust or rusts (*Puccinia* spp.), will it confer its immunity to the wheat x rice amphidiploid? Or will man by such scientific folly open a Pandora's box and form a bridging species which would open the floodgates to invasion of rice by the wheat disease parasites and vice-versa? Were this to happen, we would have set the stage for the "Death of Grass" as envisioned by novelist John Christopher.

In the face of the continuing, relentless pressure of population growth, I believe it is absolutely necessary for plant and tree breeders to use more and more imagination and aggressiveness to produce higher yielding plants, and thereby hold the line on the food and fiber production front. By so doing, agriculturists and foresters can buy an additional 2 or 3 decades in the hope that by then *Homo sapiens* will wake up to the pending cataclysm of continued, uncontrolled population growth. Social, biological (human) Utopia is a goal we should strive to achieve, but as biologists (and especially as geneticists) we know that at best it can be only a working hypothesis. We must channel, guide and cultivate our idealism wisely if we are to improve the living standards of the world's masses, and if we are to survive as a species. Unbridled idealism and emotionalism, unguided by reason and common sense, can unfortunately also lead us into oblivion.

To the ecologists and environmentalists, who are feverishly working to prevent further deterioration of our environment and who are now finally being heard and getting a "big play" in television, radio and the press, I say, beware of conveying an oversimplified, distorted picture of achieving a rapid and permanent solution to this problem, for you are dealing with only one isolated aspect of the larger, complex population problem. To the millions of idealistic students who are actively, and vociferously, concerned with changing governments and building a better world where peace will reign and where the rights of all individuals will be given complete expression, I say, beware of being misled into believing that any kind of government - capitalistic, socialistic, communistic, anarchistic or military dictatorship - can provide such a Utopia while essentially ignoring the underlying, monstrous, and evergrowing human population problem. We only need to reflect on the degenerative social behavior of rats in overpopulated cages; or on the periodic suicidal migrations of the Arctic lemming, which springs from response to overcrowding and is led by the younger members of the population, to know that we must face up to the population growth problems if we are to survive. The time is late!

Although I have built the last part of this presentation around a plea for more creative breeding in food crops, I also now challenge all forest geneticists and tree breeders "to think big --- think and act Paul Bunyan!"

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