AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

1. SUBJECT CLASSIFICATION	A. PRIMARY	Agriculture
	B. SECONDARY	Cereal Crops

2. TITLE AND SUBTITLE

The development of hybrid corn technology in the U.S. and selected countries

3. AUTHOR(S)

Sprague, G.F.

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1975	89 p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Office of Agriculture, Technical Assistance Bureau,
Agency for International Development, Washington, D.C. 20523

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

(In Technical series bulletin No. 16) Free copies available from Ilene Coleman, TA/PPU/EUI, Room NS-2669, Agency for International Development, Washington, DC 20523.

9. ABSTRACT

A presentation of the background and recent developments of the new high-yielding, more nutritive corn types and an explanation of their significance to malnourished populations of countries deficient in food. This new high lysine (an amino acid) corn out-yields native corn types and has more than doubled the nutritive value of ordinary corn with protein quality essentially equal to that of skim milk. Worldwide development and acceptance have been relatively rapid. Unlike ordinary corn, these new types are not deficient in two essential amino acids -- lysine and trytophan. Shortages of these amino acids in the diet of humans (and other monogastric animals) cause serious protein-deficiency diseases, and utilization of the new high-lysine corn types can be a major means of combating this form of malnutrition.

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAB-702	

12. DESCRIPTORS		13. PROJECT NUMBER
Hybridization Maize Product development USA	Varieties	14. CONTRACT NUMBER AID/TA/AGR 15. TYPE OF DOCUMENT

AID 590-1 (4-74)

AGRICULTURE TECHNOLOGY
FOR
DEVELOPING COUNTRIES

Technical Series Bulletin No. 16

The Development of Hybrid Corn Technology in the United States and Selected Countries

March 1975

Office of Agriculture
TECHNICAL ASSISTANCE BUREAU
AGENCY FOR INTERNATIONAL DEVELOPMENT
Washington, D.C. 20523

The Development of Hybrid Corn Technology in the United States and Selected Countries

by G.F. Sprague, Consultant

March 1975

Office of Agriculture
TECHNICAL ASSISTANCE BUREAU
AGENCY FOR INTERNATIONAL DEVELOPMENT

ACKNOWLEDGMENTS

For the background information and data provided, grateful acknowledgments are extended to the staffs of the following organizations: CIMMYT, INIA and PRONASE in Mexico; CIAT, ICA and Caja Agraria in Colombia; Agroceres, Cargill, Instituto Agronomico (Campinas) and Sal Paulo University (Piricacaba) in Brazil; Maize Research Station at Kitale in Kenya; Agricultural Research Institute, National Seed Corporation (Delhi), Uttar Pradesh Agricultural University and the Terai Development Corporation (Pantanagar) in India; IACP in Thailand; the University of the Philippines at Los Banos; and to AID's Division of Crop Production of the Office of Agriculture for its special efforts in making this publication possible.

Acknowledgment is further extended to Linda Pokorny, Agronomy Department, University of Illinois, and to Catherine M. Glass and Mary Felder, Office of Agriculture, Technical Assistance Bureau, for their contribution in typing the manuscript.

FOREWORD

This publication is one of a series being issued by the Office of Agriculture, Technical Assistance Bureau of the U.S. Agency for International Development (TA/AGR/AID) on subjects of primary importance to developing countries. This issue presents the background and recent developments of the new high-yielding more nutritive corn types and explains their significance in food-short countries among malnourished populations. This new high lysine corn out-yields native corn types and has more than double the nutritive value of ordinary corn with protein quality essentially equal to that of skim milk. Worldwide development and acceptance have been relatively rapid. Unlike ordinary corn, these new types are not deficient in two essential amino acids--lysine and trytophan. Shortages of these amino acids in the diet of humans (and other monogastric animals) cause serious protein-deficiency diseases. Infants and pregnant and nursing mothers are particularly vulnerable to lysine deficiency and the young may be prevented from attaining normal physical or mental development. The utilization of the new high-lysine types can be a major means of combating this form of malnutrition.

In view of the importance of corn in helping solve the world food problem, the Agency for International Development (AID) is publishing this bulletin to provide policymakers, specialists, technicians, and students with the history of hybrid corn development in the United States and the adoption of related technology in selected countries. AID commissioned Dr. George Frederick Sprague to write this bulletin because of his unique qualifications. Dr. Sprague has spent his entire professional career in corn research and development. From 1958 until his retirement from the U.S. Department of Agriculture in 1972, he was in charge of the national and international corn research programs. In this capacity he remained in close contact with major corn breeding programs around the world, including the highly successful African Major Cereals Project which is sponsored by AID. Many awards and honors have come his way in recognition of his valuable contributions to corn improvement.

Additional copies may be obtained from TA/AGR, through the USAID Mission, or through the Regional Offices of AID. Requests for more detailed information should be directed to this office.

Leon F. Hesser
Acting Director
Office of Agriculture
Technical Assistance Bureau
Agency for International Development
Washington, D. C. 20523

TABLE OF CONTENTS

TABLES

ILLUSTRATIONS

THE DEVELOPMENT OF HYBRID CORN TECHNOLOGY IN THE UNITED STATES AND SELECTED COUNTRIES

INTRODUCTION

The origin of corn (*Zea mays* L.) has long been a subject of speculation and controversy, but current evidence places it in the Americas, probably in Mexico. Corn belongs to the tribe Maydeae, and eight different genera have been recognized by the taxonomists. Three of these are found in the Americas and the remaining five are Asiatic in distribution.

The three American genera, *Zea*, *Euchlaena* and *Tripsicum*, are much more closely related to each other than to any of the Asiatic genera. Corn's closest relative is *Euchlaena* (teosinte) with which it crosses freely, and the hybrids are normally completely fertile. Evidence now available appears quite convincing that corn was derived from *Euchlaena* through the accumulation of a small number of mutations, possibly no more than seven or eight. Some taxonomists have even classified *Euchlaena* as a species of *Zea*.

Regardless of the adequacy of the current interpretation of the origin of corn, it is well established that corn was widely distributed throughout both North and South America prior to the time of the first visit by Columbus. It was grown as far north as the latitude of New England and as far south as Argentina. The types of corn grown within this area differed widely in maturity, plant and ear characteristics, and kernel color and texture. Such a distribution and diversity suggest that the crop was not of recent origin, and this postulation is amply supported by carbon dating of archeological findings and by pollen studies. Comparable evidence for the presence of corn in other areas of the world at comparable times in history is completely lacking.

The type of corn characterizing U. S. agriculture, dent corn, was unknown at the time of Columbus. Dent corns were derived from crossing two quite distinct types - - the New England flints and the Southern Gourdseed. Various types of corn moved northward from Mexico, probably at differing times. One of these groups was the type now known as New England flints. These were widely grown in the area when the Pilgrims landed, and the role they played in the survival of these early settlers is well known to every school child. It is the remains of this type of corn which are found in excavations of the mound builder and basketmaker cultures of the Eastern United States.

The corn type known as gourdseed was of later introduction but the timing is somewhat uncertain. The northward and eastward movement, however, was into areas where the New England flint types were already in use. As we know these two types today, they would possess some degree of genetic isolation arising from differences in times of flowering. Isolation was not complete, however, and some natural crossing must have occurred during this migration period. Colonists in Virginia in the early 1700s recognized the two types, designated "he" and "she" corn, and that both extremes could be found in many fields. This mixing continued, both naturally and by design, and a new type was stabilized from such crossings which we now know as dent corn.

UNITED STATES

Varietal Development

Improvement of corn started with the beginnings of domestication. Credit for the diversity of types and maturities developed must be assigned to the Indian planter as a plant breeder. Corn played an important role in his religious ceremonies and great care was taken to maintain the identity of types having special significance. The early American settler continued selection to stabilize the new dent type. Dent corn was carried westward by the migrating settlers. These original dent strains were further modified by selection to fit maturity requirements of the new ecological zones into which they were introduced. Continued selection in such new environments was rapidly effective in modifying maturity and plant type, but there is little evidence to suggest that productivity was materially improved.

Prior to about 1900 corn improvement (varietal development) was largely in the hands of interested farmers rather than public institutions. Such important varieties as Reid, Leaming, St. Charles and Boone County Whites, to name only a few, were developed by farmers, each of whom had very specific ideas as to what the ideal plant or variety should look like. Some of these varieties became very widely disseminated, usually because of winnings at corn shows, and were subsequently further modified by selection in the hands of corn enthusiasts.

A score card for judging corn was prepared by Orange Judd for the Illinois State Fair of 1891. This score card emphasized regularity of kernel rows, cylindrical ears and the shape of kernels and degree of indentation. This score card was widely adopted and corn shows became the vogue. Winning at state and national shows created a demand for the winning varieties or strains involved and played an important role in the wide distribution of such varieties as Reid and Leaming.

The score card ideal had a marked influence on a whole generation of farmers. Seed was purchased or varieties retained on the basis of appearance of a selected sample rather than on field performance. Gradually it came to be appreciated that the attributes stressed on the score card were not closely associated, if at all, with field performance.

Mass selection, as this system of breeding was designated, was judged to be relatively ineffective. It is now known that this judgment was in error, but the question was not reexamined until the 1950s. In the meantime there was an increasing emphasis on relative differences in field performance among varieties. Differences in yielding ability were substantial and the higher yielding varieties were used extensively when interest later turned to inbreeding and hybridization.

When the public institutions began to play more than a minor role in corn improvement -- about 1900 -- two new concepts were advanced and extensive studies initiated. The first of these was varietal hybridization. Beal, working at the Michigan Experiment Station, initiated an extensive series of experiments comparing varieties and their F_1 hybrids. This work expanded to other states and was vigorously pursued until about 1910. The results of a large number of such varietal hybrid studies were summarized by Richey (1922). Approximately 80 percent of the hybrids involved in these studies exceeded the average yield of the parents and 56 percent yielded more than the better parent. Where substantial increases in yield were obtained, the two parents differed in maturity or plant type and, more commonly, in kernel texture. Flint or flour x dent combinations were common in the hybrids exhibiting substantial amounts of heterosis or hybrid vigor. Data reported by Hays and Olsen (1919) illustrate this rather general relationship (Table 1).

Even the best of the varietal hybrids never achieved any extensive use. Two factors were probably involved: (1) The F_1 hybrids did not conform to the then current standards of appearance and were therefore unattractive to many farmers, and (2) there was no commercial mechanism for the production of hybrid seed on a continuing basis. Possibly the concept of the commercial use of hybrid vigor was ahead of its time. A number of the F_1 varietal hybrids gave increases in yields as great as double-cross hybrids introduced so successfully and extensively at a later date.

A second important development was the introduction of the ear-to-row system of breeding by Hopkins at the Illinois Station in 1896. These initial studies were directed toward increasing or decreasing the oil and protein content of the corn kernel. As the name implies the method involves choosing a group of ears on the basis of some specific criteria and growing these in individual ear-row progenies,

Table 1. Comparison of yield of parental varieties and their F_1 hybrids with Minnesota 13, a dent variety.

Pistillate parent	Yield of pistillate parent as a percentage of Minnesota 13 (staminate parent)	Yield of hybrid as a percentage of the higher yielding parent
Flour		
Blue Soft	96.7	132.5
Flints		
Smutnose	110.8	116.8
King Phillip	110.0	119.9
Longfellow (NK)	100.5	119.1
Longfellow (Bwls)	104.9	109.2
Mercer	91.8	97.3
Dents		
Northwestern	105.9	109.8
Chowen	99.0	114.9
Rustler	112.1	100.3
Minn. 23	96.7	110.9
Silver King	100.9	105.8
Murdock	80.3	101.6

normally in an isolated field. Selection is practiced within and among progenies and ears saved from the most desirable individuals for a repetition of the same selection process the ensuing generation.

Progress was rapid for changes in both oil and protein percentage. As a result of this success, comparable ear-to-row tests involving other attributes were initiated at Illinois and a number of other experiment stations. Selection experiments involving high and low ear placement and for high and low leaf area appeared to be as successful as earlier studies on chemical composition. Selection experiments involving yield, however, presented a quite different picture Such studies appeared to show promise for one or two cycles, followed by either no progress or an actual decrease in yield. It was rapidly concluded that the ear-to-row system was ineffective in modifying yield and further selections for yield were discontinued. A logical explanation for these differences in relative effectiveness did not become available until major developments had been made in both quantitative genetics and in experimental design.

The Illinois Selecton Experiment for high and low oil and high and low protein has been continued to the present time -- over 70 years, (Dudley, et al., 1972). The results achieved are illustrated in Figure 1. Progress at a fairly uniform rate has continued throughout this period indicating the persistence of genetic variability. The presence of substantial amounts of genetic variability is further indicated by the effectiveness of reserve and switch-back selection initiated in the late 1940s and the middle 1950s. These experiments are now classic; they represent the longest term, controlled selection experiments with any plant material.

The failure of varietal hybridization to gain acceptance and the general disenchantment with ear-to-row selection for yield appeared to leave little hope for any further real improvement in corn yields. Fortunately, during this early period Shull (1908, 1909) had presented evidence on the effects of inbreeding and hybridization in corn. In the 1908 paper he demonstrated that when corn was inbred there was a rapid reduction in vigor but that when certain inbred lines were crossed, F_1 yields were equal or superior to the original variety. He concluded: "(1) that in an ordinary field of corn the individuals are very complex hybrids, (2) that the deterioration which takes place as a result of self-fertilization is due to the gradual reduction of the strain to a homozygous condition, and (3) that the object of the corn breeder should not be to find the best pure lines, but to find and maintain the best hybrid combination." In his second paper Shull (1909) presented a general outline of methods which served as a general model for corn breeding for many years. Following the reports by Shull, several stations initiated programs on the development of inbred lines. Several of these were rather short lived, the general impression being that the inbred lines were so lacking in vigor and yielding ability as to make the production of hybrid seed economically unfeasible. This situation was changed with the report by Jones (1918) of the performance of double-crosses.

Many extensive breeding programs were initiated in the early 1920s. Lacking both experience and research data as a guide, it was generally assumed that any inbred line which could be maintained was potentially useful. Therefore selection during the inbreeding process was minimal. As experience accumulated it was recognized that a line had potential commercial value only if it possessed sufficient vigor and yielding ability as a line to minimize large-scale production problems. It came to be recognized that inbreeding served only one primary function: to develop a reasonably true-breeding type which could readily be maintained and which could then be evaluated in hybrid combinations. The average yield of a large number of inbred lines in single-cross combinations will be essentially equal to the yield of the variety from which the lines were derived. Only a very small percentage of lines, when combined as hybrids, will produce yields significantly greater than the parent variety. The major problem, therefore, became one of evaluating the combining ability of large numbers of lines, rather than the development of inbred lines.

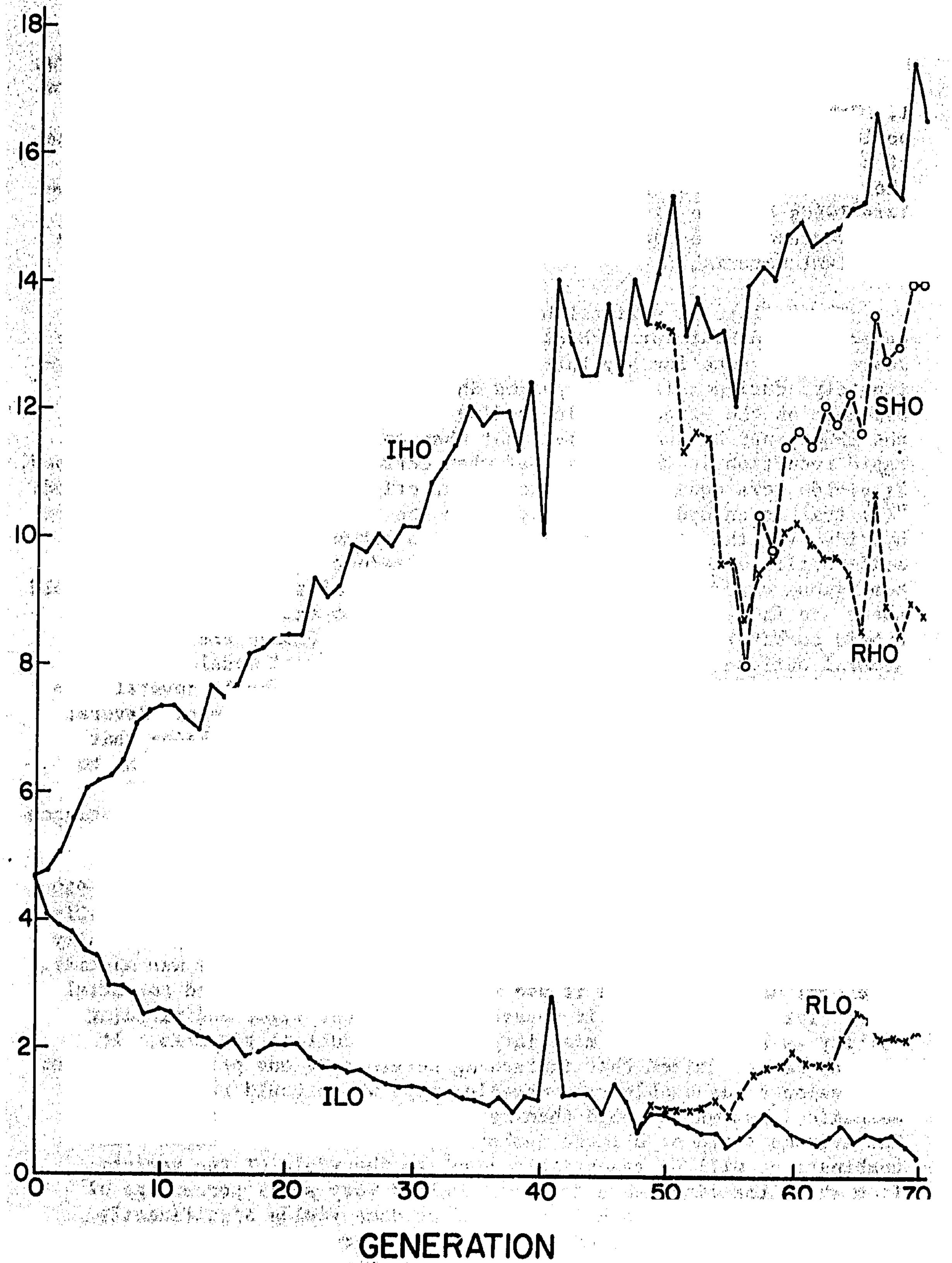

Figure 1. The effects of continuous selection in the Illinois High and Low Oil and High and Low Protein strains.

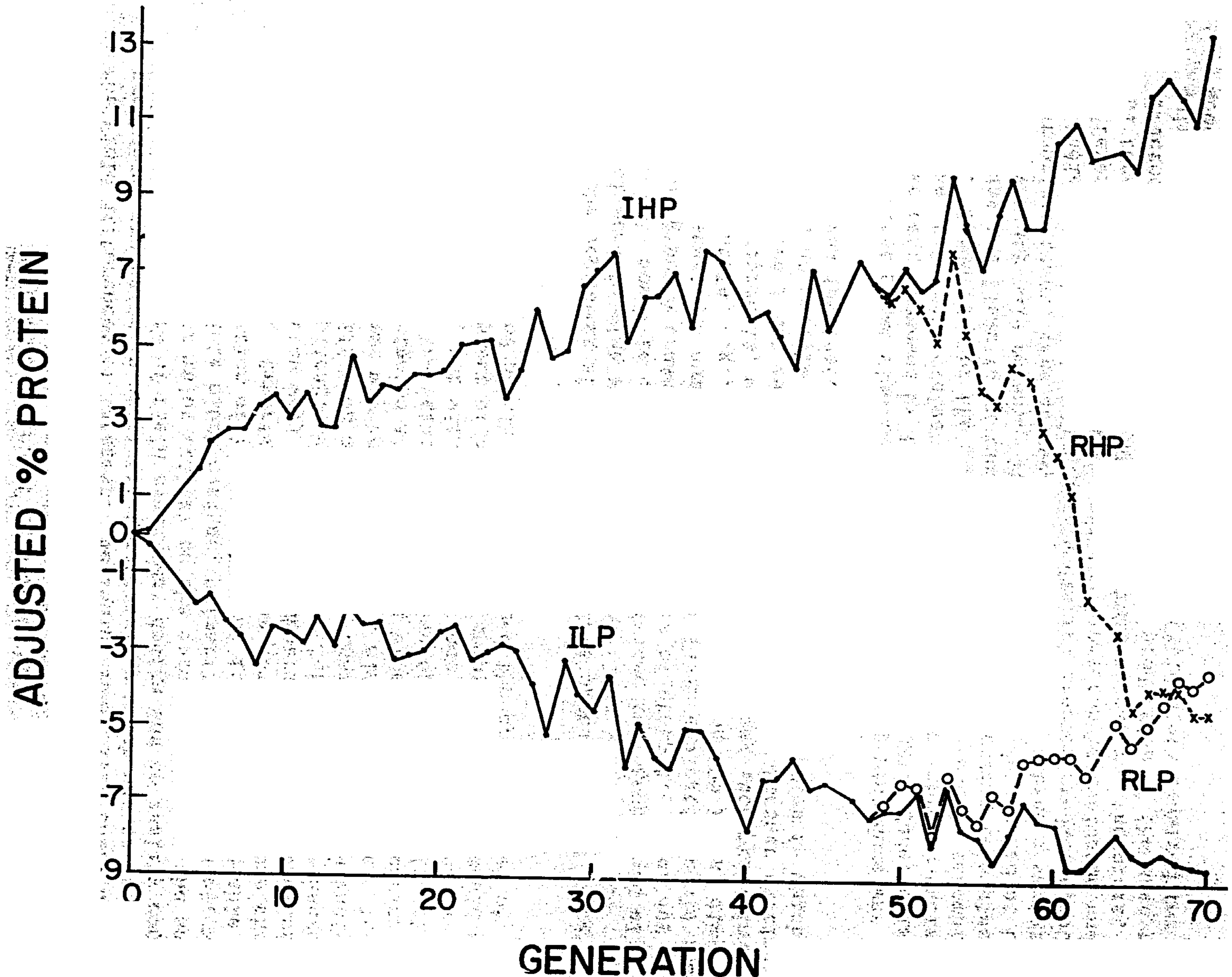

Figure 1b. The effects of continuous selection in the Illinois High and Low Oil and High and Low Protein strains.

Agriculturalists have long used field experiments to evaluate differences in yielding ability among varieties or the response to cultural or fertilizer practices. Much of this early work was done with but little appreciation of the universality of soil variability and the need for randomization and replication to obtain valid estimates of the yield differences of interest. Beginning about 1920 there was a tremendous expansion in statistical methodology which was to prove useful to all aspects of field experiment design and to quality control. The new procedures of major utility to the corn breeder were the several new types of incomplete block designs, primarily lattice squares, which permitted the evaluation of large numbers of items with acceptable levels of precision. Experiments involving comparisons of more than 25 items lose precision very rapidly as numbers increase regardless of the number of replications used. As the lattice designs measure or control soil variability on a block rather than a replication basis, large numbers of items may be included in a single experiment. The corn breeders participated actively in the experimental evaluation of these new designs. The details of this development are outside the scope of this paper, but without this increase in precision of field testing, the development of commercially acceptable hybrids would have been long delayed and possibly never reached the present level of precision.

In the beginning of the hybrid corn development, inbred lines were evaluated in single-cross combinations (line A x line B) as diallels (all possible combinations) or divided into groups and all members of group A crossed with all members of group B. Under any one of these systems the number of crosses for field evaluation could reach staggering totals, e.g., diallel combinations among 100 lines, disregarding reciprocals, would total 4,950. Following such preliminary testing, inbred lines were discarded or retained for further testing on the basis of average performance involving all crosses in which a given line was involved.

The first great simplification of this testing procedure was the top-cross test proposed by Jenkins and Brunson (1932). Under this procedure, the first evaluation of new lines was in inbred x variety crosses. Production of the required seed could be readily accomplished by growing the lines in an isolated field with recurring rows planted to the variety male parent. The inbred lines were detasseled at the appropriate time. Thus any seed produced would be inbred x variety. As indicated previously 100 lines in diallel crosses produce 4,950 different combinations. These same 100 lines can be evaluated under the top-cross procedure as 100 items. This procedure, therefore, effected a very great economy in both the production of the seed required for testing and in the numbers of field plots required for adequate evaluation.

The development of the top-cross list provided a partial solution to the problem of excessive numbers of items to be tested. In the earlier illustration we assumed 100 new lines to be evaluated. Let us further assume that half of these could be eliminated after the top-cross test, leaving 50 lines for more detailed testing. Hybrid corn for commercial use at this point in history was at the double-cross level, (1 x 2) x (3 x 4). With 50 inbred lines it is possible to produce 690,900 different double-crosses, disregarding reciprocals. This potential number poses a very real barrier to progress. Various approaches were tried. One option was to proceed with inbred evaluation at either the top-cross or single-cross level to further reduce the number of lines to be evaluated in double-cross combinations (the formula for determining the number of possible double-crosses is (n) (n-1)(n-2)(n-3)/8). Thus even though the original 100 were reduced to 10 the number of possible double-crosses would be 630, still a very large number. Another approach was to make only a small proportion of the possible hybrids, choice of those to be made being based on personal judgment.

This problem was greatly simplified through research conducted by M. T. Jenkins (1934) on double-cross predictions. He established that double-cross performance could be predicted with reasonable accuracy using an average of either the top-cross or single-cross performance (yield, quality, disease resistance, etc.) of sets of four lines. These methods came into general use and punched-card equipment was used to simplify the prediction operation. Only a small segment of this potential number need actually be produced and subjected to detailed field evaluation trials.

It may be advisable to digress at this point to outline the transition from open-pollinated varieties to hybrids. It should be emphasized that many public and private organizations contributed to this development. Only a very small percentage of the inbred lines developed and hybrids tested (certainly less than 10 percent and more probably less than one percent) had sufficient merit to be commercially acceptable. Practically no hybrids were successful having all parent lines derived from a single varietal source and relatively few hybrids were the product of a single breeding program. Progress was greatly facilitated by the free and open exchange of both materials and ideas. Substantial progress was to continue and is still continuing but the hybrids which went into production in the 1930s were developed using the information and procedures described in the preceding sections.

In 1930 the extent of farmer acceptance of hybrids was still to be established and the economics of specialized seed production as a business venture was unknown. Many small companies were created and several states organized hybrid corn schools to instruct farmers on the techniques of seed production.

A variety of extension efforts were devoted to acquainting the farmer with the new technological development -- hybrid corn. States initiated yield tests to provide comparative data on performance of hybrids and open-pollinated varieties; demonstration plots were conducted by county agents; small quantities of hybrid seed were given to farmers who wished to conduct their own comparisons; and many articles appeared in local papers and farm journals describing the advantages of hybrid corn. Even with all this exposure, considerable quantities of seed were sold in the early 1930s on a performance basis; if the hybrid seed did not out-perform the farmer's local strain he was not obliged to pay for the seed. Average increases in yield were of the order of 25 to 35 percent. Improved standability, however, was nearly as important a factor in adoption as the increase in yield levels.

Rate of adoption was most rapid in those areas where corn was a major crop. The rate of adoption is illustrated in Figure 2. An essentially complete transition from open-pollinated varieties to hybrids was effected in Iowa and Illinois in about 10 years, for the Corn Belt in 20 years, and for the whole of the U.S. in 30 years. In the fringe areas of the Corn Belt and in areas outside the Corn Belt, rate of adoption was slowed materially due to a lack of suitable hybrids and improved production practices.

The impact of hybrids on per acre yields is illustrated in Figure 3. Yield increases in the 1930 to 1945 period were due largely to plant breeding. Following 1945, production practices underwent tremendous changes: the use of nitrogenous fertilizers in ever increasing amounts, concommitant increases in plant densities, and increasing use of herbicides and pesticides. Along with these changes in production practices was an equally rapid change in hybrids grown. New hybrids were developed which could respond effectively to the new management practices. These several changes were occurring simultaneously and it is extremely difficult to assess their individual effects. The point of major importance, however, is that the yield trend line has continued upward since about 1945 and there is no evidence that the rate of yield increase is diminishing.

In the early stages of hybrid seed marketing, substantial quantities of station developed open-pedigree seed were sold. At the same time there was a rapid expansion of private seed companies which marketed closed-pedigree hybrids. The quality and field performance of these two classes of hybrids were essentially equal. With time, however, the private companies assumed ascendancy and by 1950, possibly the bulk of the seed sold was closed pedigree. This transition was due largely to economic factors. The small operator might be a skilled producer but was often lacking in business experience. Capital investment increased rapidly with size of operation. Increased volume of business required an extensive advertising campaign and sales force.

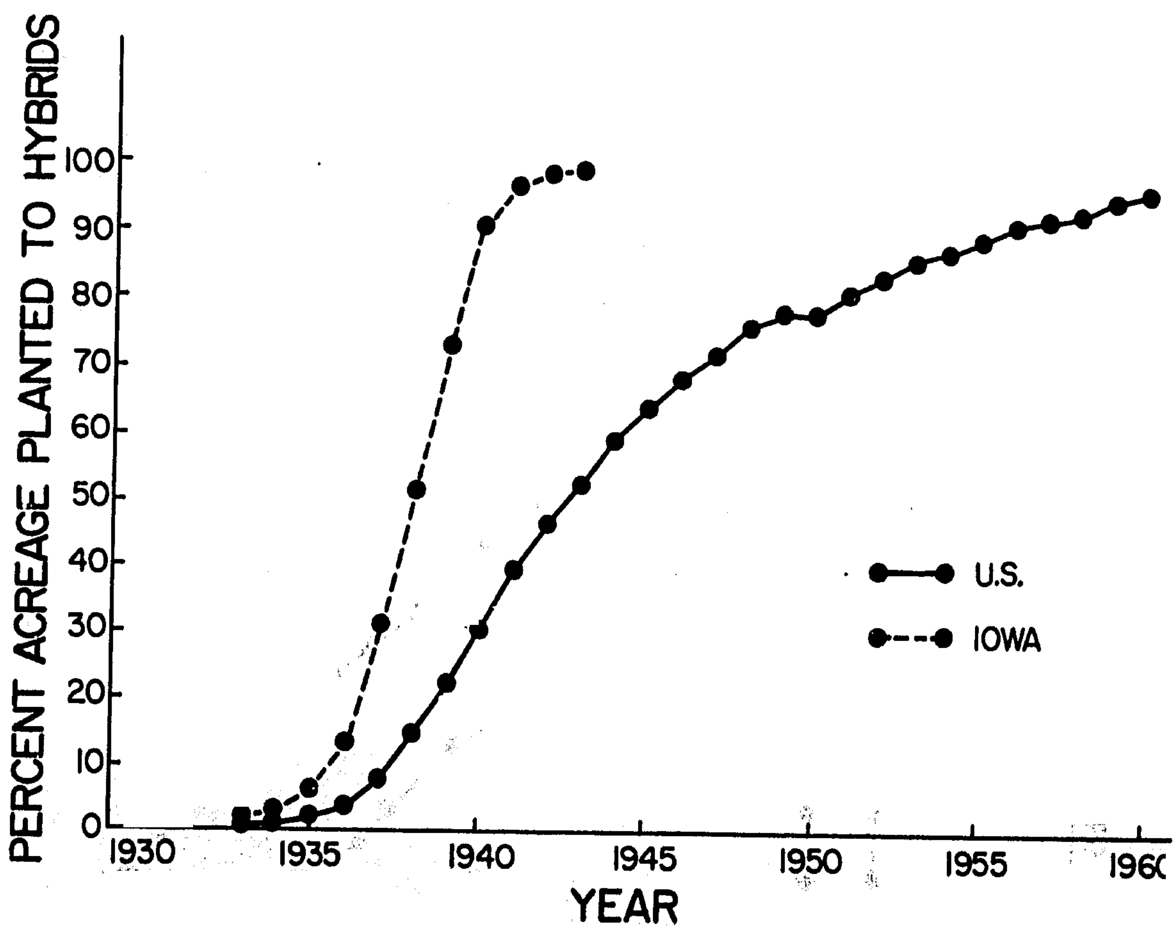

Figure 2. Rates of adoption of hybrid corn in Iowa and in the United States.

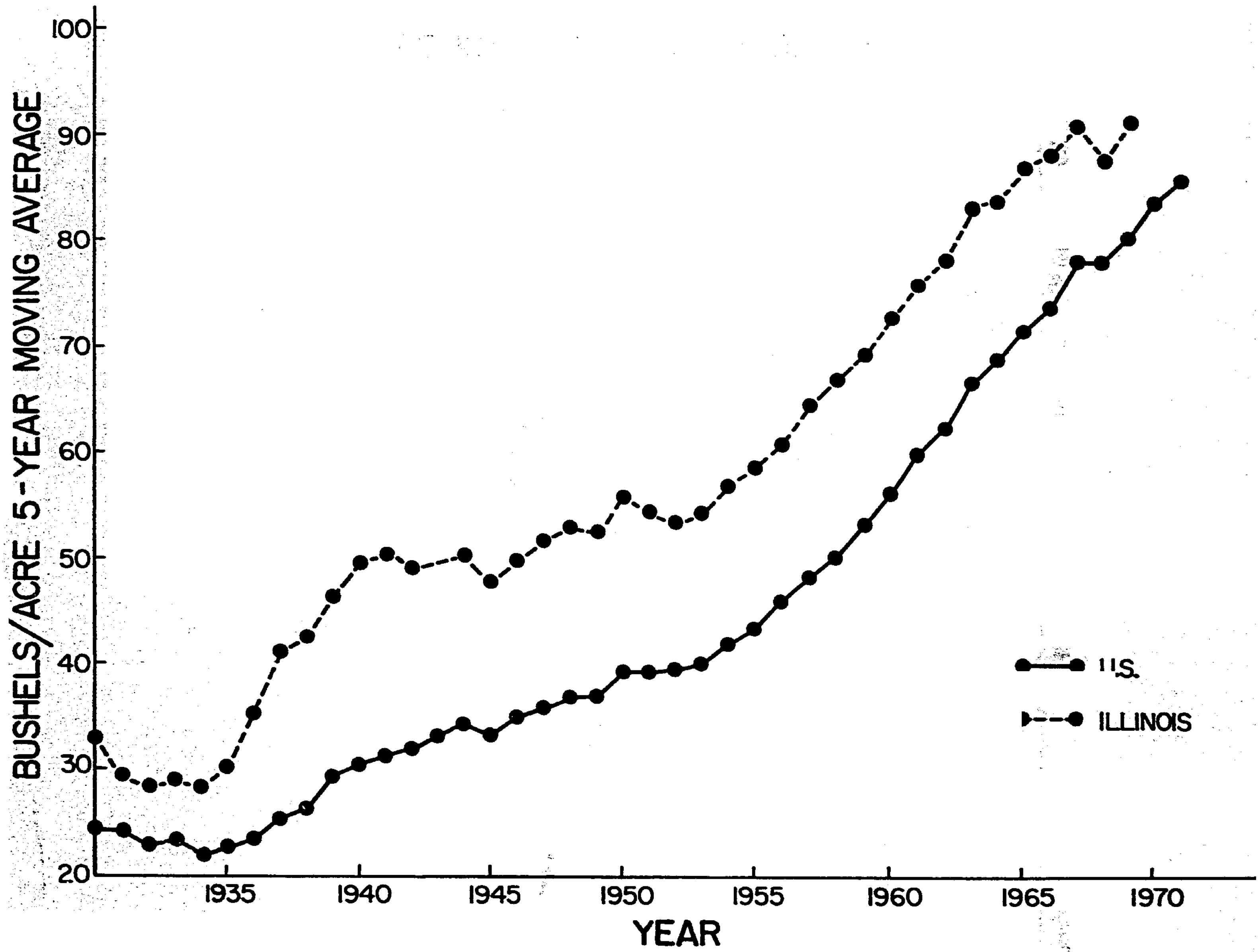

Figure 3. Average yields in bushels per acre (5-year moving average) for Illinois and the United States, 1930 to 1971.

Many of the small companies were unable to make this transition and either discontinued seed production or were bought by larger companies. Small companies still exist but they currently account for considerably less than half of the seed sold.

At roughly this point (1940-1945) some corn breeders interpreted the difficulty in obtaining still better hybrids as evidence that genetic variability had been largely exhausted, i.e., that the advantage to be derived from hybrids had been largely realized. They concluded that further improvements would be minor and would be achieved through greater resistance to disease, better kernel sizing properties, etc.

Others felt that the apparent yield plateau was the result of inefficiencies in breeding procedures and in an understanding of the relative importance of the different types of gene action involved in heterosis. This philosophy led to a greatly expanded effort on the development of new breeding schemes and to important developments in quantitative genetic theory.

In spite of the differing philosophies among corn breeders, corn breeding continued as a very active enterprise. Lines now in extensive commercial use have been derived from (1) backcross improvements of older lines, (2) inbreeding within hybrid populations and synthetics, and (3) as by-products of studies designed to evaluate new breeding systems. The post-1941 literature is voluminous and a detailed review and interpretation will not be attempted. Rather, we shall consider only a few selected studies which had an important impact on further developments.

The first inbred lines used in the production of commercial hybrids were direct isolates from open-pollinated varieties. Subsequently, new lines were developed in one of three ways: (1) further direct sampling of varieties, (2) the development of improved lines through backcrossing, and (3) isolation of lines from the best single or double-cross hybrids. The last two methods are still in extensive use.

Resampling of varieties proved to be somewhat disappointing and has been largely discontinued. As mentioned previously, the great bulk of lines isolated will, when intercrossed, give performance approximately equal to the parent variety. Exceptional lines, those of sufficient value for commercial use, occur in low frequency. Resampling on the same scale, therefore, would not be expected to produce new lines markedly superior to those first isolated. Some slight improvement might be expected if standards of acceptable vigor at the inbred level had increased materially. However, vigor at the inbred level is not closely related to hybrid performance; thus any gains from more intense visual selection during inbreeding would be expected to be minimal in modifying hybrid performance. These facts were but little appreciated before 1940. In any event, the experience with resampling varieties was uniformly disappointing and relatively little further effort has been devoted to this procedure.

Backcrossing is a technique for modifying some trait of interest within an existing inbred line, i.e., a method for correcting certain faults within existing lines. The major fault of some inbred line, say B14, may be susceptibility to certain leaf diseases. B14 would then be crossed to some resistant source (A) and the F_1 hybrid crossed again to B14. Further backcrossing to B14 may continue for three or more generations, taking care in each generation that the plants used as female parents are resistant. Following the backcrossing, two or more generations of self-fertilization are required to fix or stabilize the introduced trait, resistance to the leaf disease. Recovery of the B14 genotype during backcrossing follows the series 1/2, 3/4, 7/8, 15/16, etc. The objective is to recover the essential portion of the B14 (recurrent) genotype and at the same time retain the desired genes for disease resistance introduced from the non-recurrent (A) parent. The final product, if the procedure was successful, is a new line, B14a, which performs like the original B14 in hybrids but which is resistant to the leaf disease of interest.

This method of breeding has been widely used. In the early period attempts were made to improve many lines. Gradually, it came to be realized that while the method had great value most inbred lines did not warrant this further expenditure of time and resources. At the present time backcross improvement is used for only the very best lines available.

The third method, second cycle selfing, was and still is used very extensively. The operational hypothesis was that many of the undesirable features of the original varieties had been eliminated in the inbreeding practiced and in the severe selection involved in identifying combinations with superior combining ability. Therefore, when such hybrids were inbred, the new lines should be markedly superior as lines and should combine to produce still better hybrids. This expectation was realized only in part. The average array of inbreds derived from such hybrids was, in fact, superior to a comparable array of lines derived directly from open-pollinated varieties. Improvement in hybrid performance, however, was less than many investigators had expected, Hull (1945). This dissatisfaction stimulated further interest in certain aspects of quantitative genetics, particularly in the types of gene action involved in heterosis and their relative importance. This interest led to a better understanding of the genetic basis for past breeding procedures and eventually led to new concepts and breeding procedures.

One of the early papers dealing with quantitative aspects of gene action in corn (Sprague and Tatum, 1942) detailed a procedure for separating the variances for general and specific combining ability. (General combining ability measures the performance of a line or group of lines when combined with a group of other lines. The variance for specific combining ability measures the extent of departure from expectation based on average performance.) It had been observed that certain inbreds were uniformly good or poor in hybrids while others were somewhat erratic, performing well in certain combinations and poorly in others. Estimates of general combining ability are primarily based on additive effects while specific combining ability measures the non-additive effects: dominance and epistasis (factor interaction). These two types of effects had long been recognized by the geneticist but previous techniques were unsuitable for adequate distinctions when dealing with heterogenous populations or groups of inbred lines. The statistical procedure was useful in providing a new experimental approach for the study of plant and animal breeding problems. Studies on general and specific combining ability provided a satisfactory explanation forthe efficiency of such operations as the top-cross test and double-cross prediction.

Following this first rather crude separation of genetic effects, a new breeding system was devised which offered promise of greater efficiency than the conventional inbreeding-hybridization. This new system was designated "recurrent selection" and three rather distinct types were initially recognized based on the type of gene action presumed to be of major importance in heterosis or hybrid performance. These subsystems were designated recurrent selection for general combining ability, for specific combining ability, and for reciprocal recurrent selection. Operationally the three were very similar. In each case one or more base populations were developed; these populations might be open-pollinated varieties or synthetic or composites developed by inter-mating selected inbreds or varieties. Individual plants in such populations were selected at the time of pollination on the basis of appearance. Such plants were self-pollinated (to maintain genetic identity) and the same collection of pollen used to pollinate a series of ears (usually 5 to 10) of a tester parent. The crossed ears having a common male parent were bulked and the bulked seed used for yield test evaluation. Usually 100 to 200 such sets of crosses would be produced to sample a given source. When the field performance data become available the following season some arbitrary fraction (usually 10 to 20 percent) of the group is retained. Using remnant selfed seed, these selected items are grown and recombined through controlled intercrossing. This new population, commonly designated C_1, forms the basis for the next cycle of selection.

The three types of recurrent selection differ only in the type of material chosen for the tester parent. In recurrent selection for general combining ability, the tester parent is an open-pollinated variety, synthetic or some heterozygous and heterogeneous source. In recurrent selection for specific combining ability, the tester is an inbred line. This type of recurrent selection was devised on the assumption that overdominance was an important type of gene action in heterosis. The third type, designated reciprocal recurrent selection (Comstock, et al., 1949) differs from the first only in that two base populations are involved, each serving as the tester for the other.

Genetic theory is rather similar for each of the three types. Individual test crosses are superior because of the genetic superiority of the male parent involved. Recombination among this superior group should increase the gene frequency for all traits under selection. Relative performance, as measured with a given tester, should increase with successive repetitions of the process: $C_0 > C_1$, $C_1 > C_2$, etc. This progressive improvement in the base populations should be reflected in two ways: (1) an increased frequency of superior lines when the population is inbred and (2) a further increase in hybrid performance when the populations are intercrossed or when the derived lines are tested in single or double-cross hybrids. Improvement might also be expected in the performance of the population per se. Such potential yield increases, at the population level, however, can be easily obscured by inbreeding depression effects if the number of items recombined in each cycle is small. Population yield trends, therefore, do not provide a completely satisfactory measure of gene frequency changes.

In 1940, Jenkins described a simple procedure for improvement in southern prolific types. Modifications of this general procedure were later called recurrent selection for general combining ability.

Hull (1946, 1952) was disappointed in the performance of second-cycle inbred lines and concluded that overdominance ($Aa < AA$) was likely the major type of gene action involved in heterosis. This conclusion was based on the following assumptions: (1) mass selection for yield was ineffective, (2) ear-to-row breeding for yield was ineffective, (3) synthetics had not been developed which were superior to open-pollinated varieties, and (4) epistasis (factor interaction) was of limited importance. Items 1 through 3 would, if true, indicate a lack of additive genetic effects. If overdominance were of major importance, then recurrent selection for specific combining ability (use of an inbred line as tester parent) should have maximum efficiency. No experimental data were presented in support of this breeding procedure.

The question of the relative importance of overdominance was, in some measure, the stimulus for extensive developments in quantitative genetics. The groundwork had been laid by Fisher in 1918. Extensive developments by Fisher, Wright and Haldane had done much to clarify the effects of selection, mutation, genetic drift and assortative mating from an evolutionary viewpoint. These concepts, however, had but little impact on plant breeding. This situation underwent a drastic change beginning about 1945 primarily under the leadership of active groups at both North Carolina State and Iowa State Universities. The details of much of these developments lie outside the scope of this report. However, a large number of experimental designs were developed which permitted the estimation of various population parameters, types of gene action, average degree of dominance, etc. Many of these designs, together with genetic expectations, have been summarized by Horner et al., (1959). All of the subsequent studies on recurrent selection have drawn heavily on this theoretical quantitative genetic base.

In 1949 Comstock et al. described a method designated reciprocal recurrent selection. In this method two base populations are used, each serving as the tester parent for the other. Theoretical considerations indicated this procedure should be as efficient as recurrent selection for general combining ability if additive effects were of primary importance and nearly as efficient as recurrent selection for specific combining ability if epistasis or overdominance effects were of primary importance.

Later, still other types of recurrent selection were proposed. These include mass selection, ear-to-row selection, S_1 testing and full-sib selection. Basically two different approaches were used to evaluate these several alternatives: (1) studies designed to provide a direct evaluation of the relative importance of different types of gene action involved in heterosis and (2) direct comparative studies of the efficiency of two or more methods. One point of concern in either approach was the relative importance of overdominance in heterosis.

Sprague and Miller (1950) proposed a scheme which should provide a fairly direct measure of the importance of overdominance. Recurrent selection for specific combining ability was to be initiated in two heterogeneous sources using a common inbred tester. If improvements were effected in the two populations their performance, when crossed, should differ depending on the type of gene action involved. Using the symbols AC_0 and BC_0 to represent the original populations or composites and C_1, C_2, C_3, etc. to represent successive improvement cycles, the critical test involves comparisons of C_0 x C_0 vs. C_3 x C_3 on some other advanced generation. If additive effects are of primary importance, the series C_0 x C_0, C_1 x C_1, C2 x C_2, etc. should exhibit an increasing yield trend. If overdominance is the primary factor in heterosis, a decreasing yield trend would be expected as selection in both populations is directed toward development of the genetic opposite of the tester parent. Thus, if selection is for overdominant loci the two populations would become progressively more alike.

The cumulative data obtained (Russell et al., 1973) strongly indicate that additive effects are of primary importance and that overdominance, if it exists, is of limited importance.

Alternative approaches to this same problem were designed to obtain statistical estimates of the average level of dominance.1/ This was accomplished by comparing estimates obtained from F_2 and F_n populations. At the F_2 level repulsion linkages would be at a maximum and decrease to equilibrium values with successive generations of random mating. In a study reported by Gardner et al. (1953) estimates of average level of dominance for yield were significantly greater than 1.0. In advanced generations, however, estimates of average level of dominance were not significantly greater than 1.0. In a second study, involving different populations, Moll et al. (1969) reported essentially the same findings. These and other similar studies, therefore, do not support the concept that overdominance is of major importance in yield heterosis. It should be emphasized that the point at issue in both types of studies was the relative importance of overdominance in yield heterosis. The existence of this type of gene action has not been in dispute.

A very large number of studies have been reported bearing on the efficiency of one or more of the recurrent selection schemes. In every case progress has been achieved with the methods used. Comparisons among methods, however, are difficult due to the fact that the various investigations have dealt with different base populations, different selection procedures and intensities, and the individual studies have involved different environmental conditions. Sprague (1966) has presented formulae for expected genetic progress for each of the recurrent selection schemes.

One type of recurrent selection, mass selection, deserves special mention. It was noted earlier that the consensus during the 1910-1930 period was that mass selection was ineffective in modifying yield. This was also one of the basic assumptions in Hull's argument for over-dominance. However, as quantitative genetic evidence accumulated, all studies indicated a sizeable fraction of additive genetic variances. If additive effects were present then mass selection should be effective. This question was reexamined by Gardner (1961). The parent variety, Hays Golden, was grown under isolation. At harvest, the field was divided into small blocks and the highest yielding plants identified in each block. The ears from these plants were composited and used as the base population for the next cycle of selection. The first report,

1/ Average level of dominance, "a" is estimated as the ratio of dominance and additive genetic variances: "a" $= \left(\frac{2\sigma^2_d}{\sigma^2_a}\right)^{\frac{1}{2}}$. Where $a < 1$, partial dominance; $a = 1.0$, complete dominance; and $a > 1.0$, overdominance.

covering 4 cycles, indicated an average yield increase of 5.7 percent per cycle. This study has now been continued for a total of 15 cycles with an average gain per cycle of 2.5 percent. It now seems clear that earlier experiments were unsuccessful due to the failure to recognize the importance of experimental variability. The use of small blocks as units in which selection is practiced effectively eliminates a sizeable fraction of the otherwise confusing effects of soil variability.

A review of some of the earlier evaluation studies involving recurrent selection was presented by Penny et al. (1963). Until recent years the major interest in recurrent selection was to improve populations as potential sources of new inbred lines. More recent summaries presented by Hallauer and Sears (1969), Hallauer (1973), and Eberhart et al. (1973) have concentrated on the evaluation of improved or newly developed populaticns as parents of inter-composite hybrids. These studies have demonstrated that some inter-composite hybrids give yields which compare favorably with currently grown standard hybrids. Inter-population hybrids are used extensively in the hybrid maize development in Kenya which we shall consider in a subsequent section. Genetic theory would predict that the best of a series of lines developed from the parents of high yielding inter-composite hybrids should give double and single-crosses with increased yields of 15 and 30 percent, respectively, above currently grown types. Limited experimental data obtained at Iowa support these genetic expectations.

Disease Resistance

Thus far we have been concerned primarily with breeding procedures aimed at increasing yield. Corn breeders have long enjoyed close cooperation with the plant pathologists. It is now standard practice to screen for resistance to the major disease of an area during the inbreeding phase. Inoculation techniques are available for stalk and ear rots and many of the lear blights. In consequence of the widespread use of such techniques, most inbred lines, at the time of their release, possess moderate to high levels of resistance to the diseases of major importance in the area of expected importance.

Plant pathogens are genetic entities and as such are subject to the same evolutionary forces (mutation, selection, etc.) as their hosts. As the number of spores produced by a given pathogen under epiphytotic conditions is astronomical, mutation giving rise to new forms, races, or biotypes is of regular occurrence. Lines and hybrids previously classified as resistant may be highly susceptible to some new form of the pathogen. Maintaining adequate host resistance is therefore a continuing battle. As each new, more virulent race arises, new sources of resistance must be sought and when found, incorporated into existing commercial lines and newer lines still in the developmental stage. The current levels of productivity and the relatively rare serious disease outbreaks speak well for the effective breeder-pathologist cooperation.

Insect Resistance

Close cooperation between entomologists and breeders, comparable to that of breeders and pathologists, is a relatively recent development. Even so marked progress has been achieved in developing lines and hybrids having considerable resistance to the corn ear worm (Heliothis), to the corn leaf aphid (Rhopalosiphum) and to the first brood of the European corn borer (Ostrinia). In the latter case the chemical basis for resistance has been identified and alternative laboratory screening procedures developed. Extensive search is underway for resistance to many of the other harmful insects such as the corn rootworm (Diabrotica) and the rice weevil (Sitophilus).

The search for resistance to a given insect pest and its subsequent incorporation into useful stocks is a difficult task. An effective operation requires the development of techniques for artificial rearing of the pest and the development of methods for obtaining uniform field investigations. Only as these problems are solved can effective screening be accomplished.

Genetic Traits of Special Interest

The bulk of the corn grown in the United States is used for livestock feed. Quality of grain and yield per acre have been the factors receiving primary consideration.

Certain genetic types, however, have received special consideration because of their unique properties. These would include sweet, pop, waxy, high amylose, and more recently opaque-2. Each of these has a different potential market and each poses special breeding problems.

Sweet corn is grown for human consumption, as fresh corn (roasting ears), frozen or canned. Commercial production is highly specialized and of limited distribution. Yielding ability and disease and insect resistance remain important factors but to these are added quality factors such as pericarp texture, type and amount of stored carbohydrates at the edible stage, and flavor characteristics.

Sweet corn at the "milk" stage has relatively good protein quality. From this developmental stage on to maturity protein quality decreases due to an increasing rate of deposition of the prolamine (zein) fraction which is deficient in lysine. Incorporation of such mutant genes as opaque-2 or some of the double mutant forms, e.g. o2su2(opaque-2, sugary-2) might improve protein quality slightly at the "milk" stage but would have greater nutritional impact in mature corn.

Popcorn is another speciality crop grown for human consumption. Production is centered in the Corn Belt states from Ohio to Nebraska. Special consideration has been given to selection for popping expansion and to overall tenderness of the popped product.

Waxy and high-amylose types are grown for commercial processing. Waxy corn produces starch of the amylopectic configuration. Such starch is used extensively as sizing and in the manufacture of adhesives and certain edible products such as puddings. High-amylose corn produces a high (60-80) percentage of the amylose or straight-chain starch fraction and is used in the production of various films and fibers. Several million bushels of these two types are milled annually.

Opaque-2 is a genetic type holding great current interest because of its improved protein quality. In the United States this type will have special value in the feeding of non-ruminants. In other areas of the world where corn is an important human food, opaque-2 materials will be especially valuable in the improvement of diets.

Each of the above types pose production and/or distribution problems over and above the unique problems involved in breeding acceptable types. First the material must be grown with some degree of isolation to maintain its genetic identity. Second, identity must be maintained in the market channels from producer to consumer. This is not an important problem for either sweet or popcorn but becomes very important for the waxy, high-amylose or opaque-2 types. In the case of waxy and high-amylose hybrids identity has been maintained through a contracting procedure. The grower is provided seed and a per bushel premium for the crop. In return he grows the material under isolation and markets it at a time designated by the producer. Opaque-2 may present a more difficult problem as the volumes involved may become quite large.

Future Developments of Hybrid Corn

The yield trends in Figure 3 give no indication of any significant change in slope since 1954. There must, however, be a ceiling on the production capabilities of this or any other crop. In previous sections we have indicated that the corn breeder through the years has received tremendous assistance from other disciplines -- the statisticians in developing experimental designs suitable for handling large numbers of items, the quantitative geneticist in the development of population genetic theory and designs suitable for estimating various types of effects and their interaction, and to the pathologists and entomologists in providing information on sources of resistance and effective screening and evaluation techniques. The major gap which remains to be filled is effective cooperation between breeding and biochemistry-physiology. A beginning has been made but much more needs to be done. Sprague (1969) has reported on this need in some detail. Yield determinations - the standard measure of hybrid performance - measure the mean resultant of interactions among all physiological processes involved in growth and development. The yield data, however, provide no information as to which component process may be limiting. Equality of yields need not necessarily imply that all biosynthetic pathways involved are also equivalent. Current or potential yield levels could be limited by inefficiencies in any one or more of the following broad areas: (1) energy transfer mechanisms, (2) net assimilation rates, (3) translocation and utilization of photosynthate, (4) nutrient uptake and use, (5) plant growth substances, (6) response under stress conditions, and (7) efficiency of water use. Exploration and progress in any of these areas will require the development of simple, rapid and repeatable analytical techniques to minimize sampling and environmental problems. With such tools available an effective search can then be made for different genetic control systems. Research in this area may be difficult, it certainly will be costly, but it also offers promise of being highly productive.

One of the important elements in the hybrid corn development in the U.S. was the willingness of all of the research workers involved to share breeding materials, experimental data on reaction of lines or of hybrid performance, and information on new techniques or breeding procedures. Few hybrids were marketed in which all of the component lines had been developed and tested within a single program. This same spirit of cooperation has been extended to workers in other areas of the world. A few specific instances are presented in the sections which follow.

UNRA AND THE EUROPEAN DEVELOPMENT

Although European agriculture had been severely disrupted by the war, it had had a previous history of excellence. A large number of agricultural research centers had been established, each with a long history of effective research. Trained scientists were available. What was needed was time and money to rebuild and exposure to new developments in agriculture.

Corn has long been an important crop in parts of Europe. Production reached its highest levels in Yugoslavia, Hungary, Italy, and adjacent areas. Breeding work had involved importation of U.S. varieties and selection among the locally available types. Prior to World War II studies on inbreeding and hybridization of corn had been carried out at only a few locations and at these locations on a very restricted scale. During the war, staff, funds, and facilities were diverted to war efforts and communication among scientific workers largely disrupted. In consequence, at war's end, the scientific community was largely unaware of the transformation of U.S. agriculture resulting from the development and adoption of hybrid corn. Food and feed shortages occurred throughout much of Europe and the introduction and extension of hybrid corn appeared to offer promise for alleviating these shortages.

The United Nations Relief and Rehabilitation Administration (UNRA) began the introduction of hybrid maize into Europe in 1946 and 1947. Many of the agricultural advisory services performed by UNRA were later transferred to FAO which undertook the testing of U.S. hybrids on an international scale. Large numbers of samples were sent to Bergamo, Italy, in the spring of 1947.

Dr. M.T. Jenkins of the U.S. Department of Agriculture conducted a hybrid corn school at Bergamo in the summer of 1947. This was attended by representatives of most of the European countries, including USSR. Emphasis was placed on the history of hybrid corn development in the U.S., on methods of breeding and testing as well as requirements for commercial seed production. With field plantings of inbreds and hybrids available for study and observation, the meetings were very effective in acquainting the group with new materials and developments, and possibly of equal importance, in developing a community of interest which was later to expand into a permanent organization of corn specialists. Dr. M.T. Jenkins continued to serve as a consultant to the European hybrid corn development for several years.

FAO undertook the establishment of a series of regional trials of U.S. hybrids. As corn was used for both grain and silage and because of the wide diversity of climates, hybrids were chosen representing a wide range in maturities: from 70 day maturity (Wisc. 1600) to 130-135 day maturity (U.S. 13). Due to limited facilities at many locations the number of items for observation and evaluation was kept to a minimum. Local varieties were included in each test. The data obtained therefore, permitted an assessment of the potential value of hybrids and identified the maturities holding greatest promise for each geographical area.

In 1948 samples of hybrids were supplied to Austria, Afghanistan, Belgium, Czechoslovakia, Denmark, Egypt, England, France, Greece, Hungary, Italy, Lebanon, Netherlands, Norway, Portugal, Poland, Syria, Switzerland, and Yugoslavia. Small samples of the inbred parents of each hybrid were also provided so that experience could be accumulated on inbred maintenance and local hybrid seed production could be initiated. The number of countries participating in this regional effort varied somewhat from year to year; some dropped the regional tests after one or two years of experience while other countries were added to the group as their interest developed.

Based on results from the first years of testing, more testing sites were added in subsequent years to provide a more adequate sampling within country production areas. The yearly results have been summarized

Table 2. The status of hybrid corn in 11 European and Mediterranean countries in 1952.*

Country	Total Maize Area (ha)	Total Maize Production (M tons)	Percent Area in Hybrids	Increased Production from Use of (U.S. $)	Domestic Production of Hybrid Seed (M tons)
Algeria	8,000	6,000	—	—	—
Belgium	1,421	7,190	99.0	160,000	30
Egypt	715,608	1,506,001	0.13	53,000	10
France	352,000	451,600	16.0	1,300,000	1,700
Greece	240,000	200,000	—	225,000	250
Italy	1,271,395	2,388,182	8.7	20,000,000	5,000
Morocco	468,500	260,000	1.7	50,000	5
Netherlands	14,000	50,350	75.0	500,000	540
Portugal	475,795	400,180	0.9	750,000	211
Spain	382,908	634,700	3.6	600,000	1,120
Switzerland	640,000	830,000	4.0	7,500	8

* Data assembled by Dr. R. A. Silow of FAO. In 1952 some 4 million tons of corn was imported as a feed grain in Western European countries.

in a series of FAO publications (1952, 1953, 1954) entitled "Hybrid Maize Tests in European Countries". The 1952 report carries the statement: "The estimated increased production in 10 countries from the use of hybrids in 1952 was 273,000 tons, valued at U.S. $24 million. The potential use of hybrids in the region is at least 4 million tons " (Table 2). Subsequent developments have shown this projected increase to be much too conservative.

After the 1948 harvest, the research workers met at Rome in January of 1949 to review the results obtained and to develop plans for the coming season. The group arranged for exchange and sharing of breeding stock and developed plans for continued testing of U.S. hybrids. Each country selected the maturity groups that performed best in previous tests and requested larger quantities of seed to permit tests at more locations. The major portion of the seed for the 1949 tests was contributed by members of the American Seed Trade Association. Large volumes of seed were imported for commercial plantings. Figures on imports covering the entire development period are not available but 20 tons were imported in 1948, 2000 tons in 1949.

Following the experience of 1948 several countries requested additional technical assistance involving the organization and development of breeding programs and of seed production and distribution. FAO was unable to supply this type of consultation and plans for such assistance were developed by the Organization for European Economic Cooperation (OEEC) with financial support from the U.S. Economic Cooperation Administration (ECA). The first team (Drs. R.C. Eckhardt and Ferguson) visited several countries in 1949 and their report was published as an OEEC report titled "Hybrid Maize (Corn) in European Countries". The second team (G.F. Sprague and A.L. Lang) visited most of the stations in Western Europe where corn research was underway. Their report was published by OEEC as Technical Assistance Mission No. 96 under the title "Hybrid Maize: Progress in OEEC Countries."

These on-site visits provided for further extensive exchange of breeding stocks and the identification of U.S. materials that would be of a maturity suitable to the individual locations.

In the period since 1961 hybrid corn has spread rapidly throughout Italy, France, Hungary, and Yugoslavia comprising 90 percent or more of the acreage planted. Substantial but somewhat lesser progress has been made in such countries as Spain, Portugal, Turkey, the Netherlands and Germany. U.S. lines are still used to a great extent but locally developed lines are assuming increasing importance.

KENYA

Corn is the most important food cereal in Kenya, per capita consumption equalling that of several Latin American countries. It is, however, a crop of relatively recent introduction, having largely replaced sorghum in areas with ample rainfall.

The highland area of Kenya (Trans-Nzoia and adjacent areas) was opened to European settlement following World War I. Large-scale production of both corn and wheat was undertaken by the new settlers. The first corn varieties used were of South African origin. These were modified by natural and artificial selection, and the predominant type in the highland area was designated Kenya Flat White.

After World War II a short-lived program of corn breeding and production was mounted by the British. Some inbred lines were developed but the program never developed to the stage of the commercial production and use of hybrid seed. After a period of dormancy the program was reactivated in the late 1950s under the direction of M.N. Harrison. The previously developed lines were resurrected from remnant seed and new breeding work initiated. The pressure for this renewed effort came largely from the Kenya Farmers Association. The Kenya Maize Marketing Board, the Department of Technical Cooperation, Great Britain, the Rockefeller Foundation, and the Kenya Ministry of Agriculture provided the financial support.

The experimental studies conducted by Mr. Harrison revealed that the genetic diversity within Kenya Flat White was inadequate to permit development of a sustained and highly efficient breeding program. A large number of introductions were made from the U.S. and the Latin American countries. The great bulk of these introductions were poorly adapted and were discarded without extensive evaluation. A few introductions - those coming from areas having rather similar ecological conditions - appeared to offer real promise. One of these, EC573, has since been used quite extensively.

In earlier years some studies had been conducted comparing single aspects of production practices, e.g., time and method of planting, etc. There had been, however, no comprehensive study of the effects of several production practices in combination and their interaction effects. Mr. A.Y. Allan, employed by the Kenya government under a grant from the Rockefeller Foundation, initiated comprehensive studies in 1963.

The African Major Cereals Project also begun in 1963 and Kitale, Kenya, was selected as the site for the research work on corn in East Africa. Under the original charter given EAAFRO, each country comprising the East African Community could retain responsibility for research in any subject matter field or on any crop desired. Kenya had opted to retain corn and to be responsible for research on this crop. In consequence it was necessary for EAAFRO to make special arrangements with Kenya to support the AID/ARS cooperative corn program.

When the Major Cereals Project was initiated the Kenyan Corn Program had developed commercial hybrids and had induced the Kenya Seed Company to undertake the production of hybrid seed on a commercial scale. Previously the seed company had specialized in the production and sale of high-altitude tropical grass seed and the production of sunflower seed for the export market. It had been demonstrated that the population cross hybrid, H611 (Kitale II x EC573), produced yields comparable to the double-cross, H621, at elevations of 1500 meters and was markedly superior at elevations of 1800 meters and above. Kitale II and the parental lines of H621 had been developed from the Kenya Flat White complex.

The Major Cereals Project was requested to participate in the corn improvement program with particular emphasis on the development and evaluation of effective methods of producing improved varieties and hybrids. The conventional method of inbreeding and testing was discounted because of the long lag-time involved. At this time (1964) recurrent selection studies had progressed to the point of demonstrating the general efficiency of the method but essentially all of the emphasis had been directed toward improvement of populations. Less emphasis had been given to the possible effect of improvement in performance at the inter-population or varietal hybrid level. Genetic theory, however, indicated that any improvements effected in the performance of such populations in hybrids. The decision was made, therefore, that the main focus of the high altitude Kenya program would be directed toward the use of a comprehensive breeding system for the improvement of the Kitale II and EC573 populations and the advanced generation of the cross between these two populations. This provided a flexible program as either base population could be used directly as a variety, the cross between the two populations could be used as a commercial hybrid, or inbred lines could be developed from either population to produce top-cross, three-way cross, or double-cross hybrids. Several recurrent selection schemes were initiated with the expectation of comparing their relative efficiencies.

The recurrent selection approach has several theoretical advantages over conventional inbreeding and hybridization. First is the differing time requirements. The inbreeding and testing procedure normally requires 7 to 10 generations to achieve a fully tested commercial product. Under recurrent selection each new cycle of improvement, if the gains have been of sufficient magnitude, can be substituted into the commercial production scheme as open-pollinated varieties or as parents of population cross hybrids.

Secondly, the recurrent selection approach is less demanding in terms of labor and financial allocations to the breeding and testing program and in terms of acreages and isolated field requirements for commercial seed production.

Thirdly, the recurrent selection approach appeared to offer certain long-term advantages. With conventional inbreeding, after the first gains have been achieved, the breeder is forced to resampling, the initiation of backcross improvements or sampling from selected hybrids for further increment of improvement: each new increment requiring the same 7 to 10 year period. Under the recurrent selection scheme each cycle of improvement requires only two years. The improvements which have been achieved are illustrated in Table 3.

Any changes in gene frequency associated with each cycle of improvement should also be reflected in an increased superiority of new inbred lines developed. Likewise such improvement should be correspondingly reflected at any stage of development of conventional hybrid production programs.

The results that have been achieved in the production of hybrid maize in Kenya is illustrated in Table 4.

The acceptance of hybrid corn by the small-scale farmers (total land holdings of 2 hectares or less) is a fact of great significance. It thoroughly discredits the general idea that poor, small farmers will not or cannot accept new agricultural technologies because of the costs involved. The adoption of new technologies, however, does require that these be profitable. Given profitability, the small farmer responds to the same economic motivation as his more affluent counterparts in other areas of the world. Profitability requires that the technological information be pertinent, that extension can provide the necessary counsel and guidance, that the farmer have the necessary access to the needed inputs, and that he have a relatively stable market at a price covering labor costs and cash inputs with a reasonable margin of profit.

The research done by A.Y. Allan was highly effective in identifying the relative importance of various agronomic practices. Extensive 2^6 factorial experiments were conducted comparing open-pollinated vs. hybrid seed, normal vs. increased population densities, normal vs. early planting, normal vs. adequate weed control, and zero vs. 56 kg P_2O_5 and zero vs. 70 kg N. The main effects from one series of experiments are presented in Table 5.

Using these data as a base, information was reassembled to contrast four levels of production practices (Fig. 4). The upper point gives the yield levels for the combination of all conventional practices. The right-hand box gives yields and increases in net income from utilization of low cost inputs: recommended plant populations, time of planting and weed control. The left-hand box gives comparable data for the high cost inputs: hybrid seed and fertilizer. The bottom box gives yield and income data resulting from the adoption of the entire package. The net income figures are corrected for all cash inputs but ignore all labor costs. Yield increases from the combination of practices have been of the order of 400%. This same "diamond" combination of practices has been a very useful extension device.

Table 3. Performance of varieties in the Kenya Later Maturity Variety Trials grown at 28 locations in 1970. 1/

Variety	Yield		% Lodging
	q/ha	% of Kitale II	
Kitale II	40.1	100	47
H622	51.2	128	51
H611B	52.7	131	43
H611C *	64.4	161	37
H613B	57.0	142	48
$H613C_2$*	66.7	166	41

* Improved by two cycles (four years) of reciprocal recurrent selection. The improvement in the commercial cross hybrid H611 and the top-curve hybrid H613 ((F x G) x Ec573) has been approximately 5% per year from the reciprocal recurrent selection program.

1/ Darrah et al.

Table 4. Hectarage of hybrid maize grown in Kenya from 1963 to 1974 (estimated from seed sales).

Year	Farms		Total
	Large Scale	Small Scale	
1963	158	4	162
1964	11,615	708	12,323
1965	22,137	8,110	30,247
1966	25,860	15,269	41,129
1967	55,501	46,642	102,143
1968	36,501	51,331	87,832
1969	39,500	64,291	103,791
1970	47,110	97,372	144,482
1971	63,785	149,864	213,649
1972	79,945	206,804	286,749
1973	53,370	264,699	318,069
1974	58,276	311,615	369,891

Table 5. Factors affecting 1966 yields at 6 locations in Western Kenya. 1/

Factor	Level	Yield (q/ha)	Diff.	Increased Return	Cash Outlay	Profit per ha
Time of planting	Early	52:8	18.6	$ 80.91	$ nil	$ 80.91
	Late	32.4				
Variety	H613B	52.9	18.8	81.78	4.17	77.61
	Local	34.1				
Plant population	36,000	49.1	11.2	48.72	2.78	45.94
	18,000	37.9				
Weed control	Clean	48.4	9.8	42.63	6.96	35.67
	Once-late	38.6				
Phosphate (P_2O_5)	56 kg	44.6	2.2	9.57	11.65	-2.08
	0	42.4				
Nitrogen (N)	79 kg	45.0	3.0	13.05	24.60	-11.55
	0	42.0				

1/ Fourth Annual Report, Major Cereals in Africa Report.

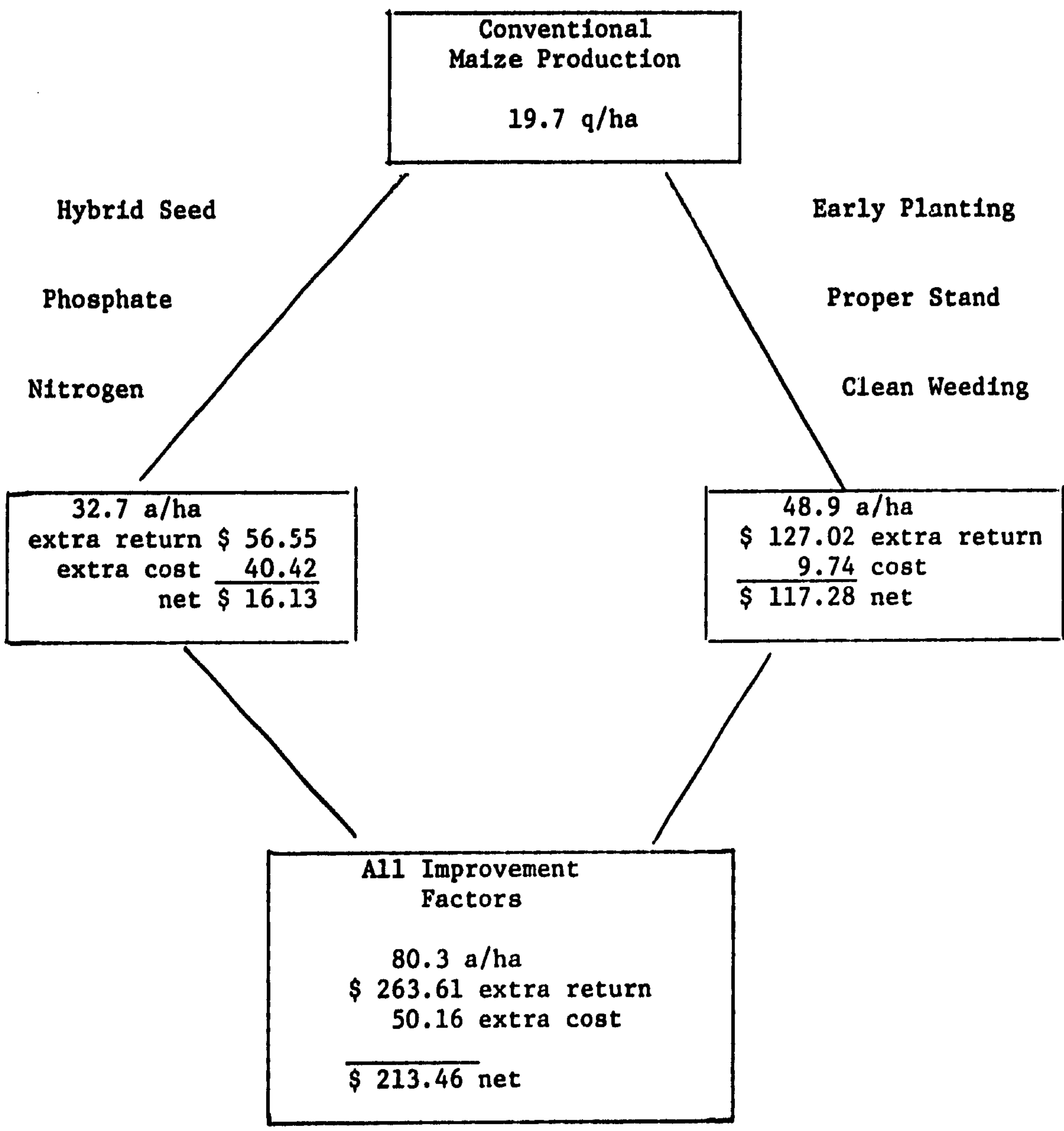

Figure 4. Comparisons involving hybrid seed, fertilizers, and improved production practices in Kenya.

In the early years of hybrid corn availability, rate of adoption by the European settlers was rapid. Adoption by the small-scale farmers required a sizeable extension effort. A hybrid corn school was held each year at Kitale. District extension advisors were invited in and the staff provided instructions on what hybrid corn is, how it must be grown to achieve maximum returns, what hybrids were available and where each was adapted, and how to conduct demonstration plots. The extension scheme adopted was for each district advisor to seek out farmers in his area who would be willing to conduct demonstrations. The farmer supplied all of the necessary inputs: labor, seed, and fertilizer. The plantings were made by the farmer, with the advice and supervision of the extension agent. The farmer held his own field days for his neighbors explaining what he had done, the agent again providing counsel, but it was always the farmer's demonstration. If the results at harvest were impressive, the neighboring farmers knew they could achieve comparable results since the farmer had provided all necessary inputs.

Initially the Extension Service had as its goal one such demonstration within walking distance of every maize grower in Kenya. In one year 5000 such demonstrations were grown. This number proved greater than could be adequately supervised. Instead, demonstrations tended to be concentrated in districts not previously covered adequately.

The impact of this hybrid corn package has been substantial. Kenya has moved from a situation of periodic scarcities to food adequacy and a small surplus in most years. Population increase has been sufficiently rapid to prevent any continuing or unmanageable surpluses. A small surplus would permit an expansion in livestock feeding. Kenya has had, for many years, a small controlled pork processing enterprise. Pork production can now be expanded. Feasibility studies have been conducted on dry lot feeding of beef and some consideration has been given to the establishment of a corn milling enterprise. Each or all of these would contribute substantially to the developing economy.

The AID/ARS Major Cereals Project has had an impact throughout eastern Africa. In 1964, an Eastern Africa Cereal Workers Conference was organized. Workers from Ethiopia, Sudan, Somalia, Uganda, Kenya, Tanzania, Rwanda, Malawi and Zambia were in attendance. Subsequent meetings have been held in Kenya-Uganda, Malawi-Zambia, and Ethiopia. These have been particularly useful in acquainting the eastern African workers with research programs under way, with the newer breeding methods and has helped develop a spirit of exchange of both ideas and materials.

In 1966-67, Dr. S. A. Eberhart initiated the East Africa Regional Corn Trials with countries from Ethiopia to Zambia participating. These trials are still being continued. They have served to identify a series of ecological zones and the current hybrids or new materials which are adapted to each. Advice and counsel have been provide to the corn research workers in each country. This has been particularly helpful as the corn programs have commonly been staffed through secondment or other short-term employees. Thus Major Cereals Project employees have served to provide some degree of stability and program continuity throughout the eastern Africa region.

The incorporation of certain qualitative genes into the Kitale breeding stocks was initiated in 1968 by Mr. M.N. Harrison. The genes of primary interest were: opaque-2 and floury-2 to improve protein quality; brachytic-2, to reduce plant height and thereby lodging; and Ht to improve resistance to northern leaf blight, Helminthosporium turcicum. This work has suffered some interruptions as a result of staff personnel changes. Current emphasis on protein quality is confined to the opaque-2 gene. Facilities for amino acid analysis are limited so major emphasis has been on the visual identification of the soft starch segregates. The widespread acceptability of these new soft-textured corns remains to be established.

MEXICO AND CIMMYT

A broad-based program designed to increase agricultural production capabilities was established in Mexico in 1943. The program involved the Ministry of Agriculture and the Rockefeller Foundation. Research activities were to be conducted under the newly organized Office of Special Studies attached to the Ministry of Agriculture. A somewhat parallel national organization was also maintained. The Office of Special Studies program as initially designed was to give attention to the improvement of corn, wheat, potatoes, beans, and forage crop production. Entomologists and soil scientists were added to the team to give coverage to all aspects of the production problems. At later stages still other activities were initiated, but we shall be concerned only with the developments with corn. A brief historical resume is justified as it provides a basis for the understanding of the current situation and the potential for the introduction and utilization of opaque-2 types in Mexico.

One of the first activities of the corn group was an intensive program of collection and classification of the indigenous corn types. This phase of the work received attention for several years and finally culminated in the publication (Wellhausen et al., 1952) of "Races of Corn in Mexico". The knowledge accumulated from such studies was so valuable that similar studies were conducted in other Central and South American countries. Much of the collection and classification work was done with Rockefeller supervision and support. In all, some 11 Race Bulletins have been published with ICA (now AID) contributing to publication costs. This identification of existing races and their characteristics has been of inestimable value in increasing the effectiveness of corn breeding programs throughout the world.

Inbreeding studies were initiated in 1944. As in the United States, the first inbreeding efforts were somewhat disappointing; it proved difficult to obtain good inbred lines. Either one or both of two alternatives appeared to be required: (1) to do inbreeding on a very extensive scale accepting the possibility that many genotypes could not be effectively perpetuated, or (2) to develop a commercial hybrid program based on lines with limited inbreeding and accept the attendant problems of maintaining genetic identity. Both alternatives were explored. The first hybrids available for potential use (1947) were developed utilizing S_1 lines.

At this same time, extensive studies were conducted comparing inter-varietal or inter-racial hybrids. Although some of these were quite high yielding no commercial use was made of such material.

In 1954 Wellhausen concluded that low average yields in Mexico were the result of four factors: (1) depleted soil fertility, (2) a low variety yield potential, (3) primitive cultural methods, and (4) an often times, limited and variable moisture supply. He presented data comparing yields of native and improved types with and without the addition of fertilizers. The following contrasts are typical.

	Varieties	
	Native	Improved
Unfertilized	5.6	7.1
Fertilized	19.4	39.5

With no changes in production practices, improvement resulting from breeding alone amounted to approximately 13% but the actual increase was so small as to be unconvincing to the farmer. Increases from fertilizer were quite impressive, nearly 4-fold, and the combination of improved seed and fertilizer were very striking, yielding approximately a 7-fold increase. The philosophy prevailed that the small-scale farmer could not afford the cash inputs for fertilizer and likely could not afford yearly outlays for new hybrid seed.

This belief led to various speculations on how best to provide improved seed to the farmers. Considerable effort was devoted to the production of synthetics and the performance of various hybrid types crossed to local varieties. Some consideration was even given to evaluation of double-crosses at both the F_1 and F_2 levels in the hopes of finding combinations which would exhibit limited inbreeding depression, thus making it possible for a farmer to save his own seed for one or two generations. These activities were more an indication of concern rather than attempts to completely redirect the breeding emphasis.

The Maize Commission was established in 1947 and given the charge of producing and distributing hybrid seed. Plants needed to be built, equipment purchased and installed, and a trained staff developed. As is true of all new seed production programs, difficulties were encountered. The quality of seed marketed was of uncertain and variable quality. Hybrids were not available for all of the ecological zones. Acceptance by farmers was low, making it difficult to gear production to potential demand.

At a later date, following a change in Mexican law, a new organization, PRONASE (Productora Nacional de Semillas) was established and given responsibility for the production and marketing of all seeds. The records of amounts of seed of hybrid and improved varieties produced during the period 1961 to 1970 are shown in Table 6. Hybrids or varieties produced during only a part of this period are not reported individually, but this production is included in the "total" column.

Columns marked by * represent hybrids produced by the Office of Special Studies. Hybrids or varieties not so marked were produced by INIA (Institute Nacional de Investigaciones Agricolas). This first group of hybrids remains the backbone of commercial use even though some have been in production for 20 years. This indicates a very slow rate of development of acceptable new material.

In no year has the amount of seed produced permitted planting more than 15% of Mexico's corn acreage to improved types. Production in 1972 would permit planting no more than 8% if all seed were used. Sale of seed by private concerns would increase these percentage figures slightly.

PRONASE has taken the position that not more than 20% of Mexico's 8 million hectares of corn is suited for hybrid use. Low fertility levels and limited and variable rainfall are cited as factors limiting potential use of hybrids. An additional limitation is that Federal law prohibits irrigation of corn in public water districts. Others feel the limited use of hybrids is a reflection of the poor quality of seed produced and lack of local availability at planting time. Criticisms of seed quality were widespread but no data were available comparing PRONASE and station-produced hybrids.

In 1961 the Office of Special Studies was disbanded. Some of the previous activities were returned to the complete control of the Ministry of Agriculture and were incorporated into a new organization INIA which was given responsibility for all agricultural research dealing with crops.

Table 6. Production in tons of seed of hybrids and improved varieties by PRONASE for the period 1961-1972 (figures in tons).

	H28	H125*	H127*	H129*	US201	H220*	H309	H352	H366	Cafime	H412*	H503*	H507*	Total
1961		47				455	85	490				412		2,070
1962		140	133		86	1,344	527	691		90	520	3,577	388	8,518
1963	33	300	151	91	65	845	1,070	1,043		214	906	3,804	1,513	11,276
1964	30	350	135	78	90	892	1,638	301		577	1,551	3,025	2,161	12,151
1965	204	27	174	83	40	469	762	601		237	1,573	3,781	3,025	11,479
1966	232			330	84	134	618	1,096	169	499	1,815	3,473	3,851	12,511
1967	68					14	721	904	234	118	1,811	1,851	1,224	7,179
1968	200	98	141	257		36	716	845	292		1,785	1,396	1,208	6,974
1969	272	104	119	100	55	146	1,141	372	1,800	46	1,161	1,625	1,809	8,752
1970	144	94		296	68	235	1,320	170	878	82	2,313	2,934	2,616	11,435
1971	411	520	31	520	9	16	977	490	619	105	5,899	2,111	1,512	13,013
1972	423					249	1,645	721		60	384	2,119	60	6,363

* Hybrids produced by the Office of Special Studies.

At the time INIA was established, it was provided all breeding stocks and records from the Office of Special Studies and has been responsible for all national breeding developments since that date. This new program has not been highly successful. Hybrids accounting for the bulk of the sales were developed and entered production during the life of the Office of Special Studies. None of the new INIA hybrids have achieved any substantial volume. Angeles (1971) in a report given to the First Maize Workshop made the following pertinent observations:

> "Improved varieties and hybrids have been available in Mexico for many years, but the area planted to them has never exceeded 15%. This is partly due to a deficient extension service but it is mainly because the official institution in charge of seed production has not been able to offer seed of the improved varieties and hybrids in sufficient amounts and with adequate genetic purity. The poor seed delivered to the farmers for many years has made them reluctant to buy seed of the improved varieties. This has caused the proliferation of private companies, mainly backed by foreign funds.
>
> "The seed production situation has been aggravated because the obsolete seed law does not permit these companies to work with the improved varieties obtained by official research, even though these companies are willing to pay a royalty for use of the improved seed.
>
> "The critical situation with respect to production of improved seeds is limiting corn production in Mexico and has to be corrected... Another factor limiting corn production is the lack of an organized efficient and integrated structure, preferably regional, that would provide to farmers all necessary supplies and facilities such as seed, feritlizers, pesticides, credit extension and marketing at a convenient time. As illustrated by the Puebla Project, the benefits of such organization will be reflected in the gradual increase of corn production."

Both INIA and the Mexican government favor retaining all seed production and distribution responsibilities under strict governmental control. Several private companies now market seed within Mexico but this is done through sufferance rather than official sanction. To obtain full legal authority to develop and market improved varieties, two requirements must be met: (1) an authorization must be obtained from the government to conduct agricultural research (at present this authority is both assigned and restricted to INIA), and (2) a procedure developed which would permit certification of seed produced. The Agency responsible for authorizing research or granting eligibility for certification is the Comite Calificador de Varidades Mejoradas. This committee includes representatives from INIA, PRONASE, the Director General of Agriculture, the Ministry of Industry and Commerce and Plant Quarantine. The national policy requires that all commercial enterprises be under the control of Mexicans. Thus, foreign-based seed companies are unlikely to receive authorization to conduct research.

Private companies are now permitted to enter hybrids in official tests. However, no standards have been established for eligibility and there is, therefore, no assurance that eligibility will be granted even though performance is equal to or better than currently grown hybrids.

Mexico has approximately 1.6 million hectares under cultivation. Corn is planted on approximately half of this area. Corn is grown under a tremendous array of ecological conditions -- from sea level to 2,700 meters in areas with ample and well-distributed rainfall to droughty conditions where production is extremely hazardous, etc. The feeling is that hybrids have a place only in the more favored localities. If improved types become available for the more arid areas, these will likely be improved varieties or synthetics. Little breeding work has been done for such areas so the increases in productivity which may be achieved remain highly speculative. The breeding accomplishments thus far and the current philosophy and emphasis set definite limits on the impact of opaque-2 for the next few years.

The opaque-2 gene is being incorporated into all of the standard lines currently used in hybrids. If derived opaque-2 hybrids were substituted for all existing normal hybrids, the impact would be minor and would leave unaffected 80% of the people living in the less favored areas where both caloric and protein deficiencies may be of periodic importance. The possibility of substitution will be largely dependent upon relative yield levels and relative storage losses.

Limited work is planned on developing improved populations. Opaque-2 could easily be incorporated into such materials either at the time of population formation or at any subsequent cycle of improvement. Although interest has been expressed in such developments, progress may be limited unless such work receives much higher priority than has been true in the past.

<u>The Puebla Project</u>

Corn has often been expressed that improvements in production capacity resulting from research benefit only the more wealthy, leaving the small-scale or subsistance farmer relatively untouched. Thus, the disparity between the two groups becomes ever greater.

It has long been recognized that improvement of the lot of the subsistence farmer is difficult. He is bound by tradition but it is this same tradition that has ensured the survival of himself and his family. He is slow to make any changes which may jeopardize his survival. Given the opportunity, however, he will respond to economic incentive to the same degree as his more affluent neighbors either locally or on a worldwide basis. The problem has been, how can this opportunity be provided? Two somewhat similar approaches have been tried -- the one in Kenya, discussed previously, and the Puebla Project now underway in Mexico.

The Puebla Project was initiated in 1967. Many agencies participated, notably the Ministry of Agriculture of Mexico, the government of Puebla State, CIMMYT (International Maize and Wheat Improvement Center) the Graduate College of the National School of Agriculture, several credit banks, and various national agencies. Details of the individual contributions of these and other agencies, while of great importance, are not vital to an appreciation of the total progress achieved.

An area of approximately 116,000 ha was selected in the Puebla area, used largely for corn production. This area is characterized by small landholding, low yields, traditional farming practices, and a high per farm consumption of produce.

The program as designed was very comprehensive, involving breeding and agronomic practices including fertilizers, herbicides, insecticides, etc., credit, insurances and extension inputs such as demonstration planting, field days, etc. Recognizing that this is an area subject to periodic drought the average results have been most impressive.

Response to applications of nitrogen and phosphatic fertilizers have been sizeable. Data from 22 experiments grown in 1967 are presented in Table 7. Results from combinations of fertilizer and population density studies are given in Table 8.

The increases in yield achieved through increased fertilization and stand densities are very substantial. Both of these factors normally exhibit large interaction effects with hybrids. Thus, had adapted hybrids been available, even greater responses might have been obtained.

Breeding

In preliminary trials eight local varieties and four hybrids and two populations presumed to be adapted to the area were compared at six locations in 1967. At only one location, Santa Ana, did one of the commercial hybrids outyield the best local variety. The hybrids included in this test were selected because of their general adaptation to high valleys, though none of these had been previously tested in or recommended for conditions typical of the Puebla area. In order to provide some genetic input into the project, an extensive survey was conducted among existing varieties and populations to identify material better suited to this geographical area. From this survey a number of items were chosen for improvement studies concurrent with other Puebla activities. The average yields of the items chosen are shown in Table 9.

The anticipated life of the project was 5 years, requiring simple and rapid improvement procedures if any genetic input was to have

Table 7. Comparative yields of plots receiving no fertilizer and "best" Fertilizer treatment. 1/

Exp. No.	Yields (kg/ha)		
	No Fertilizer	Best Fertilizer Treatment	Increased Due to Fertilization
02	100	6470	6370
04	150	5750	5600
05	30	5290	5260
06	510	4620	4110
07	250	5520	5270
08	510	7500	6990
09	1010	4100	3090
10	410	3210	2800
11	30	5660	5630
12	200	3790	3590
14	630	2600	1970
15	2880	4100	1220
16	1490	6510	5020
17	1990	2710	720
18	3540	4660	1120
19	480	3580	3100
20	830	4640	3810
21	2290	4600	2310
22	1490	4480	2990
23	970	4450	3480
25	320	5050	4730
27	1400	3020	1620
Av.	978	4650	3672

1/ Puebla Project, 1967-1969.

Table 8. The maximum effects of fertilization and population in rate-densities studies carried out in 1968.

No. of Exp.	Yield (kg/ha)		Increase
	No fertilizer and 30,000 plants/ha	Best fertilizer and stand combination	
06	210	7610	7400
07	810	8790	7980
08	2200	7770	5570
09	1280	8630	7350
10	870	4500	3630
11	850	7040	6190
12	2510	5600	3090
13	640	5510	4870
Av.	1171	6931	5760

Table 9. Yields in tons/ha for the hybrids and varieties included in the Puebla Improvement Program.

Entry	Yield	% Local Check	Days to Bloom
H129	6.0	115	100
H28	5.9	113	92
Composite 1500	5.8	112	98
Pinto	5.7	110	95
Local Variety	5.2	100	92

Table 10. Some pertinent information on various aspects of the Puebla Project. 1/

	1968	1969	1970	1971	1972
Total farmers in area (000)	47.5	47.5	47.5	47.5	47.5
Total hectarage of maize (estimate) (000)	75	75	75	75	75
Farmers taking credit	103	2561	4833	5259	6202
Hectarage receiving credit	76	5743	12,661	14,438	17,581
Average yield of maize by credit users (kg/ha)					
Farmers on credit lists	3985 2/	2829	2732	2679	2920
All Farmers	2140	1832	1962	1927	2499

1/ From Report to CIMMYT Trustees, Program Review, 1972-73.

2/ Estimated from first 103 credit borrowers. Possibly not relevant to subsequent years.

impact during this period. Two procedures were followed: mass selection and the use of cryptic double-crosses ($S_1 \times S_1$). The latter approach, because of the time required for testing, could not come into use before the last year of the project. Somewhat quicker results might be expected with mass selection but here also the improved types could be made available for demonstration plantings but not for widespread use. The details of these breeding procedures will not be reported as their effect on the success of the project are minimal.

The Puebla Project has achieved some measure of success. More striking results might have been obtained had adapted hybrids been available and prior answers been available for some of the local soil problems. However, the effort has been worthwhile and has had a decided impact on corn production in the area. Some pertinent data are reported in Table 10.

The results obtained in the Puebla Project strongly indicate that substantial increases in corn yields are possible even in areas previously characterized by low yields. If potential yield level is the only factor determining use of hybrids, then the current philosophy in both INIA and PRONASE may require re-examination. Had suitable hybrids been available, based on experience in other areas, fertilizer and population-density responses would have been even greater than those obtained.

CIMMYT

CIMMYT was established in 1966 in Mexico as an international center to conduct research on corn, wheat, barley, rye, and triticale in various areas of the world but with special emphasis on the developing countries.

With corn (Osler, 1973) the objectives are listed as follows: (1) to assist in the development of national and regional maize improvement programs,and to supply technology for those programs which will benefit the largest number of farmers, especially in developing countries, (2) to increase the efficiency of maize yields, as measured by yield per land unit, and by production costs per measure of grain, and (3) to improve the nutritional quality of maize, especially in protein quantity and quality.

To assist in achieving these objectives, five regional centers are currently operative: (1) Central American Maize Program - Mexico; (2) Andean Maize Program - CIAT, Colombia; (3) West African Tropical Maize Program - IITA, Nigeria; (4) East African Tropical Maize Program - Kitale, Kenya; and (5) the Inter-Asian Corn Program - Bangkok, Thailand. CIMMYT also sponsors international trials, workshops, training programs, and maintains the maize germ plasm bank. In addition to these more formal activities cooperation has been established with various institutions within the United States dealing with specific problems of mutual interest. Possibly no other single agency has a similar potential for the production and distribution of new materials or techniques on a worldwide basis.

CIMMYT conducts three separate types of international trials. The first of these, the International Maize Adaptation Trials (IMAN), includes entries representing the world diversity of germplasm. These trials are grown at selected sites in the corn-growing areas of the world to determine areas of adaptation of races or composites and to obtain preliminary information on the influence of various environmental factors (day-length, temperature, etc.) on flowering and yield responses. The greatest diversity of corn exists within the Latin American countries and this material is being extensively used in other areas of the world. Information on areas of adaptation of the races or racial types would permit a more intelligent distribution and more efficient use of exotic materials.

A second group of international trials involves populations undergoing systematic improvement or newly formed populations of special interest. Such populations are grown at several locations in Mexico where they are subjected to artificial exposure to pathogens and insects of major local importance. These populations are also evaluated in other selected areas of the world where experience has shown them to be reasonably well adapted. This procedure provides a very broad environmental exposure and, hopefully, will permit development of populations having a wider than normal range of adaptation.

Opaque-2 is being introduced into a number of these populations using a bulk backcrossing scheme (Fig. 5). This procedure permits population improvement to proceed uninterrupted and provides an opportunity for opaque-2 sub-populations to be derived at any stage of improvement.

If the development of high-lysine types merits high priority, greater efficiency would be achieved if the breeding procedure were reversed, using the opaque-2 stock for direct selection and progeny testing and carrying the normal as the back-cross population. This would ensure fixation of modifiers affecting kernel texture and would permit selection for special gene combinations influencing yield or disease and insect resistance that may operate differentially in opaque-2 and normal genetic backgrounds.

A third series of international trials were initiated in 1970 involving only opaque-2 materials. Any short-range commercial production of opaque-2 must come from this material. The number of countries participating in these trials is listed in Table 11. The summarized data on yield for the 1970 and 1971 tests are given in Table 12.

Considerable emphasis is being given to "modified" opaques in the hope that a more nearly normal texture endosperm will minimize problems of yield, disease and acceptability. The limited comparative data now available (Table 13) indicate that modified types are somewhat higher yielding than typical opaque-2 but remain lower yielding than normal. It appears that for sometime to come any acceptance of opaque-2 must be based on its contribution to improved nutrition.

Figure 5. Schematic representation of procedures used for parallel improvement in normal and opaque-2 counterpart populations.

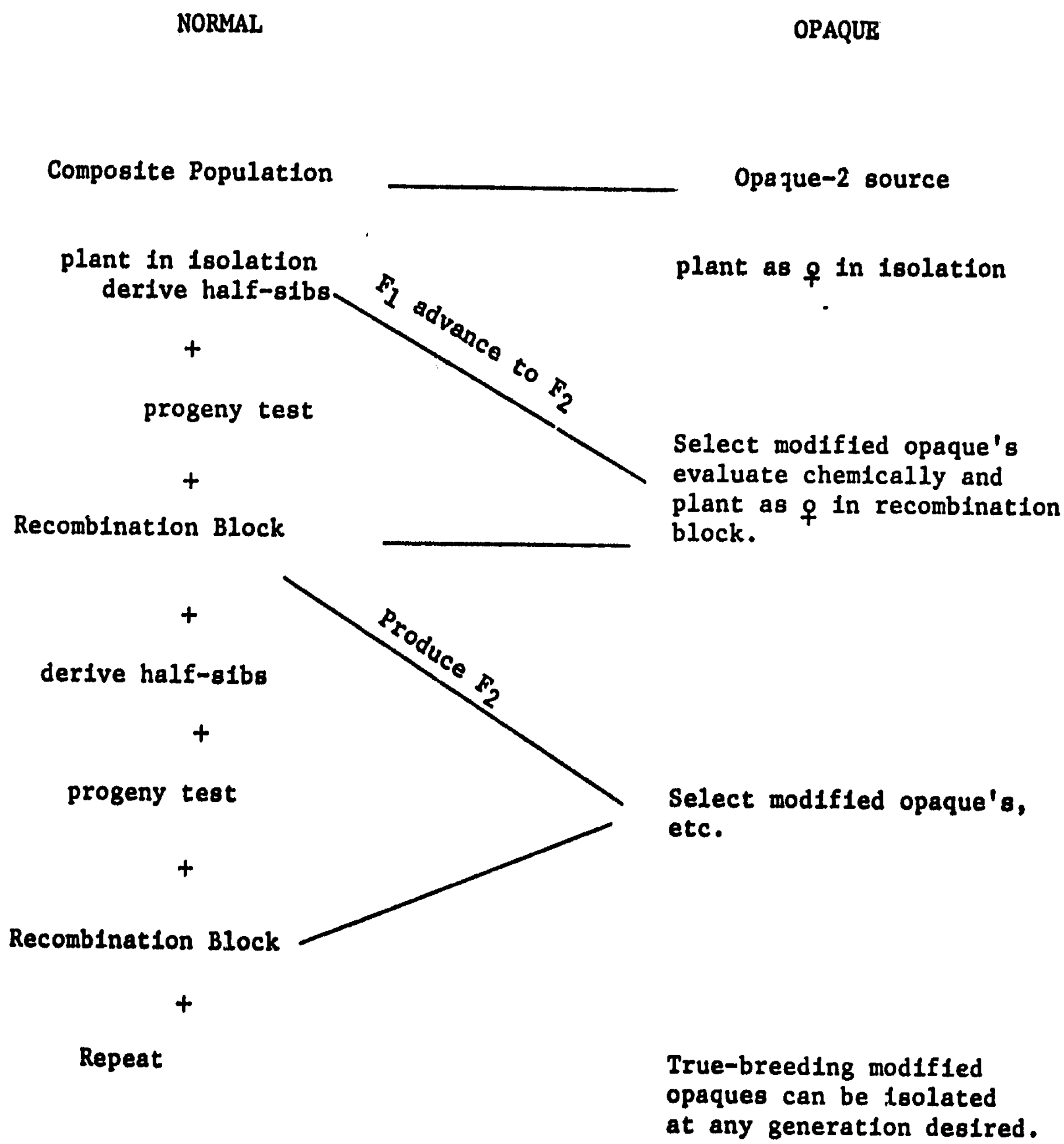

Table 11. International opaque-2 maize trials sent to different countries during the years 1970-1972.

	1970	1971	1972
Angola	--	--	1
Argentina	--	1	1
Brazil	1	3	2
Colombia	1	2	6
Nicaragua	1	1	1
Panama	1	1	--
Guatemala	1	1	--
Honduras	1	1	--
Costa Rica	1	1	--
Ecuador	--	--	2
Venezuela	--	1	--
Peru	--	2	2
Chile	--	1	1
Ivory Coast	--	--	2
Jamaica	--	1	1
Philippines	1	1	1
Ceylon	--	--	1
India	3	2	4
Thailand	1	1	1
Pakistan	1	1	--
Nepal	--	--	1
Ethiopia	--	--	1
Ghana	--	1	1
Kenya	--	--	2
Uganda	--	--	1
Nigeria	--	--	3
Mexico INIA	4	4	7
USA	--	1	1
UAR	--	1	--
El Salvador	1	1	--
FAO	--	1	10
	18	30	54

Table 12. Varietal means from the 1970-71 IMAN (International Maize Adaptation Nursery) trials compared over 23 locations.

Variety	Mean Yield (kg/ha)	Days to Flower	
		American Tropibal	African Tropical
QK 37	4989	70	85
Pioneer X304A	4769	69	84
Local	4610	71	80
Agroceres 501	4545	68	83
H512	4235	68	79
H511	4176	67	74
Central Mex	4121	71	85
Comp. L. (ME)C2	4009	65	79
Poey T-66	4007	72	87
Poey B15	3947	70	82
(MIX.1 x Col. GPO.1) x Eto BL	3943	74	90
H507	3929	76	91
Eto Blancho	3924	73	88
H613B	3669	79	88
Pioneer x 306A	3668	67	81
Comp. Norte Americano	3608	66	76
Kisan	3550	68	81
Vijay	3539	66	78
Nicarillo	3500	70	85
Sint. Lin. Res. Ach.	3487	68	82
Comp. Caribe C3	3473	72	86
PMS 264	3439	73	86
(USA x Carib. Comp.)	3430	63	73
Comp. B (C2)	3408	72	88
H. Abati 2	3332	58	65
Harapan	3319	70	86
Metro	3287	68	81
PB 5	3276	69	82
Agroceres M20L	3236	72	87
Tuxp. Comp C3	3155	73	88
Sint. 10 Lin. AM.Crist.	3136	69	84
Cortazar M-C4	3124	74	87
Jaune De Bouake	3123	72	86
H507E	3050	76	92
Comp. Res. Thrips	2904	70	80

Table 12 continued.

Variety	Mean Yield kg/ha	Days to Flower	
		American Tropical	African Tropical
H. Pergamino Guazu	2804	56	62
ClPB-ACl-Comp. 1	2737	62	66
Atherton Dent	2712	71	84
PMS 263	2394	79	89
KO No.6	2381	54	61
Fukko No.8	2297	53	58
Sint. Nicaragua 2	2278	59	68
American Early	2220	69	80
ClPA	2209	59	61
Hgo. 8-PC4	2025	72	76
NA3 EL-Gamal	1947	58	65
Zapalote Chico Oax 179	1777	51	57
United 106	1672	48	54
Funks G43	1658	48	56
Laltine	1534	56	66

Table 13. Grain yields (kg/ha) of normals, modified, and opaques in 5 different populations. 1/

Population	Yield		
	Normal	Modified	Opaque
Composite K	4767	4010	4072
Yellow Hard Endosperm Composite	4685	4338	3621
Ver 181 - Ant. gpo 2 Ver 1 Opaque-2	3928	4235	3176
CIMMYT o_2 Composite	5238	4419	3744
White Hard Endosperm Composite	5606	4460	4113

1/ From Progress Report of UNDP-CIMMYT Global Research Project Report.

COLOMBIA AND CIAT

The development of CIAT (Centro Internacional de Agricultura Tropical) in Colombia parallels that of CIMMYT to some degree. Both are nonprofit organizations dedicated to the acceleration of agricultural development and productivity so as to improve the diets and welfare of the peoples of the world and both had their roots in cooperative programs involving a national government and the Rockefeller Foundation.

OIE (Officina Investigaciones Especiale) was organized in 1950 to give special emphasis to the improvement of corn, beans, wheat, and potatoes. The preceding national research activities with these crops were completely merged in this new organization. In 1955 a new and expanded organization was developed and designated DIA (Departimento Investigaciones Agropecuaria). Still later ICA (Instituto Colombiano Agropecuaria) was formed which is now responsible for all national agricultural research, education, and extension. ICA cooperates closely with other governmental agencies responsible for land development, natural resources, production and marketing, and agricultural credit.

ICA

The problem of corn improvement in Colombia is complicated due to great differences in altitude, temperature, rainfall distribution and intensity, and variation in soil characteristics. Corn acreage is estimated at approximately 850,000 hectares.

Colombia has been divided into five climatic zones covering the corn producing areas from sea level to 2800 meters. The current breeding stations and the elevations they serve are as follows:

Zone 1	Tulipana	10 - 600 meters
Zone 2	Palmira	600 - 1200 meters
Zone 3	Tulio Ospinia	1200 - 1700 meters
Zone 4	La Selva	1700 - 2200 meters
Zone 5	Bogota	2200 - 2800 meters

Each of these stations has one or more associated satellite stations where regional trials are conducted. Additional district stations are available for demonstration plantings of improved types and various agronomic practices. In each of the regional trials information is obtained on the relative resistance to disease and insect pests as well as yield.

Corn breeding under the OIE and DIA (Department of Plant Sciences) regimes followed the conventional pattern of isolating inbred lines and the utilization of these in the production of double-cross hybrids. The first hybrids released were adapted to zones 2 and 3 where corn production reaches its greatest intensity. Some effort was also devoted to the development of improved varieties.

The ICA program is both dynamic and modern and closely geared to the requirements of the country. It is recognized that a very long time period will be required to develop an array of hybrids to serve all of the ecological niches where corn is currently grown. As an alternative, increasing emphasis is being given to the development of improved populations and the evaluation of these in inter-population hybrids.

Improved seed is used to plant approximately 30 percent of the total acreage. This use, however, is concentrated in the Cauca and Atlantic areas where 90% and 50%, respectively, of the acreage is planted to hybrids. These are areas of large-scale mechanized farms. The 70 percent of the corn acreage not planted to improved types largely represents the small landholders who live in areas where current hybrids may not be markedly superior to the local varieties.

Considerable emphasis has been given to the development of inter-population hybrids. This approach has been useful in developing material for the higher elevations, zones 4 and 5. Consideration is also being given to assisting selected farmers representing special niches within these areas to conduct mass selection for prolificacy in their local types. Long-term selection experiments conducted at Bogota for prolificacy have been shown to be highly effective in increasing both ear number and yield. In one composite population, 4 cycles of selection increased average ear number by 33% and yield by 49%. Further evaluation trials may bring some slight reduction in these percentage gains but there can be no question as to the overall efficiency of the selection practiced. Effective indirect selection can therefore be done by observant but untrained personnel.

Agronomic studies involving fertilization, population densities, and the evaluation of herbicides and insecticides are conducted at each of the breeding and satellite stations. ICA is responsible for the evaluation and registration of all agricultural chemicals.

ICA has conducted extensive studies and demonstrations with opaque-2 materials. The opaque-2 gene has been or is being introduced into all commercial lines and into many of the populations undergoing improvement. Studies with flour processed from opaque-2 corn indicate it can be substituted for 30% of wheat flour for making bread, 50% in pastas, and 70% in cakes and cookies. Since Colombia is an importer of wheat such substitutions could have an appreciable effect on balance of payments.

Extensive studies have been conducted by El Instituto Colombiano de Bunestar Familiar - Division of Nutricion on the nutritional value of opaque-2 in the feeding of protein-deprived children. Return to normal health and growth patterns have been spectacular.

Feeding trials with pigs have been conducted on farms using the traditional system and substituting only opaque-2 for normal corn. The results have been quite striking, resulting in a 2 to 4-fold increase in growth rates.

In spite of these extensive demonstrations of the potential value of opaque-2 corn, little increased use is visualized for the present hybrids. Commercial processing will continue at about the current level. Other food or feed uses will be dependent upon the development of new types.

In highland areas the corn used for human food is floury in texture. Opaque-2 materials would be readily acceptable but the current opaque-2 hybrids are adapted to much lower elevations. The problem of incorporating the opaque-2 gene, floury in texture, into populations, already floury due to the floury-1 gene, posses special genetic problems. The two floury types are indistinguishable to the eye and either chemical analysis or genetic test-crosses must be used for identification.

Preliminary evidence suggests that the new ninhydrin test may provide a rapid method for the identification and separation of floury-1 and opaque-2 kernels. If the efficiency of this rapid chemical test is confirmed it can be substituted for the more time-consuming test-cross system used till now. High lysine populations adapted to the highlands should be available within a two-year period.

At lower elevations both ear rots and insect infestation become much more serious. Corn used for human food is characteristically flint. The modified opaque-2 types may provide a partial answer to these limiting factors. Such types are in an advanced stage of development. Additional demonstration and field trials will be conducted to establish acceptability and insect resistance as rapidly as experimental seed quantities will permit.

Although the price of corn in Colombia is about twice that of the world market, acreage is decreasing because soybeans and cotton are more profitable. An early corn type is now available which could be grown preceding the regular cotton crop. Legal restrictions prevent planting of cotton before about July 15 in this region. If the practice of growing early corn preceding cotton is adopted a substantial increase in corn production could result.

Caja Agraria

The Caja Agraria is a government agency organized to provide credit to the agricultural sector. It also had the initial responsibility for the commercial production of hybrids and improved varieties. It still remains the sole source of the two opaque-2 hybrids, ICA 207 and ICA 255. Caja Agraria has production areas and processing plants within each of the five corn breeding zones. At present some 23 hybrids and improved varieties are commercially available. The production and sale of the opaque-2 hybrids are shown in Table 14.

Seed production was somewhat reduced in 1972 because delays in planting resulted in lower yields per hectare in the seed fields.

Table 14. Seed of opaque-2 corn produced and distributed through Caja Agraria, 1968 through 1971.

Year	Tons sold	Hectares planted	Farmers benefited
1968	2	100	250
1969	8	500	400
1970	40	2000	8000
1971	230	13,200	52,800

Private Seed Production

Several people who received training in Caja Agraria have now established private seed companies. The largest of these is Proacol with headquarters at Palmira. This company has its own breeding program and now markets material of its own development as well as materials developed and released by ICA.

It appears likely that private seed companies will eventually produce and sell the bulk of the hybrid seed used. The private companies are less interested in the production and sale of improved varieties as these do not carry the same likelihood for repeat sales. There is considerable observational data indicating the commercial use of F_2 or advanced generation seed. There is also evidence that the local varieties in many areas have been changed in appearance and increased in yield through natural crossing with the improved types.

CIAT

CIAT (Centro Internacional de Agricultura Tropical) near Palmira was organized in 1968. Close cooperation with ICA has permitted effective operation even though the new facilities were not completed until late 1973.

CIAT states its basic operational philosophy as follows: (1) to develop and demonstrate a pace-setting level of program performance; (2) to collaborate and cooperate with national institutions throughout the lowland tropics on research educational and extension programs, and to assist in the strengthening of these institutions; (3) to be catylitic in the economic and agricultural development of the tropics; (4) to maintain mutually complementary programs and relationships with other international and regional organizations, particularly the International Rice Research Institute (IRRI), the International Maize and Wheat Improvement Center (CIMMYT), the International Institute of Tropical Agriculture (IITA), and the Instituto Interamericano de Ciencias Agricolas (IICA); and (5) to develop and maintain cooperative linkages with agricultural research and training institutions in the developed countries.

The corn program is a broad-based integrated operation which attempts to give consideration to improvement, to all aspects of the production system, and to final utilization as food, feed or industrial processing. A preliminary step has been to make an assessement of those factors which limit production in the Andean zone and to give these factors primary consideration in research activities.

The breeding program involves the collection and testing of a wide range of diverse collections and types. CIAT participates in the evaluation of the International Maize Adaptation Nursery (IMAN) and the several early generation trials from CIMMYT as well as trials from the Central American (PCCMCA) and Inter-Asian (ICAP) Programs. A summary of these trials is presented in Table 15.

Promising populations or races identified are subjected to one or more types of recurrent selection or the conventional inbreeding and hybridization approach. Most all of the lowland tropical types are characterized by a very low grain-stover ratio. The excessive height contributes to serious lodging problems. Extensive use is being made of the dwarfing gene, brachytic-2, and to the short plant types developed in the Central American Program. Opaque-2 is being introduced into all populations of interest.

Table 15. Results of international trials planted at CIAT near Palmira, Colombia during the seasons 1970B and 1971B.

Trial	Name		Number Entries	Number Reps	Yield kg/ha	Best Entry	kg/ha	Origin
E70B-20	IMAN		50	2	1816	Comp Nte Am	5445	Peru
E71B-20	"		50	2	6106	ICA H154	9828	Colombia
E71B-21	ICAP		21	4	6597	HS209	8116	"
E71B-27	"		9	2	6756	Cuba 40 x Cuba	7945	Thailand
E71B-25	PCCMCA	(ME)	27	4	7248	Dessarraul Exp	9671	Honduras
-24	"		30	4	7199	" HB-105	9029	"
E71B-25	"	(op)	9	4	4852	Comp B1 Car o_2	6214	CIMMYT
-26	"	(br)	9	4	6481	J6309 x 6309	9114	Poey Seed Co.

In the Cauca Valley, the Atlantic, and the Llanos zones, temperature and rainfall distribution would permit the production of 2 or 3 crops per year if suitable varieties were available. Experiments have been conducted to establish critical day lengths and photo-sensitive or insensitive types. Photo-insensitivity appears to be rather simply inherited and can thus be incorporated into any line or population giving it a broader range of adaptation. All breeding populations are routinely evaluated for insect and disease resistance.

In the Andean zone, yields average about 1000 kg/ha. This is due to low fertility, low population densities, and inadequate weed control. Fertilizer-density experiments have shown marked yield response to fertilizer applications and plant populations. In some areas minor element deficiencies are important, probably as a result of unavailability due to high pH. In other areas low pH and low phosphate availability are important problems.

The potential for 3 crops per year requires some consideration be given to various systems of minimum tillage to reduce the time between harvest and replanting. Data from 3 crop seasons at CIAT indicate no yield differences among: (1) complete removal of stover, (2) burning, (3) chopping, or (4) leaving the entire plants on the soil surface. No land preparation was done for any of these crops except the machine planting operation.

All new populations are evaluated for industrial potential and nutritional qualities before release for commercial production.

BRAZIL

Brazil ranks second in world corn production. Approximately 85-90% of this production is in central and southern Brazil, in the states of Minas Gerais, Sao Paulo, Parana, Santa Catarina, and Rio Grande do Sul. In these areas the primary use is livestock feed, primarily hogs and chickens. The remaining 10-15% is distributed throughout the remainder of Brazil and a sizeable fraction of this production is used for human food.

More acreage is devoted to corn than to any other single crop. Average yields are low throughout Brazil, approximately 1300/kg/ha. The situation is even worse than these figures imply. The large-scale farmers in the major corn producing areas are fully mechanized and use all the recommended technologies. Yields obtained by these farmers would average in excess of 4000 kg/ha. Some small-scale farmers have adopted hybrid corn but have made no other adjustments to their farming practices.

Native soil fertility is low throughout much of Brazil. Most soils range from acid to highly acid, aluminum toxicity is widespread, and phosphate deficiency almost universal. In addition, the soils tend to be low in organic matter and to have a low base exchange capacity, and minor element deficiencies (zinc, boron, sulphur, molybdenum, etc.) are widespread. ANDA, a national association of fertilizer manufacturers and dealers, estimates that the average fertilizer use on corn is 4 kg/ha of the elements N, P and K. Lime is available, but the initial cost plus the added costs of transportation and distribution limits its use.

Research on various aspects of corn production has been conducted at only a few research centers. The generality of these research findings is uncertain as no detailed soils map has been developed. These facts plus the low farmer price for corn may account for the continuation of the traditional system of corn culture.

The production situation has worsened appreciably in recent years through the introduction of two new crops, soybeans and sorghum. As both crops are new to Brazilian farmers' experience, they have been willing to adopt new technologies. Mechanization is required as both crops are becoming established in the "frontier" areas. They are also replacing corn in the large-scale mechanized farms in the older established areas. Yields of corn and soybeans are roughly comparable, but at current price levels soybeans enjoy a 5-fold price advantage. Many experts feel that if the trend from corn to soybeans by the more productive farmers continues, Brazil may soon become a corn importing nation. Such a situation would have a very adverse effect on both pork and poultry production.

Eighty-five percent of Brazil's corn production lies south of 16^{o} latitude. Within this area it is estimated that 45% of the corn acreage is planted to hybrids or improved varieties. Both public and private agencies are involved in the production and distribution of improved seed but all research on production practices is done by state or federal research agencies.

Public Research

Campinas. Corn breeding research was initiated at the Instituto Agronomo at Campinas in 1932. A series of double-cross hybrids were developed. Following the earlier pattern with cotton, responsibility for seed production was assigned to Extension. Hybrid seed was produced and marketed under the auspices of the Secretary of Agriculture of the State of Sao Paulo. In addition, foundation single-cross seed was supplied to qualified farmers who produced and marketed certified seed. Seed sold by the Secretary of Agriculture is rather heavily subsidized. Inbred lines are not released to private agencies but they may purchase seed of foundation singles or improved populations. A record of seed sold by both public and private agencies for the period 1947 through 1974 is presented in Table 16.

The corn program at Campinas was reorganized in 1962 and subsequent work has been devoted almost entirely to population improvement studies involving 9 populations. The protein quality genes, opaque-2, opaque-7, and floury-2, are being introduced into all of these populations along with a series of other endosperm mutants (shrunken-1, shrunken-2, sugary-1, sugary-2, waxy, etc.). The interest in this latter group of mutants stems from their possible interactions with opaque and their general response to modifiers affecting either texture or quality.

The population improvement studies involve the close cooperation of the breeder, entomologist, pathologist, and chemist. Considerable progress has been achieved in developing increased levels of resistance to the rice weevil. In the third cycle of selection, levels of infestation have been reduced by 50%. The increased resistance is related to a greater husk extension, a greater number of leaf blades (i.e. husks), and to an increased incidence of prolificacy. It is much easier to get good husk extension on two or more small ears than a single large ear.

The main disease proglems are leaf blight (Helminthosporium turcicum) and rust (Puccinia sorghi). Single gene resistance to the first has been available from Illinois and to the second from Iowa. Both types of resistance have been quite effective under field conditions. The fall army worm (Spodoptera sp.), the ear worm (Heliothis), and several types of stalk borers remain serious problems.

Detailed studies have been conducted on the yields of the individual populations and their performance in inter-population hybrids. The best of such crosses are essentially equal to the best commercial double-cross hybrids. No plans are being considered for the development of lines from such populations. If this were done combinations among the best of these should give an additional yield increase of 25 to 30%. Populations will be released to the private companies who can do inbreeding and hybrid evaluation if they choose.

Some research has been done on hybrid evaluation at various population densities and fertility levels. De Miranda and De Miranda (1971) have published data involving 50 fertilizer trials conducted over a three-year period. Response surface functions were fitted and fertilizer formulas were calculated which would lead to: (1) maximum yield, (2) maximum profit per acre, or (3) maximum profit per capital input. Results varied with the different soils studied but as a broad generaliza-

Table 16. Sales of corn hybrids in Brazil for the period 1949-1974.1/

Year	Agroceres	Secretary of Agriculture Sao Paulo	Associated Growers		Total
			Minas Gerais	Sao Paulo	
1947	125	1,875			2,000
1948	2,900	9,075			11,975
1949	4,450	15,625			20,075
1950	5,425	6,200	1,250		12,875
1951	13,000	32,975	2,500		48,475
1952	18,325	42,970	10,000		71,295
1953	73,750	38,925	18,750		95,425
1954	54,200	25,875	22,500		102,675
1955	65,200	71,300	37,500		174,000
1956	71,625	43,700	32,500		147,825
1957	88,175	54,650	50,000	7,000	199,825
1958	138,100	56,000	50,000	34,000	278,100
1959	133,975	132,975	43,750	50,000	360,700
1960	147,775	107,517	50,000	50,000	355,292
1961	192,800	162,500	60,000	60,000	475,300
1962	246,100	207,062	70,000	87,500	610,662
1963	332,825	208,750	88,000	100,000	729,675
1964	154,650	242,500	35,300	100,000	532,450
1965	346,350	168,750	28,000	181,824	770,824
1966	351,000	240,000	75,000	127,528	845,014
1967	358,425	325,000	65,000	291,369	1,115,258
1968	417,919	292,500	63,000	304,300	1,153,419
1969	500,823	397,596	79,250	318,852	1,317,669
1970	560,775	259,000	171,250	320,500	1,311,525
1971	2/	154,425	185,750	284,500	624,675
1972	582,100	164,550	191,000	584,350 3/	1,522,000
1973	456,700	260,000	177,500	603,000 3/	1,497,200
1974	480,150	243,000	162,000	550,000 3/	1,435,150

1/ Figures given are numbers of 40 kg bags.

2/ Seed produced on T cytoplasm females and sold as feed corn.

3/ Includes seed production by Cargill.

tion, economic responses (maximum profit per capital input) could be expected from application of 14 to 41 kg/ha N and 16 to 18 kg/ha P. This contrasts with the average, 4 kg/ha of elements, which are actually used.

Piricacaba. The School of Agriculture of the University of Sao Paulo is located at Piricacaba. Work on corn breeding is concentrated on population improvement, no work being done on the development of inbred lines or hybrids and very little work on production practices.

Two broad populations are being studied; one largely flint in origin and the other dent or semi-dent. The dwarfing gene, brachytic-2, is being introduced into both populations to reduce plant height and thus achieve greater resistance to lodging and a better dry matter distribution. Opaque-2 is also being used but at present facilities are limited for routine chemical evaluation.

Seed of improved types is available for sale to certified growers. The main emphasis of this program, however, is directed toward quantitative genetic studies rather than plant breeding per se.

Corn breeding programs have been underway for some years in the states of Minas Gerais and Rio Grande do Sul. In each case lines have been released for general use but such lines have not played an important role in the hybrid seed development picture thus far.

Federal

In the past, the great bulk of the corn breeding and crop production research has been conducted by the state research systems. Plans have now been developed for a more active Federal involvement. SPAR (Special Project for Agricultural Research) has been established under a $13 million USAID loan to the Brazilian government. This organization has as its objective: "To develop in the National Department of Agriculture (DNPEA), its Institutes, and in cooperating agencies the capacity to plan, orient, execute and evaluate priority research on a national basis. The research should provide advanced technology necessary to transform traditional agricultural methods and increase agricultural production." The staff for this organization is not yet fully assembled but plans are to concentrate on corn, sorghum, soybeans, beans, rice and livestock. Work with crop plants will include breeding, soil fertility and land use, cultural practices, plant pathology, entomology, weed control, harvesting and storage, and economics. This program could become extremely effective in establishing research priorities for the different ecological areas in providing training and in supplementing the existing research competence of the existing state research agencies.

Cornell University and North Carolina State College, operating under a USAID/TAB contract, have been engaged in a very extensive study of fertilizer response data, the establishment of soil-testing laboratories, and the development of suitable analytical techniques which will permit valid and economic fertilizer recommendations. Current soil extraction procedures for phosphorus in the acid oxysols correlate poorly with plot or field results.

One experimental site is located near Brasilia on infertile soils low in calcium, magnesium, and phosphate and high in aluminum. This area is characterized by Cerrado vegetation indicating low water-holding capacity, and therefore subject to drought even during the rainy season. Corn is being used as the test crop. Yields of 7 to 8 tons per acre have been obtained with the following fertilizer regime: 4 tons dolomitic lime, 135 kg P, 70 kg K, 225 kg N distributed at 3 periods, 50 kg zinc sulphate, 10 kg borax, and 0.5 kg sodium molybdenate Yearly fertilizer applications at this level would not be economic. Long-term experiments will be required to establish residual effects and, therefore, the optimum yearly rates of fertilizer application. These Cerrado soils are not extensively used at present.

Extension

In the State of Sao Paulo the Extension Service has responsibility for sale of foundation seed and for the production of the double-cross seed sold by the Secretary of Agriculture. In Sao Paulo and throughout the rest of Brazil, Extension Agents advise farmers as to time and rate of planting, on weed control, and on proper procedures for harvesting and storage. With corn, such advice has been adopted only on the large-scale mechanized farms. Small-scale farmers continue to follow their traditional practices. Corn is not a cash crop for this group and, therefore, any cash crop takes precedence in either timeliness of operations or cash inputs.

A new and extensive Extension effort was mounted in 1973 funded by CIC. One hundred demonstration tracts, each 10 hectares in size, were distributed along the 3 export corredors. The crops grown were corn, sorghum, and soybeans, and modern machinery and technology were employed. Fertilizers and herbicides were used, and the resulting crop harvested by machine. Cost figures will be accumulated so the relative profitability of each crop can be assessed. One or more field days were held for each site.

Private Research

The certified or associated seed growers account for a sizeable fraction of the total seed produced (Table 17). Such producers, however, bear no share of the cost of hybrid development. They are entirely

Table 17. Yields from the first International Corn Trials in Brazil, 1970-71.

Variety	Yield kg/ha	Variety	Yield kg/ha
QK 37	4989	Metro	3287
Pioneer x 304A	4769	P. B. 5	3276
Agroceres 501	4545	Agroceres M-206	3236
H 512	4235	Tux. Comp. C3	3155
H 511	4176	Sint 10 Lin Am. Crist.	3136
Centralmex	4120	Cortazar M-C4	3124
Comp. L(Me) C2	4009	Jaune De Bouake	3123
Poey T-61	4007	H 507 E	3050
Poey B-15	3947	Comp. Res Thrips	2904
Mex. I x Col. GPO-1 x Eto B1	3943	H. Pergamino Guazu	2803
I 507	3929	C1PB-AC1-Comp. 1	2737
Eto Blanco	3924	Athertien Dent	2712
I 6138	3669	PMS 263	2394
Pioneer x 306A	3668	Ko No.6	2381
Comp Norte Americano	3608	Fukko No.8	2297
Kisan	3550	Sint Nicaragua 2	2277
Vijay	3539	American Early	2220
Vicarillo	3500	CIPA	2209
Sint. Lin. Res. Ach.	3487	Hgo. 8 PC4	2025
Comp. Caribe C3	3472	Nab El-Gamal	1946
MS 264	3439	Zapalote Chico Oax-179	1777
SA x Carib. Comp.	3429	United 106	1672
Comp. B. C2	3408	Funks G43	1657
Abati 2	3332	Laltine	1534
arapan	3319	Variedade Local	4610

dependent upon the public programs for new parental stocks and the emphasis in public programs has shifted almost completely to population improvement. New improved types, therefore, will be either populations or population hybrids. Extensive data are not available but Table 18 provides comparative data on the relative performance of some of the current hybrids and populations. These data represent results obtained in Brazil from one of the CIMMYT Maize Adaptation Trials. While grown for another purpose, they do provide some comparative information on hybrids and populations. The highest yielding entries are hybrids. Higher yielding populations will certainly be developed but none now compare favorably with the hybrids. Only limited tests have been made of inter-population hybrids.

Agroceres

Corn breeding work was started at Vicosa, Minas Gerais, in 1936. Using materials developed in this program, Agroceres was founded in 1945 and produced 11 tons of hybrid seed. It now is reputed to be the fifth largest seed company in the world. In addition to hybrid corn, it now produces and markets forage and legume seed for pastures, vegetable seed, and most recently, four breeds of swine.

Foundation materials in the corn breeding program include the local Cateto type, yellow Tuxpan from Texas, related yellow Tuxpano from Mexico, the Caribbean races, and additional local varieties. The bulk of the breeding work has been devoted to conventional inbreeding and hybridization though more recently, some effort is being expended on population improvement. Such improved population will eventually be used as sources of new lines as the company policy is to market only hybrid seed.

In both inbreeding and testing phases, selection pressure is applied for yield, prolificacy, insect and disease resistance, and suitability for machine harvesting. Opaque-2, waxy, and the dwarfing gene, brachytic-2, are being incorporated into all hybrids and populations.

Breeding work is conducted in 3 areas; Rio Grande do Sul, Sao Paulo, and Gois. Nine seed production centers are located within this three-state area. Heavy reliance was placed on T cytoplasm and in 1970, severe losses were sustained from Race T of Southern Corn Leaf Blight. All T cytoplasm hybrid seed was marketed as feed grain. Normal cytoplasm seed was increased and by 1973, seed sales were nearly equal to the pre-1970 volume.

Table 18. Comparative yields of opaque-2 corn in Brazil and their average yield in International Trials, 1972-73.

Variety	Yields in kg/ha	
	Brazil	International
Shakty	3670	3503
Agroceres 502	3551	3605
(Mix.1 x. Col. Gpo) EtoB	3550	3470
Ven. 1 Opaco-2	3548	3486
Comp K x La Posta	3507	3486
Agroceres 504	3452	3527
Comp. Bl. Caribe	3408	3550
Local Normal	3401	3700
INIA 20 x 19	3371	3948
Thai Opaque-2 Comp.	3334	4171
Tuxp. PD (MS6) Sel Am	3237	3297
Comp. Opaco	3114	3216
INIA H412	3065	3348
Nicarillo	3021	3691
Tuxp. x Ant Gpo 2	3009	3462
INIA (AC x RD) br-2	3008	3528
Proteina	2933	3714
ICA 208	2926	3745
D19	2912	3647
D17	2884	3736
Local o-2 Variety	2739	3663
Comp. Grano Duro	2738	3631
Thai Opaque-2 Comp. 1	2737	3368
Ver. 181 x Ant. Gpo 2	2699	3289
Raltan	2698	3518
INIA Comp. 412	2678	3516
La Posta	2621	3489
Foremaize Opaco-2	2547	3153
CIMMYT Opaque-2 Comp.	2323	3049
Composite K	1789	3701

Agroceres in Brazil and Caja Agraria in Colombia are the only two organizations in Latin America marketing any significant amounts of opaque-2 hybrids. Agroceres has marketed opaque-2 hybrids since 1970 and production has now reached 1000 tons. It is anticipated that production will hold at about this level until a stronger demand develops.

Initially Agroceres maintained a strong promotional program for opaque-2 hybrids. This involved recommendation of opaque-2 corn in school lunch programs and on farm feeding trials with swine. Currently, much of this promotional work is being left to the Extension Service.

Yield data for a series of opaque-2 types compared in the 1972-73 trials are presented in Table 18. Agroceres 502 was one of the first opaque-2 hybrids marketed but has since been largely replaced by Agroceres 504. A comparison of the rankings in the Brazilian and International trial averages indicates that genotype x environment interactions may be of considerable importance. Despite these variations in ranking Agroceres 504 exhibits a consistenly above average performance while that of the CIMMYT opaque-2 composite is uniformly poor.

Cargill

Cargill has been producing hybrids for only a few years. Figures on volume of sales are not available but it is reported they rank second to Agroceres in total production.

The breeding program makes use of the same general germplasm source: Caribbean, Cateto, Tuxpano, but with somewhat greater reliance upon dent corn types from the southern part of the United States. Some population hybrids are being produced and sold.

Government Seed Production Policy

The government of Brazil has established the policy of fostering the development of a private seed industry. The public agency responsibilities are to be limited to the development of basic stocks. The seed industry would have responsibility for the development of the final commercial product.

This general policy is being followed in all states except Sao Paulo. The current system of nonrelease of inbred lines and the direct competition in the sale of hybrid seed may eventually be modified but there appears to be little likelihood of such a change in the near future.

The price of hybrid corn seed sold by the private companies is quite low, amounting to approximately 4 to 5 times the minimum commercial grain price. The price of seed sold by the Secretary of Agriculture of Sao Paulo is even lower. Comparable ratios in the United States would be 10 to 1 or higher, depending on the type of hybrid.

Public seed production is highly subsidized. It bears no share of the research and development cost and only part of the production and merchandizing cost. Under such conditions and with current prices, public vs. private competition is not in the best interest of the development of a strong seed industry.

INDIA AND SOUTHEAST ASIA

Approximately 15% of the world corn acreage is grown in Asia with India, Indonesia, and the Philippines accounting for the major fraction of this total. The acreage devoted to corn has been increasing but yields per hectare have remained relatively static. In most of this area, corn is grown for human food, relatively little being used for feeding swine or poultry. Thailand presents an exception to this general pattern, most of its production being exported to Japan.

Many problems are common throughout this entire area. Locally adapted varieties have been grown under minimal conditions for many generations. Possibly as a result of this selection for survival under adverse conditions, the capacity to respond adequately under the better levels of management has been largely lost. The local varieties constitute an extremely narrow genetic base and thus opportunities for substantial improvement, without the introduction of exotic material, are limited. Historically corn improvement has received little attention and until recently there were no effective programs for the production and distribution of either improved varieties or hybrids. Diseases and insects pose a real problem. In many areas two or more generations of maize can be grown per year. Thus conditions are favorable for the development and maintenance of high levels of both disease and insect pests. Adequate sources of resistance have not been identified and, in consequence, yield losses tend to be high.

A considerable number of insect pests and diseases are common throughout the area. Among the plant diseases, downy mildew is probably the most serious. Four species have been implicated: *Sclerospora sacchari*, *S. maydis*, *S. philippensis* and *S. rayssiae*. A fifth species, *S. sorghi* has been reported from Mexico and 12 or more states within southern U.S. Work in Taiwan indicates some progress in developing sources of resistance to *S. sacchari* and some types resistant to *S. philippensis* have been developed in the Philippines. Extensive tests in the U.S. have also identified some resistance to *S. sorghi*. On the basis of these limited successes it appears possible that more intensive research might reveal adequate resistance to this important group of diseases.

Stalk rots, leaf blights, and rust are also endemic. Resistance to these diseases have been identified in other areas and presumably adequate sources of resistance can be found if an intensive screening and selection program is undertaken. The principal current limitations to such a large-scale program is lack of facilities and sufficient trained personnel.

The more important field insect pests would include several species of stalk borers, army worms, and ear worms. Search for resistance to insect pests is a complicated problem requiring facilities and techniques for mass rearing of the pest. Artificial infestation is a necessity to insure valid comparisons among genotypes. Some progress along these lines has been achieved in India but even there the effort does not compare with the magnitude of the problem.

The potential for yield increases in this area are great but may be achieved only if several requirements are met: (1) an expanded research program designed to develop types having a higher yield potential, (2) the development of fertilization and management practices which will utilize the genetic potential of the varieties grown, (3) adequate seed production and distribution facilities, and (4) pricing policies which will permit the farmer to realize a fair profit above the labor and cash inputs required.

In the sections which follow, an attempt will be made to present a brief resume of three of the country programs.

India

Rice, wheat, and sorghum are the most important food cereals of India. In the hill regions of India, however, corn has been a major food crop. As in many other areas of the world, the local varieties tend to have rather low yielding ability and respond poorly to improved production practices, particularly response to fertilizers.

The Indian Council of Agricultural Research initiated a corn breeding program in the Punjab about 1945. One hybrid was produced which outyielded native types by about 20%. At a later date TCA (now AID) provided seed of U.S. 13 to Dr. Boshi Sen who produced seed at the hill station at Almore, Utter Pradesh, for several years. Other programs were started in the states of Rajsthan, Andhra Pradesh, and Mysore. Improved types were developed but in the absence of a seed industry and for other reasons, none of this material became of commercial importance.

U.S. TCA (now USAID) also played a role in this development. In cooperation with the Indian Council for Agricultural Research (ICAR), hybrids were introduced from the United States and from Australia for extensive testing in Punjab and Utter Pradesh. Some of these hybrids outyielded local varieties by 80 to 120% but again, such hybrids had no continuing effect. All were dent types and the local preference for food use is the hard kerneled flints. Food preferences are difficult to change and a substantial yield increase was not sufficient to effect a change in food habits.

In 1954 Drs. E.J. Wellhausen and U.J. Grant of the Rockefeller Foundation, at the request of the Indian government, made an extensive assessment of the corn potential in India. They concluded that the Indian corns represented such a narrow germplasm base that an effective program could not be developed relaying solely on such materials. They further recommended that extensive use be made of the Latin American types from Mexico, Colombia, and the Caribbean area. They proposed the establishment of a fully coordinated Indian program. The ICAR adopted this latter proposal and convened all of the corn scientists in India to develop a fully integrated program. Dr. U.J. Grant was the first joint coordinator, succeeded by Dr. E.W. Sprague in 1959. Dr. Dhawan served as the Indian representative for the first 10 years of the program. This system of operation was judged so successful that it has since served as a pattern for the establishment of All-India Coordinated Schemes for wheat, rice, sorghum, and millet and, most recently, for pulses.

Extensive corn introductions were made from the Latin American areas and from the United States. Much of this material was evaluated directly in hybrid combinations. Two of the first hybrids developed from this diverse parentage are still in commercial production -- Deccan and Ganga 101.

During this period U.S. TCA provided assistance to the government of India and to several of the states in the establishment of a number of seed testing laboratories and in an extensive series of field demonstrations involving use of hybrids, fertilizers, and various cultural practices. Results from such demonstrations indicated that yield increases of 30-60% over the best local varieties could be readily achieved.

India has had a long experience with plant breeding, but this experience involved only improvement of varieties, usually of the self-pollinating crops. Such improved seed was distributed to selected organizations or individuals with the expectation it would gradually diffuse throughout the area of its adaptation. Such a system obviously was completely inadequate for seed of the hybrid crops where new seed must be obtained each year.

The decision to use hybrids commercially required that some provision be made for seed production and distribution. The first governmental agency organized was the National Seeds Corporation with headquarters in Delhi. The Ford and Rockefeller Foundations provided counsel and some financial support in the planning and initial operation of this organization. U.S. AID also supplied an officer, part-time consultants, commodity assistance, and training grants to facilitate various aspects of this new development.

Hybrid seed production is a specialized undertaking requiring great care in the maintenance of purity in the inbred parents and equal care in the production of both the parental single-crosses and the final commercial double-cross. Hybrid seed, poorly produced, may be but little better than local varieties.

The progress which has been achieved in the hybrid seed program (corn, sorghum, and millet) is indicated below (R. W. Cummings, 1970).

Year	Foundation seed (acres)	Certified seed (acres)	Hybrid acreage (000 acres)
1963-64	193	1,618	115
1966-67	3,754	51,114	750
1967-68	5,807	117,000	5,511
1970-71	8,300	261,000	19,500

Great difficulties have been experienced in maintaining the essential degree of purity of the parental lines. No data are available but contamination at this level must have a direct adverse effect on hybrid performance and therefore affect the rate of adoption of hybrid maize. The government has not actively supported development of private breeding programs and has discouraged the development of foreign-based programs, so small-scale producers were entirely dependent upon the quality and quantity of parent seed available from the National Seed Corporation.

This seed organization has experienced operational difficulties. Two factors have been of major significance. First the production and sale of the new short-statured wheats have been highly profitable and posed little strain on the technical resources of the company. Second, corn is of much lesser importance in the area and the cost of seed production is substantially higher than for wheat. Had higher yielding corn hybrids been available, farmer acceptance might have increased and costs of production and distribution reduced proportionately.

The National Seed Corporation is also responsible for certification standards, field inspections, and purity and germination determinations.

Seed production and distribution were established in Uttar Pradesh with the development of the Terai Development Corporation. This is essentially a stock company with shares distributed as follows: 40% Agricultural University, Pantangar; 40% farmers; and 20% National Seed Corporation. The company is governed by a board of directors having representation comparable to the stock holders. The Vice Chancellor of the University serves as chairman of the board.

In so far as possible, seed production is allocated to the farmer shareholders. Wheat and rice production has received more emphasis than corn but considerable quantities of hybrid seed have been produced. The government price on seed has somewhat limited production and sizeable quantities of seed are sold on a black market at several times the official government price.

Several small-scale seed companies also produce seed of both hybrid maize and sorghum. As yet these companies do not have their own breeding programs and are dependent for their parental stocks on either the National Seed Corporation or the Terai Development Corporation.

The widespread adoption of hybrid corn posses a production problem of great magnitude as well as a social and economic problem. High quality seed is essential. The quantity of such seed will continue to pose both production and distribution problems unless tightly controlled but decentralized production and distribution facilities are established. There has also been concern that the Indian farmer cannot afford the yearly cash outlays for seed and fertilizer. To avoid this possible restriction, considerable attention has been given to the development of synthetics or composites. Several of these have been developed (Vijay, Amber, etc.) and are in limited commercial use.

Synthetics can be handled as open-pollinated varieties, the farmer saving seed from his production to satisfy his own seed needs. This economy in seed cost is at least partially offset by a reduction in yield potential. Initially no serious effort has been made to improve the performance of the synthetics through some type of recurrent selection. The use of synthetics to produce inter-varietal hybrids has also received little attention even though some such combinations, in experimental plantings, have given yields substantially greater than the currently grown double-crosses.

P.L. 480 funds have been used extensively in India to further the objectives of the corn program. Special projects were established in pathology, entomology, and in agronomic practices. As a result of the projects in pathology and entomology, large numbers of lines and collections were screened for the diseases and insects of local importance. Some degree of resistance or tolerance has been found for the Indian strain of downy mildew, to several of the stalk rots and to certain of the stalk borers. The coordinated program should simplify the incorporation of such resistance into the synthetics now in existence or new synthetics under development.

Results from the agronomic practices studied showed a rather general need for phosphorus. Many of the soils were also found to be deficient in zinc. Studies on planting density indicated an optimum of approximately 57,500 plants per hectare, roughly comparable to the densities used in the higher rainfall areas of the United States or 23,000 plants per acre.

Thailand

The All-India Coordinated Maize Program provided the pattern for the establishment of the Inter-Asian Corn Program (IACP) now headquartered at Bangkok, Thailand. The IACP has assumed responsibilities for regional trials of new plant breeding developments, for downy mildew regional nurseries, for the organization of a yearly workshop, and for an international training program. Some 13 countries, representing 85% of the maize grown in southeast Asia, regularly participate in the regional testing and workshop activities.

Corn is second only to rice in importance in Thailand. The bulk of the corn grown is of the Tiquisate Golden Yellow type introduced from Guatemala 30 years or more ago. This is a hard textured, deep orange type grown primarily for export to Japan. Other similar colored and textured varieties have been imported more recently from the Caribbean area. Production increased nearly three-fold in the period from 1960 to 1970 but per acre yields have remained relatively static averaging about 1800 kg/ha. This yield level is not greatly different from that in the United States in the pre-hybrid period.

Corn is produced throughout Thailand but production is most concentrated in the upper central region where recently cleared soils are relatively fertile. The supply of these virgin soils is rapidly being exhaused and continuous maize culture is found to rapidly deplete fertility to an unprofitable production level. Relatively little research work has been done on either fertilizer response or production practices.

An intensified program of research and extension was initiated in 1966 with the establishment of the National Corn and Sorghum Research and Training Program at Farm Suwon. This national program receives support from the Rockefeller Foundation and is closely coordinated with IACP activities.

Extensive introductions have been made from the Caribbean area and a number of newly derived populations are being used in recurrent selection programs. Insect and disease problems are serious but with the expanded germplasm base significant improvements over the currently grown types can reasonably be expected. Several new varieties are in the advanced experimental testing stage. As corn is grown primarily for export little effort is being devoted to the development of high lysine types.

There is, as yet, no formal seed production and distribution system. New varieties are distributed by the Department of Agriculture or other governmental agencies. As the breeding program progresses there will be an increasing need for more effective arrangements for seed multiplication and distribution. Adequate seed storage facilities must be a part of this development as climatic conditions are not conducive to maintaining either seed quality or viability.

Philippines

Corn ranks second to rice as a staple food in the Philippines. Both acreage and production have increased strikingly over the last 10 years. More encouraging still, yield per acre has increased at about the same rate as that for rice although average rice yields are still nearly double those for corn. About half of the total production is on Mindanao.

White and yellow corn are grown, the white corn being used for human food and for industrial processing. Most of the corn is consumed as grits. Some corn is consumed at the green stage. For this purpose, white and yellow types are equally acceptable. Yellow corn is used almost exclusively for livestock feed but the supply has been quite inadequate for the demand.

Corn breeding has had a long history under the sponsorship of the University of the Philippines, College of Agriculture, and the Bureau of Plant Industry. In the earlier years this effort was devoted to the identification and improvement of locally adapted varieties. Later, with some assistance from Cornell University, work was initiated on the development of inbred lines and the evaluation of these lines in hybrid combinations. Hybrids developed from these and subsequent programs have performed very well in the University test plots but have not been widely accepted by farmers. This lack of acceptance is largely due to three factors: (1) the hybrids do not possess the necessary resistance to downy mildew to justify widespread utilization, (2) the lack of a continuing supply of high quality seed and of an effective extension program, and (3) lack of a marketing system that permits farmers to recover the cost of cash inputs and a reasonable return of labor.

Downy mildew (Sclerospora philippensis) has been the most seriously limiting disease of corn. Infestations are often severe and yield losses may reach 80-100%. Extreme difficulty has been experienced in the development of resistant types. Two new varieties, Philippine DMR-2 and MIT Var. 2, have been released but yield of these has been lower than of the previously developed UPCA varieties. This reduction in yield is undoubtedly due to inbreeding during development. Further selections offer promise of higher yielding types. These new varieties represent an important development and it is hoped they will provide an adequate basis for an expanded extension program.

In 1971 the government approved and funded a program of research on downy mildew with provision for expanded training and production components. This work will be centered at the Central Mindanao University and Mindanao Institute of Technology. Research will be concentrated on varietal improvement, chemical control of downy mildew, and management and production practices.

If disease and insect problems can be solved, economic problems will still pose a serious barrier to an important expansion of corn production. Farmers normally borrow from middlemen to provide agricultural inputs, fertilizers and insecticides. These loans are repaid at harvest at prices set by the middleman. The Rice and Corn Administration attempts to stabilize corn prices. However, these support prices apply only at strategic centers and due to transportation problems, the farmers produce is sold locally. Thus, price supports have not been highly effective in increasing the price received by farmers.

The problems associated with increasing the efficiency of extension activities, seed production, and the marketing system may be as difficult to solve as the problem of obtaining really superior varieties.

LIMITATIONS TO TECHNOLOGY TRANSFER

In earlier sections the point has been made that a successful program of introducing new agricultural technology must involve at least five elements: (1) improved genetic material, (2) the development of agricultural practices which will permit increases in productivity and which are compatible with the nation's needs and resources, (3) a vigorous seed production and distribution agency to ensure adequate volumes of the improved seed, (4) an agri-business infrastructure which will provide adequate and timely supplies of all materials to support the agronomic practices (fertilizers, herbicides, etc.); a marketing, distribution and storage system to handle production above substance needs; a credit and price structure which will ensure farmer participation and permit achieving production goals, and (5) an effective system of extension. If any one of these five elements is not adequately satisfied, increases in productivity will be limited. The enumeration of these five elements in this simplified form may be useful in an assessment of possible areas of deficiency in the transfer of corn technology.

A country by country assessment will not be attempted, rather we shall use a review along the line of the 5 basic requirements listed earlier. An in-depth survey of existing deficiencies is not possible without detailed historical information on governmental or institutional policies and priorities, production and price trends, and other relevant background information. The following assessment will be based on general observations which may serve to identify deficiencies but which cannot provide an adequate analyses of the cause.

The development and utilization of hybrid corn had its origin and initial acceptance within the United States and it history may logically serve as our standard of reference. The U.S. Department of Agriculture and the Land Grant Universities have provided a continually expanding research base supporting increased production capabilities and an effective system of extension. The agricultural business infrastructure developed concurrently with increasing agricultural production potential. Private enterprise has provided adequate supplies of the necessary production inputs such as seed, fertilizers, herbicides, etc. Our marketing system has been generally adequate and supply and demand, modified by some governmental policies, have kept farm prices at a level to ensure near maximum utilization of research findings. The total system has permitted and supported a three-fold expansion in corn production over the last 40 years. The system, however, adjusts very slowly to certain possibilities for change.

Opaque-2 corn provides a case in point. This type of corn is characterized by such an improvement in protein quality that greatly reduced quantities of protein supplementation are required in growing and fattening rations. Studies have shown that yields of opaque-2 hybrids equal to 95% or more of normal would be economically valuable to the livestock feeder. Opaque-2 hybrids exhibiting this yield level are available but any shift to such hybrids has been slow and exhibits no signs of an immediate acceleration.

The limited shift to opaque-2 hybrids becomes understandable when all aspects of the situation are considered. Some of the important factors are listed below.

1. All of our corn acreage is planted to hybrid corn. Seed for this acreage is purchased each year from one or more of 5 or 6 large companies or a very much larger number of smaller companies. Corn acreage has remained relatively stable with only small year-to-year fluctuations. Increased sale of opaque-2 hybrid seed must therefore be at the expense of sales of normal hybrids.

2. There is a sizeable cost attendant to the build-up of parental seed stock. The large companies produce their own parental stocks and the smaller companies purchase seed from foundation seed organizations. In either case any shift in production whether from one normal hybrid to another or from a normal hybrid to opaque is expensive. Such shifts will be made only to protect or improve a firm's competitive position.

3. Seed sales are predicted and new production planned on the base of past records. Unpredicted shifts in farmer demands are costly. If seed of a desired item is not available the sale may go to a competitor. This is undesirable as it may result in the permanent loss of a customer. Overestimation of demand will result in carryover stocks. This means a sizeable investment yielding no immediate return plus the expense of controlled storage costs necessary to maintain viability and ultimate salability.

4. Our system of grain sales are geared to bulk handling at each step as grain moves from the farm to its ultimate designation. Any crop or segment of the crop, e.g., opaque-2, which requires maintenance of genetic identity poses problems. In other specialty crops, separate marketing channels are established (sweet corn, popcorn) or special marketing procedures are established, e.g., growing and marketing under contract. Contract production of waxy or high amylose corn has historically carried a premium. Such an arrangement has been reasonable for the small volumes involved but becomes a serious barrier to an expanded use of opaque-2 where large volumes may eventually be involved. Current production of opaque-2 is largely limited to grower-feeders. Under this system maintenance of genetic identity is not a serious problem. A system of bulk handling which permits maintaining genetic identity remains to be developed.

The problems detailed above will become important in other areas of the world as efforts are directed toward increased production and utilization of opaque-2 corn.

DEVELOPMENT OF IMPROVED GENETIC MATERIAL

Extensive experience and observation indicate that local varieties or strains, having been developed to fit a given agricultural production system, have only limited capacity to respond to improved management situations. This is as true of the selected varieties of the Corn Belt as of the strain maintained by some subsistence farmer.

The development of improved materials within the United States has been detailed in an earlier section and need not be repeated here beyond the acknowledgment that a large number of individuals and institutions were involved and the financial input was very substantial. The basic principles developed have universal applicability although the specific products, inbred lines and hybrids, have rather definite ecological limitations. Where U.S.-developed material was directly useful, progress in adopting the new technology was rapid; where new materials required development, progress was correspondingly slower.

Post-World War II Europe was characterized by an adequate supply of trained manpower, competence in agricultural production, and the existence of management and marketing systems. It was, however, extremely short of funds for both reconstruction and operation of research facilities. It was also relatively uninformed of the new developments which had taken place in the United States prior to and during the war years. These limitations were rapidly eliminated under the combined efforts of the individual governments and support from UNRRA, ECA, FAO, and other agencies.

The rate of adoption of hybrid corn in Europe has varied among countries but has closely followed the U.S. pattern of dependence upon hybrids between inbred lines. The first hybrids used were directly imported from the United States. After the first evaluation, inbred lines of the open-pedigree hybrids were imported and local hybrid seed production programs initiated. A number of seed companies were also established representing subsidiaries of U.S. private seed companies. These companies, for the most part, produced closed-pedigree hybrids. Inbreeding of local types was conducted on an extensive scale. The hybrids currently grown in Europe make some use of locally developed materials.

The first hybrids grown commercially in India were also developed from lines introduced from Mexico, Colombia, and the United States. Pakistan still relies heavily on U.S. lines and hybrids.

In the tropical areas of the world, U.S.-developed lines and hybrids tend to be poorly adapted and improved types must be developed from local strains or exotic materials introduced from other similar ecological areas. The utilization of hybrids in Kenya provides a useful illustration. Two main types of hybrids are utilized, one a conventional double-cross developed from a local variety, Kitale Flat White, and the second a varietal hybrid, Kitale Flat White x Ec572. The strain Ec572 is a high-altitude type introduced from Ecuador.

In the Latin American countries a wealth of genetic diversity exists. The first hybrids developed were similar to conventional double-crosses except that the parental lines involved only a minimum of inbreeding. Improved varieties and intervarietal hybrids are also being used extensively in certain areas.

The one common element in all corn programs is the clear recognition that substantial improvements are possible. There is a very wide diversity in the breeding systems employed in recognition of the diversity of ecological niches to be satisfied, the trained manpower and facilities available, and the local system for seed production and distribution.

RESEARCH ON AGRONOMIC PRACTICES

In the United States research on crop production practices and fertility response studies have proceeded concurrently with the development of improved plant materials. This has been much less true in other corn growing areas of the world.

In Europe, which accepted a direct lateral transfer of hybrid corn, there was a corresponding adoption of U.S. production practices; increased fertilization, increased planting densities, use of herbicides, etc. Where U.S. materials were less directly useful, all aspects of the temperate zone production practices required reexamination.

The Kenya corn program provides a useful illustration. Limited information was available on the effects of various production practices on yield. A series of 26 factorial experiments were used to simultaneously evaluate the effects of a series of changes in the production system. The results obtained indicated that all components of the system interact to such a degree that data on single-factor substitutions provided the necessary information for the development of an economically viable "package" and at the same time provided a useful extension tool.

In some countries considerable effort has been devoted to a study of fertilizer response surfaces. Such studies are useful and informative but they do not provide a completely satisfactory answer. Fertilizer response is greatly influenced by the genetic capacity of the test material, time of planting, population density, and other variables. Thus, to be most useful, studies on production practices and fertilizer response must be a continuing effort closely geared to changes in plant materials, to management systems, and to economic factors affecting value of product and costs of inputs.

SEED PRODUCTION AND DISTRIBUTION SYSTEMS

The initial stages of hybrid corn development in the United States occurred in the absence of a hybrid seed industry. Interested farmers were initially encouraged to produce hybrid seed as an adjunct to their regular farming operations. It soon became apparent that this was not feasible because of conflicting labor demands. Such producers had two options: (1) to discontinue seed production and concentrate on their general farming activities, or (2) to become a seed production specialist. The present hybrid seed industry had its beginnings in this same period. In the intervening years the hybrid seed industry has grown tremendously and now accounts for approximately 70 to 80% of all the seed sold. This shift to large-scale production has come about because of economics of management and merchandising rather than due to any inherent differences in quality of seed or yield potential of the hybrids marketed.

Several countries have established government seed monopolies (Mexico, India, Yugoslavia). In each case criticism of the production and marketing system is widespread. The most common complaints are: (1) the seed marketed is of inferior quality and genetic identity is not carefully maintained, (2) the distribution system is inadequate and seed is often not locally available at the optimum time for planting, and (3) there is little or no incentive for hybrid replacement. This may be as much the fault of the breeding program as the production and distribution systems but the average life of hybrids often becomes excessively long.

Agri-Business Infrastructure

Maximizing yields within economic constraints is dependent upon credit, price, storage, and marketing system and the timely availability of all needed inputs. These separate elements have been so long available in the U.S. that we often overlook the essential role they play in agricultural productivity.

Credit and price are hardly separable. The small farmer, particularly, must have a supply of credit before he can afford substantial cash inputs, even when these may return a handsome profit. Similarly a government guaranteed price is of no benefit to the small producer if he must sell a part of his crop immediately upon harvest to satisfy his creditors. The government guaranteed price is of no benefit to the small producer unless delivery can be made locally and adequate storage space is available for such purchased grain.

At present Brazil has a long range plan to expand corn production along three export corridors. Local, intermediate, and port storage facilities are quite inadequate for current production and would become a major bottleneck if increased production is achieved.

Local distribution points and timely availability are essential for such commodities as seed, fertilizer, herbicides, and fungicides. Limited supplies or delayed availability will certainly limit opportunities for economic use. Private enterprise has a much better operational record in these regards than do governmental programs.

Extension

Extension has played a vital role in the development of a high level of agricultural productivity in the United States. The effectiveness of the Extension effort has been due in large part, however, to the accumulated reserves of research findings and to a functioning agri-business infrastructure conducive to an expanding agricultural productivity. Where such elements are lacking Extension can play a very limited role.

Extension efforts in the developing nations have been patterned after the U.S. system with possibly only limited apprecation of the basic differences involved. The widespread criticism of Extension efforts in the LDCs arises in part from a lack of appreciation of what Extension may accomplish. Efforts to increase corn production cannot be effective unless the information provided on varieties and production practices is soundly based, is applicable to the farmers' special circumstances, and unless the new practices will reduce labor inputs or return a greater net income per unit area or per unit cost of inputs.

Motivating small-scale farmers to adopt new technology is commonly held to be difficult. Limited instances, however, e.g., Kenya, suggest that such farmers respond to economic incentives in the same fashion as their more progressive neighbors. The Extension service approach must be quite different. Single-trait substitutions seldom produce yield differences sufficiently great to be impressive. A combination of substitutions, "a package", is normally necessary to achieve yield gains of 100% or more. Even in such cases Extension demonstrations are required. Such demonstrations are much more convincing if they are conducted with the small-scale farmer - under the general guidance and supervision of extension personnel - rather than directly and wholly under Extension or governmental control. Obviously such demonstrations must be soundly based; an ineffective demonstration will nullify the benefits of several successful demonstrations.

Literature Cited

Angeles, H. H. 1971. The corn breeding program of the National Institute of Agricultural Research (INIA) in Mexico and its relation to CIMMYT. Proc. 1st Maize Workshop. El Batan, Mexico. pp. 21-24

Comstock, R. E., H. F. Robinson and P. H. Harvey. 1949. A breeding procedure designed to make maximum use of both general and specific combining ability. Agron. J. 41: 360-367.

Cummings, R. W. 1970. Seed production in India. In "Change in Agriculture", Ed. A. H. Bunting. Gerald Duckworth & Co., Ltd., London.

Dudley, J. W., R. J. Lambert and D. E. ALexander. 1974. Seventy generrations of selection for oil and protein concentration in the maize kernel. In Seventy generations of selection for oil and protein in maize. J. W. Dudley, Ed. Crop Sci. Soc. of Amer. Special Publication. In press.

Eberhart, S. A., Seme Debela and A. R. Hallauer. 1973. Reciprocal recurrent selection in the BSSS and BSCB1 maize populations and half-sib selection in BSSS. Crop Sci. 13: 451-456.

Fisher, R. A. 1918. The correlation between relatives on the supposition of Mendelian inheritance. Trans. Roy. Soc. Edinburgh 52: 399-433.

Gardner, C. O., P. H. Harvey, R. E. Comstock and H. F. Robinson. 1953. Dominance of genes controlling quantitative characters in maize. Agron. J. 43: 186-191.

Gardner, C. O. 1961. An evaluation of effects of mass selection and seed irradiation with thermal neutrons on yield of corn. Crop Sci. 1: 241-245.

Hallauer, A. R. and J. H. Sears. 1969. Mass selection for yield in two varieties of corn. Crop Sci. 9: 47-50.

Hallauer, A. R. 1973. Hybrid development and population improvement in maize by reciprocal full-sib selection. Egyptian J. Gen. and Cyt. 2: 84-101.

Hayes, H. K. and P. J. Olsen. 1919. First generation crosses between standard Minnesota corn varieties. Minn. Agr. Exp. Sta. Tech. Bull. 183: pp. 5-22.

Horner, T. W., R. E. Comstock and H. F. Robinson. 1955. Non-allelic gene interactions and the interpretations of quantitative data. N. C. Agr. Exp. Sta. Tech. Bull. 118.

Hull, F. H. 1945. Recurrent selection and specific combining ability in corn. J. Am Soc. Agron. 37: 135-145.

Hull, F. H. 1946. Overdominance and corn breeding where hybrid seed is not feasible. J. Am. Soc. Agron. 38: 1000-1103.

Hull, F. H. 1952. Recurrent selection and overdominance. In "Heterosis", Chapter 38, pp. 451-473. Iowa State College Press. Ames, IA.

Jenkins, M. T. and A. M. Brunson. 1932. Methods of testing inbred lines of corn in crossbred combinations. J. Am. Soc. Agron. 24: 523-530.

Jenkins, M. T. 1934. Methods of estimating the performance of double-crosses in corn. J. Am. Soc. Agron. 26: 199-204.

Jenkins, M. T. 1940. The segregation of genes affecting yield of grain in maize. J. Am. Soc. Agron. 32: 55-63.

Jones, D. F. 1918. The effects of inbreeding and crossbreeding on development. Conn. Agr. Exp. Sta. Bull. 207. pp. 5-100.

Jugenheimer, R. W., R. A. Silow and Y. T. Mao. 1952. Cooperative hybrid maize tests in European and Mediterranean countries. FAO Development Paper No. 31.

Jugenheimer, R. W. and R. A. Silow. 1953. Cooperative hybrid maize tests in European and Mediterranean countries. FAO Development Paper No. 35.

Jugenheimer, R. W. and R. A. Silow. 1954. Cooperative hybrid maize tests in European and Mediterranean countries. FAO Development Paper No. 42.

De Miranda, L. E. C. and L. T. De Miranda. 1971. Adubacao Do Milho IV. Estudo Economico de Adubacao do Milho no Estado de Sao Paulo Instituto Agronomico Campinas, Projects BNDE/ANDA/CIA No. 14.

Moll, R. H., M. F. Lindsay and H. F. Robinson. 1964. Estimates of genetic variances and levels of dominance in maize. Gen. 49: 411-423.

Osler, Robert D. 1973. What is CIMMYT. CIMMYT Information Bulletin No. 8.

Penny, L. H., W. A. Russell, G. F. Sprague and A. R. Hallauer. 1963. Recurrent selection. Stat. Genetics and Plant Breeding NAS-NRC Pub. 982. pp. 352-367.

Richey, F. D. 1922. The experimental basis for the present status of corn breeding. J. Am. Soc. Agron. 14: 1-17.

Russell, W. A., S. A. Eberhart and U. A. Vega O. 1973. Recurrent selection for specific combining ability in two maize populations. Crop Sci. 13: 257-261.

Sprague, G. F. and L. A. Tatum. 1942. General vs. specific combining ability in single crosses of corn. J. Am. Soc. Agron. 34: 923-932.

Sprague, G. F. and P. A. Miller. 1950. A suggestion for evaluating current concepts of the genetic mechanism of heterosis in corn. Agron. J. 42: 161-162.

Sprague, G. F. 1966. Quantitative genetics in plant improvement in plant breeding. Chapter 8, pp. 315-354. Iowa State Univ. Press, Ames, IA.

Sprague, G. F. 1964. Germplasm manipulations of the future. In Physiological Aspects of Crop Yield. pp. 375-387. ASA-CSSA Symposium, Madison, Wisc.

Shull, G. H. 1908. The composition of a field of maize. Am. Breed. Assoc. Rept. 4: 296-301.

Shull, G. H. 1909. A pure line method of corn breeding. Am. Breed. Assoc. Rept. 5: 51-59.

Wellhausen, E. J., L. M. Roberts and X. E. Hernandez. 1952. Races of maize in Mexico. Bussey Inst. of Harvard Univ. pp. 9-223.

Wellhausen, E. J. 1954. Modern corn breeding and production in Mexico. Phytopath. 44: 391-395.

GLOSSARY OF ACRONYMS

ARS/USDA - Agriculture Research Service, U.S. Department of Agriculture.

CIAT - International Center of Tropical Agriculture (Centro Internacional de Agricultura Tropical), Colombia.

CIMMYT - International Maize and Wheat Improvement Center (Centro Internacional de Mejoramiento de Maize y Trigo), Mexico.

DIA - Departimento Investigaciones Agropecuaria, Colombia.

DNPEA - National Department of Agriculture.

EAAFRO - East African Agriculture and Forestry Research Organization.

EAC - East African Community.

ECA - Economic Cooperating Administration.

FAO - Food and Agriculture Organization of the United Nations.

IACP - Inter-Asian Corn Program, Thailand.

IAR - Institute for Agricultural Research, Ahmadu Bello University, Nigeria.

IBRD - International Bank for Reconstruction and Development (World Bank).

ICA - Instituto Colombiano Agropecuaria, Colombia.

ICAR - Indian Council for Agricultural Research.

ICRISAT - International Crops Research Institute for the Semi-Arid Tropics, India.

IICA - Instituto Interamericano de Ciencias Agricolas, Costa Rica.

IITA - International Institute of Tropical Agriculture, Nigeria.

IMAN - International Maize Adaptation Nursery, CIMMYT.

INIA - Instituto Nacional de Investigaciones Agricolas, Mexico.

IRRI - International Rice Research Instituto, Philippines.

OAU/STRC - Organization of African Unity/Scientific, Technical and Research Commission.

OEEC - Organization for European Economic Cooperation.

OIE - Officina Investigaciones Especiale, Colombia.

PCCMCA - Programa Cooperativo Centroamericano para el Majoramiento de Cultivos Alimentos, El Salvador.

PRONASE - Productora Nacional de Semillas, Mexico.

SPAR - Special Project for Agriculture.

TAB - Technical Assistance Bureau, AID.

UNDP - United Nations Development Program.

UNRA - United Nations Relief and Rehabilitation Administration.

USAID - United States Agency for International Development, formerly ICA (International Cooperation Administration) and TCA (Technical Cooperation Agency).