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UNIVERSITY OF ILLINOIS

AGRICULTURAL COLLEGE AND EXPERIMENT STATION

A Program of Corn Improvement

In cooperation with Office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agriculture

By C. M. Woodworth

Plant Selection is an Important Operation

Note the erect habit, the strong, vigorous, healthy appearance of the plants, and the manner in which the ears are borne, indicating healthy shanks. It has long been recognized that the parent plant, as well as the seed ear, should be considered in selecting seed corn.

URBANA, ILLINOIS

THE PROGRAM of corn improvement set forth in this circular is based on the results of field and laboratory experiments extending over several years. The Illinois Agricultural Experiment Station and the Office of Cereal Investigations of the United States Department of Agriculture have cooperated in these investigations.

Corn is the most important crop in Illinois, and therefore receives the major part of our attention. The growing of better strains is one way by which the acre yield of corn can be increased and the quality improved. It is believed that better strains can be produced by carrying out the suggestions contained in this circular.

This program is published separately from Bulletin 255, of which it is a part, so that the information can have wider circulation than otherwise would be possible. It is to be understood that the program is drafted for the future as well as the present. It is meant to set forth all that appears best in theory and practice in the light of present-day knowledge of corn-breeding.

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A Program of Corn Improvement[1]

By C. M. WOODWORTH, Associate Chief in Plant Breeding

During recent years important developments have occurred in the theory and practice of corn breeding. Investigations of inheritance in this plant have resulted in putting corn improvement on a more scientific basis. The once popular ear-to-row method, which was markedly effective in some cases, has been discarded by many practical corn breeders. The recent work on corn root, stalk, and ear rots has emphasized the necessity of considering disease resistance in any corn improvement program for the corn belt. The need for improvement and the opportunities in corn breeding are believed to be as great as ever. The time is considered opportune, therefore, for outlining briefly a corn-breeding program in the light of these developments.

Choice of Foundation Stock

The choice of the foundation stock for a program of corn improvement is essentially a choice of variety. Varieties differ greatly not only in such characters as color of grain, time of maturity, and tendency to sucker, but also in the degree of adaptation to certain soils and climatic conditions, and in the relative resistance to certain fungous diseases and insect pests. Even strains within a variety may show differences which, in some cases, are wider than those between so-called varieties.

A variety should be chosen that is well adapted to the local environmental conditions. It should mature well; it should be of a type that is not discriminated against commercially; and it should be sufficiently variable to show possibilities of improvement. The common varieties grown in the various sections of the country, in most cases, are well adapted to the conditions in those sections. Some strains, however, may have a low average production as compared with others, or may respond only feebly to a program of improvement. *Attention at the outset to the foundation stock to be used is essential to success.*

Two Methods of Improving Corn

Two methods for corn improvement are suggested. The first emphasizes the importance of *selection* as a method of improvement. It is particularly adapted to the corn grower who desires a simple but effective method of improving his own crop. It also is adapted to the seed-corn producer who has built up a trade in seed corn with his neighbors because of his integrity and his ability to select good seed,

[1]This circular is essentially a reprint of a section with the same title in Bulletin 255 of this Station entitled "Corn Root, Stalk, and Ear Rot Diseases and Their Control Thru Seed Selection and Breeding," by James R. Holbert, W. L. Burlison, Benjamin Koehler, C. M. Woodworth, and George H. Dungan.

handle it properly, and sell it at a reasonable price. Many farmers do not care to take the trouble and time necessary to get good seed, and are quite willing to pay others to do it for them. The seed-corn grower can therefore be of distinct service to his community and at the same time develop a good business for himself.

The second is called the *pure-line method*. It is believed to have a distinct place in a program of corn improvement because of its possibilities. By this method it would appear possible to produce hybrid strains that are resistant to at least a majority of the diseases affecting corn; that are adapted to the special conditions obtaining in different sections of the state, such as soil types, soil acidity, dry weather, lengths of season, and insect attack (the chinch-bug and European corn borer); and that are adapted to special uses, such as for silage production, grain production, and manufacturing purposes (oil content). The pure-line method is fundamentally sound in theory, but the practical benefits from its use are, in the main, still to be realized.

The Selection Method

Selection of seed is probably more effective in corn than in any other crop. This is due, no doubt, to the nature of the corn plant. Naturally cross-fertilized, it is continually producing hybrids, which, in turn, cross among themselves, giving rise to a multitude of types thru recombination of characters. Hence, in any cornfield a considerable array of different types is presented. Some of these are desirable because they are vigorous and productive; others are undesirable because they are weak in stalk and root, barren, or susceptible to diseases. It is this great amount of variation in the corn plant that furnishes an adequate basis for improvement.

Much can be accomplished in the improvement of corn by paying particular attention to the plant in the field and to the ear in the seed-house and on the germinator. Selection at these three stages plays the most important part in the process of securing seed for the following crop. If this work were carefully and intelligently done year after year on every farm, the average corn yield for the state would be materially increased.

Improvement of the corn crop by the method of selection suggested here is simply and easily accomplished. The method commends itself to corn growers who have neither the time nor the inclination to perform complicated experiments on their own farms. It involves no record-keeping and no harvesting of single rows or other small areas. It is effective, nevertheless, in improving the corn crop in total yield of grain because it results in the gradual elimination of weak types and of those susceptible to the corn rots.

In corn improvement, special emphasis should be placed on the *quality* of grain produced. What is most desired is not high yield alone

FIG. 1.—A PROFITABLE COMBINATION OF PROPER SEED SELECTION AND GOOD FARMING

A commercial field of corn grown from seed that had been carefully field selected from vigorous, healthy stalks and severely culled on the basis of physical appearance. The selections were made from a strain of yellow dent that had been carefully selected over a period of years according to recommendations set forth in this circular. Farm of Mr. Ed. Main, Knox county.

but *high yield of high quality corn*. Selection for disease-resistant corn according to the method outlined below results not only in improvement in total yield, but also in an increase in the proportion of sound, marketable grain.

Selecting the Parent Plant

It has long been recognized that the parent plant, as well as the seed ear, should be considered in selecting seed corn. Evidence presented in Bulletin 255 has placed greater emphasis on this point. A diseased stalk is not likely to produce a disease-resistant ear. Moreover, a study of the parent plant enables one to consider other characters, such as vigor and degree of maturity, which are especially important in production. (See cover illustration.)

The parent plant should have an erect stalk, indicating a strong root system. It should be strong, vigorous, and healthy, free from smut, rust, and other diseases, with the leaves free from spottings, streakings, and purplings. The stalk and portions of the leaves should still be green. The husks should be dry and dead and they should be long enough to cover the tip of the ear completely. The ear should be

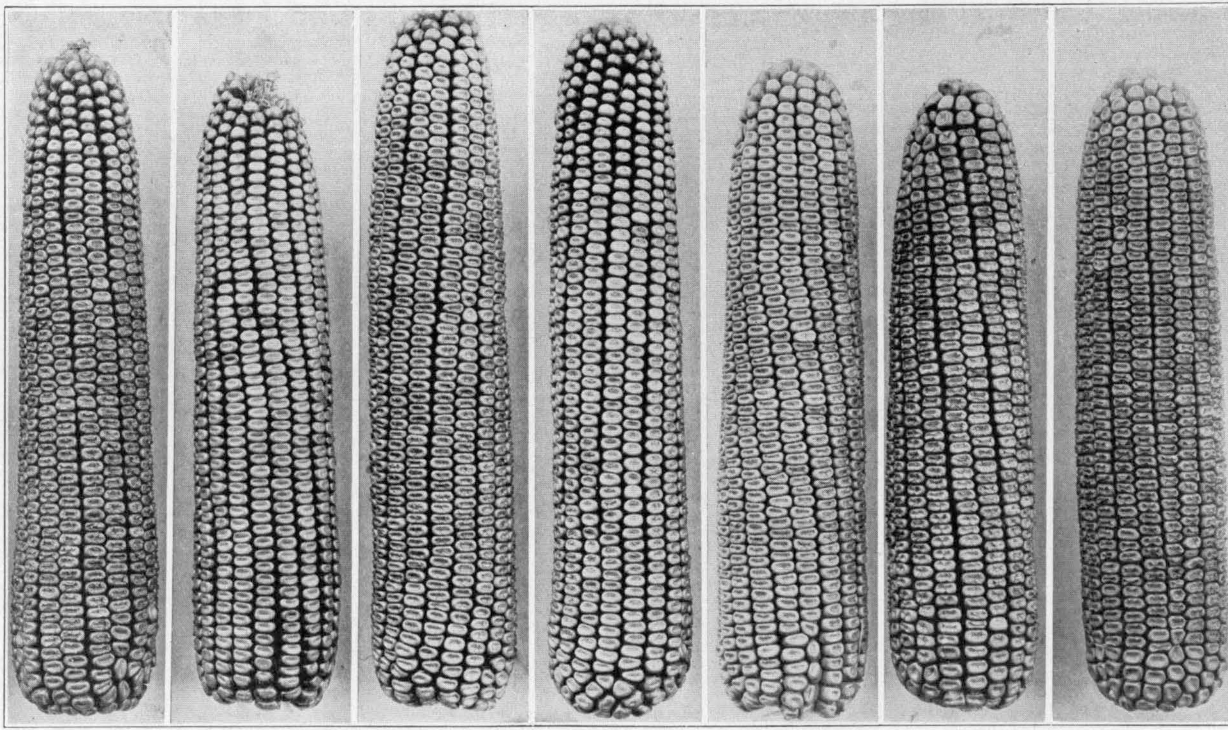


Fig. 2.—Desirable Seed Ears

These ears show a considerable range in indentation, length, kernel type, and other characteristics. It is considered unwise to select too closely toward a particular type. Not only one, but *all* points indicating good maturity and good health, should be noted.

borne at a height on the stalk convenient for husking, and on a strong shank of medium length. The angles which the ears form with the stalk should range from approximately 45° to 135°. Upright ears are likely to have large, coarse shanks, while ears hanging straight down are usually borne on small, weak, broken, or diseased shanks. Neither extreme is desirable.

A parent plant answering the above description is likely to be relatively free from infection by the corn-rot organisms and ordinarily will produce an ear which likewise is relatively disease-free.

The Best Time to Select Seed Ears

Results of experiments conducted at this Station and elsewhere indicate that well-matured ears are best for seed, as their kernels are more likely not only to germinate well and produce strong plants but also to yield better than those from immature ears. In order to select such well-matured ears, and at the same time to give due attention to the parent plant with special reference to disease, *the field should be carefully inspected in the fall before a killing frost for the purpose of locating healthy, vigorous plants that are maturing normally.* If the field inspection is delayed until all the plants are dry and dead, it is difficult to distinguish those plants that matured normally. Ears selected from normally maturing plants will be found to be sounder and better matured, on the whole, than those from plants that are diseased.

The mere fact that ears are selected in the field prior to harvest, with some attention to the parent plant, is, however, no assurance that they will make better seed ears than those selected at harvest time or even from the crib, for much depends on the care exercised in selecting the plant and in the handling of the ears afterward. Furthermore, it must be recognized that the majority of corn growers pick their seed corn at the time of harvest, and that they have obtained good results from this practice. As this method is so practical and inexpensive, it no doubt will continue to be widely used; it should not be condemned so long as it results in the selection of normally matured ears that show good germination and relative freedom from disease. This method offers opportunity to choose from all the ears in the field, since all are actually seen and handled. Furthermore, many ears that would be taken for seed in the early fall would undoubtedly be rejected at the time of harvest because their seemingly good early appearance belied their appearance when fully matured. However, it is not advisable to select seed ears very late in the harvest period. Freezing temperatures, together with abundant moisture, especially if followed by warmer weather, will not only injure the germination of the seed but also provide favorable conditions for infection and growth of fungi. At just what date in the fall harvest selection of seed ears should be discontinued must be decided individually by each corn grower in the light of conditions affecting his own crop.

Select Four or Five Times as Many Ears as Will Be Used

Four to five times as many ears should be picked for seed as will finally be used. This will allow the rejection of ears because of their appearance, or because of poor or weak germination, or the presence of disease. Much can be gained by having abundant opportunities to discard the less desirable ears in the final selection, and this is possible only in cases where large numbers of ears are on hand.

Characteristics of Good Seed Ears

That there is a relation between the general appearance of the ear and its ability to yield is shown by the results reported in Bulletin 255 already referred to. This relationship appears to be based largely on resistance and susceptibility to the corn root, stalk, and ear rot diseases. Nearly disease-free ears ordinarily can be distinguished from diseased ears by their general appearance, for the presence of disease interferes with the normal activities of the plant, and this interference is reflected in the color, luster, texture, and indentation of the kernels. A knowledge of this relationship is of distinct value to the corn breeder, for by it he can examine in a short time a large number of ears and quickly eliminate from further handling all but the very best.

Disease-free or nearly disease-free ears have thick, plump, bright, clean kernels with well developed germs, intermediate to smooth indentation, and distinctly horny endosperm (Figs. 2 and 3). Such ears are sound and solid, have a bright, rather oily appearance, and give every evidence of complete and normal maturity. Shank attachments are white, bright, and free from any discoloration due to exposure or disease. All ears that do not measure up to these standards, or as many as the seed stock will allow, should be discarded, as they probably are more or less diseased.

In selecting corn for seed to continue the strain, *all* the points that are recognized as characteristics of good seed ears should be considered. Ears superior in one characteristic, such as shank attachments for example, may be inferior in kernel texture and luster. Such ears should be rejected in favor of ears which rank high in all three characteristics. When choosing an animal for breeding purposes, not one but all the points commonly recognized as belonging to animals of merit are carefully considered. Straight back, strong, well-set legs, bright eyes, quality, intelligence, disposition, and like characteristics are noted with especial care. Superiority in all is desired because it is recognized that each plays its part in the making of a superior animal. The same principle holds true in the selection of grain of any kind that is to be used for seed.

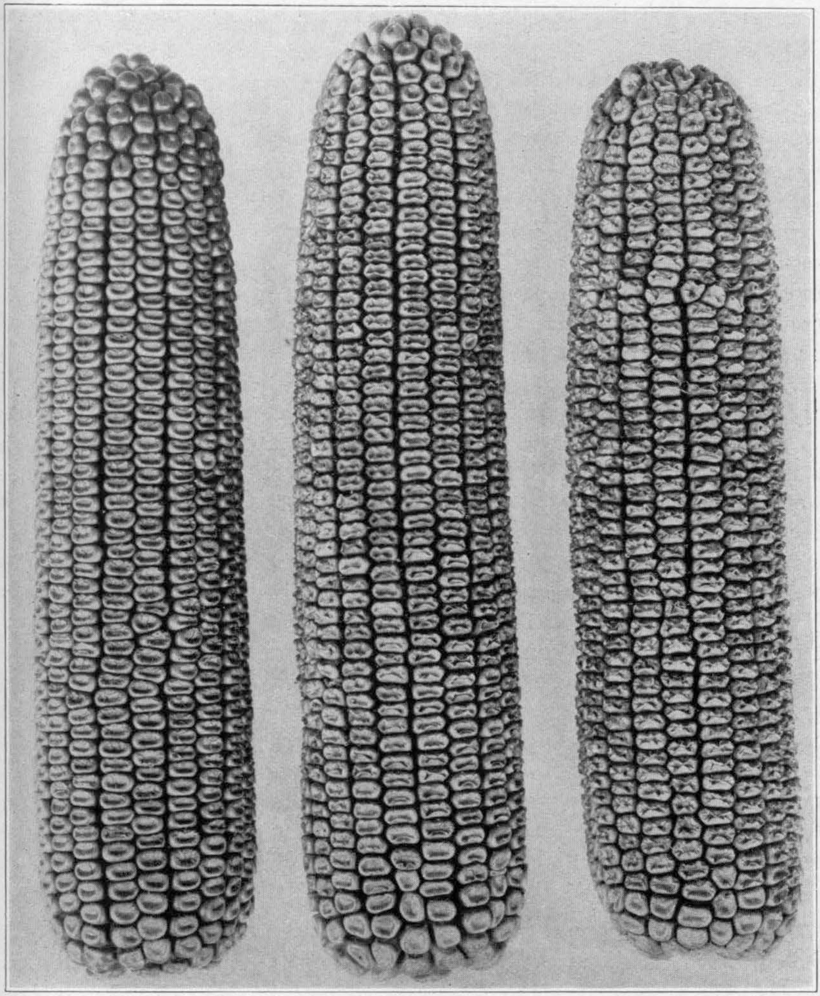


FIG. 3.—THREE DEGREES OF INDENTATION

The ear on the left represents the upper limit of the smooth class. The center ear represents the upper limit of the class variously called medium, intermediate, and mid-rough. Ears between these two in indentation would be classed as medium. The ear on the right illustrates the rough, starchy type. Avoid this type in ear selection.

Value of Germinator Selection

When circumstances permit, the ears that have been selected on the basis of their appearance should be tested on the germinator (preferably the lime-sawdust table germinator) in order to detect those ears that have high viability and seedling vigor and that are freest from the corn rot diseases.

There is considerable evidence that the germinator is especially useful also in detecting ears that are resistant to scutellum rot, resistance to which seems to be closely correlated with resistance to certain soil fungi and unfavorable environmental conditions. Thus the germination test may be very helpful in determining which are the *best* ears to use for seed.

The germination test, to be reliable, must be conducted under reasonably uniform conditions of temperature and moisture, and the results must be rightly interpreted. Many corn growers either do not have the proper facilities for conducting such a test, or are unable to read and interpret the results correctly. Emphasis must then be placed on plant and ear selection.

Since ears that have been carefully selected in the field and properly cared for can usually be depended on to germinate well and to show relatively little disease, lack of facilities for the germination test should not be considered a great handicap. Moreover, the limitations of the germination test should be clearly recognized. The use of the germinator will not always lead to improvement in all strains of corn, for some strains are incapable of further improvement, either because of defective heredity or because of their being in a relatively homogeneous condition. Other strains may be but slightly infected with the root rot organisms because of light infestation of the soil in which they were grown or because of a partial resistance to such infection resulting from conscious or unconscious selection for resistance over a period of years. *The primary purposes of the germinator are to show the presence or absence of disease and the vigor or lack of vigor of the seedlings.* If these purposes are not accomplished, for reasons above mentioned, then the use of the germinator is of no aid in the improvement of corn.

The Pure-Line Method

In the improvement of corn by the selection method just described, the ear was considered the basis of selection. Emphasis was placed on a careful study of the plant which produced the ear, i.e., the female parent; the individual male parents could not be studied because they are unknown.

It is commonly accepted that the male parent is equally important with the female so far as the transmission of hereditary characters is concerned. All the kernels on an ordinary ear of corn have the same female parent but not the same male parent. Some kernels may be the result of self-fertilization, others the result of fertilization by pollen from neighboring plants in the same or in adjacent hills, and still others may have resulted from fertilization by pollen brought by the wind from more distant plants. The several male parents of the kernels on an ear of corn presumably differ greatly in their hereditary constitution.

Hence, it is clear that the kernels may be quite different from each other even tho borne on the same cob and by the same female parent.

Corn breeders are coming to recognize the need of making the individual kernel the basis of selection rather than the individual ear if progress in corn improvement is to be most rapidly and efficiently accomplished. This means that the pollen parent must not only be known but also controlled—the male as well as the female parent must be *selected*. In order to do this, it is necessary to control the pollen parent by artificial self-pollination.

As a result of continued self-fertilization, the vigor and yield decrease quite rapidly at first, then more and more slowly until finally a point is reached where no further deterioration is observed. The strain is then said to be pure, and it will continue to breed true thereafter for an indefinite period provided no mixing occurs with other types.

A close study of the lines resulting from self-fertilization brings out the fact that some are good, others are poor, and still others are of indifferent value so far as capacity for production is concerned. Since all the plants in any one line are alike genetically, the corn breeder is confronted with the necessity of making a choice of the *best lines* rather than of the *best plants* as was the case in the selection method. Obviously, the best lines are those that possess characters favorable to production, such as resistance to disease and lodging, and that are themselves good producers of grain or of forage.

The next step toward improvement is to combine into one type the favorable factors which have been separated by self-fertilization. This is hybridization. A combination of two lines constitutes a single cross, four lines a double cross, and many lines a multiple cross. In the case of the single cross, best results are obtained by making the cross anew each year, while in the case of the double and multiple crosses it would appear possible to carry over the benefits of hybridization into the second, third, and subsequent hybrid generations by careful selection.

Briefly, then, the pure-line method involves first the purifying of strains by inbreeding and then the building up of a new and vigorous strain by outcrossing with other desirable pure lines.

Inbreeding Reveals True Character of the Stock

Self-fertilization (or inbreeding) furnishes a means of eliminating various weaknesses in the stock, such as susceptibility to smut and other diseases, weak root system (Fig. 4), blighting, rolling of leaves (Fig. 5), partial loss of chlorophyll and various other deficiencies that result in reduced growth and productiveness. Inbreeding reveals both the good and the bad characters. It spreads out before the corn breeder the characteristics of the stock so that he can study them, select the good, and discard the poor. It brings to light undesirable qualities that

FIG. 4.—ERECT AND BADLY LODGED INBRED STRAINS

Strains with inherently weak root systems may be eliminated by self-fertilization and selection.

would otherwise be covered up by desirable ones. In thus showing the true character content of the stock, self-fertilization in corn is particularly valuable as a method of breeding (Figs. 6, 7, and 8).

In corn, self-fertilization usually, if not always, is accompanied by such deleterious effects as poor germination, reduced vigor of growth, disease susceptibility, and lessened production of pollen, all of which contribute to the general effect of reduction in vigor and yield in plants that are otherwise normal. This general reduction in the plant's activities begins with the first year of self-fertilization and nearly always becomes more marked with subsequent self-fertilization. Some inbred strains become so weakened that they can be propagated only with difficulty, particularly if grown on soil infested with the corn rot

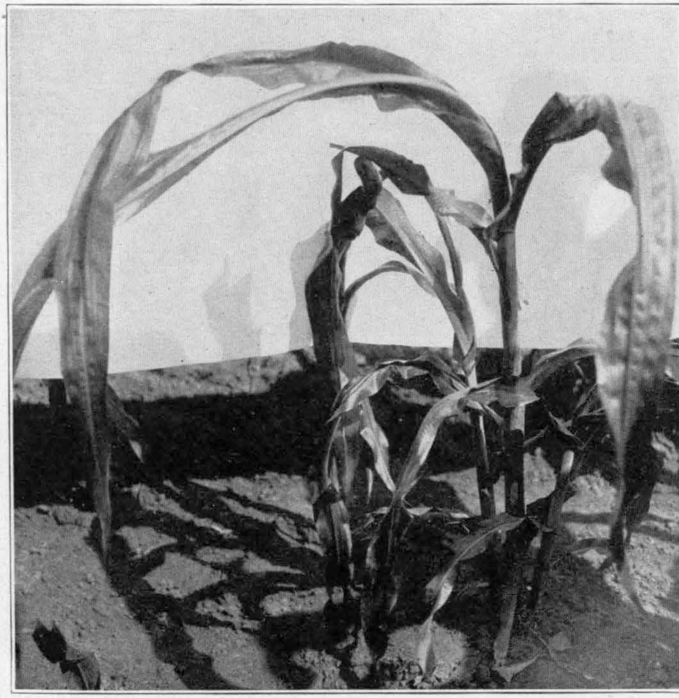


Fig. 5.—Leaf Rolling—A Heritable Weakness
Leaf rolling is a weakness found in many open-pollinated strains.

organisms (Fig. 9). Other strains, however, show themselves to be inherently stronger and more resistant to disease, and are able not only to survive but also to produce fair yields of seed.

It must not be thought, however, that self-fertilization is in itself detrimental, or that it is the *cause* of the accompanying reduction in general vigor. The cause must be sought in deficiencies of various kinds naturally present in the stock, and in the principle that self-fertilization in a hybrid brings about a separation or assortment of favorable growth factors into different lines. When all such deficiencies have been eliminated and the growth factors have been rendered pure by repeated inbreeding, no further reduction in vigor occurs. Self-fertilization may be continued indefinitely thereafter with no further detrimental effects.

Recent observations and experiments are directing attention to the physiological behavior of selfed lines of corn. There are indications that some lines are able to make more efficient use of conditions of growth than others. For example, some are more efficient users of phosphorus; some appear able to exert a selective action on the plant-food elements, absorbing only those which are needed in proper amounts and proportions, while others do not possess this power and

FIG. 6.—A GOOD INBRED STRAIN OF FAMILY A

FIG. 7.—A GOOD INBRED STRAIN OF FAMILY B

Note the sturdiness of the stalks. If these were growing in a field of ordinary corn, one would have difficulty in distinguishing them from open-pollinated plants. Valuable inbred strains may differ widely in their vegetative growth and general appearance.

consequently are injured by one or another element which they have absorbed in excessive amounts. Also, some lines are able to resist chinch-bugs to a greater or less extent; others are resistant to prolonged drouth, on account of an extensive and efficient root system; others show differences in proportion of grain to stover. As methods of testing selfed lines become more exact and refined, the corn breeder will be able to take advantage of all the variations in physiological behavior which Nature has provided, and to combine them in crosses to secure the best results.

The most difficult part of the pure-line method is the production of the selfed lines, and on account of the training, time, and equipment required, the work will probably be done largely by the Experiment Station and the professional plant breeder. However, since different lines are required for different sections of the state because of varying soil and climatic conditions, the task of finding lines adapted to them

FIG. 8.—AN INBRED STRAIN CHARACTERIZED BY BROAD LEAVES

Inbreeding is valuable in bringing to light desirable characters such as this, which can be combined in crosses with others equally desirable.

would be greatly aided if there were in each section at least one man having the requisite training for and inclination toward this special field of work.

By Hybridization Desirable Characteristics May be Combined

Outcrossing is the normal habit of the corn plant. In the ordinary cornfield, cross-pollination (or hybridization) is the rule and self-fertilization the exception. Crossing between different plants is encouraged by: (1) the separation of tassels (male) and silks (female); (2) the difference in time of maturity of pollen and silks on the same plants; and (3) the fact that the pollen is so effectively scattered about the field by the wind. Nature, then, would appear to favor any method of improvement for corn which necessitates a considerable amount of outcrossing.

Just as self-fertilization in corn usually is accompanied by reduced vigor and yield, so the hybridized condition gives increased vigor and yield. Hybridization, therefore, is a means of restoring the vigor lost as a result of self-fertilization. Hybrids between self-fertilized lines (or "selfed" lines) usually exceed either parent in yield and oftentimes outyield even the variety from which the parent lines originated (Figs. 10, 11, and 12). However, hybrids between common varieties of corn that have not been subjected to inbreeding usually show very little or no increase unless they differ from each other in several characters, and even in such cases it is questionable whether they give sufficient increases to justify their use.

Experience has shown, as pointed out above, that it is possible to find selfed lines that show very little reduction in yield and vigor compared with the original strain or variety. These lines are good because they contain a sufficient number of genetic factors favorable for growth and productiveness. With continued self-fertilization they would be rendered genetically pure for the factors they contain. It is highly improbable that all factors possessed by any two such lines would be identical. If Type I contains factors A, B, and C, Type II might contain factor A but have factors D and E instead of B and C.

With the large number of factors responsible for vigor and productiveness in corn, it is quite possible to obtain many types that differ among themselves with respect to such factors. As a result of these differences in factors, the types themselves show differences in such characters as extent of root development, height of plant, general vigor of growth, and relative resistance to the corn rot diseases and to smut. One type may be particularly good in certain of these characters, another in others, and so on. If all such characters could be combined by crossing, the resulting type should be superior to all others in yield and vigor.

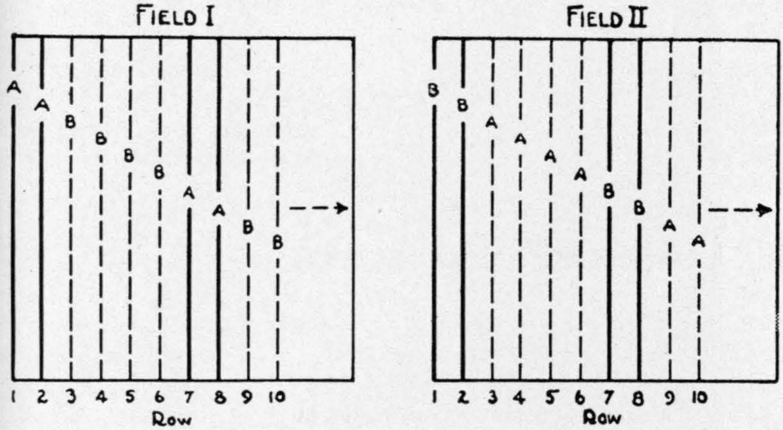
Single Crosses

The combination of any two lines into one results in what is known as a single cross. Oftentimes the hybrid is markedly superior to either of the lines composing it. This is particularly true if the parent lines differ from each other in several respects. In such case there are not only the beneficial effects in the hybrid of the bringing together of desirable characters, but also the stimulation, or hybrid vigor, which is generally so pronounced when unlike types are crossed. Some lines show relatively few obvious differences, yet when crossed the hybrid is far superior to either parent. This means that selfed lines may differ considerably in the genetic factors that control their response to environmental conditions without at the same time differing in appearance.

On the other hand, it often happens that little is gained by crossing certain selfed lines. Such a result may be due to close relationship or to the fact that, even without close relationship, the lines happen to resemble each other too closely in their genetic constitution. The genetic factors for yield and vigor being largely the same in both parents, crossing accomplishes little more than self-fertilization.

The problem of successfully crossing pure lines resolves itself into a choice of lines to use as parents. Without more information, it is possible to point out, in only a general way, the characteristics on which such a selection should be based: namely, the parental lines should be themselves fair producers of grain in order that they may be multiplied rapidly for crossing on a large scale; they should have the same grain color so that grain produced by the hybrid will be uniform in color (this, however, is not an important consideration if the grain is to be used for feeding live stock); and finally they should exhibit, so far as possible, the desirable plant and ear characteristics described in the first part of this circular.

Obviously, the best results will be secured from the use of single crosses if they are made anew each year. The following plan may be suggested for producing the hybrid seed in quantity. Let one selfed line be designated by A, the other by B. Two fields are required, Field I and Field II, sufficiently isolated from each other and from other corn fields to prevent cross-pollination. It is immaterial whether they are of the same size or not. In these fields, strains A and B are planted according to the following diagram:



In Field I, two rows of strain A alternate with four rows of strain B. All rows of strain B are detasseled, and being pollinated by A pollen produce hybrid seed only. Rows planted to strain A produce pure seed of A. In Field II, two rows of strain B alternate with four rows of strain A. All rows of strain A are detasseled, and being pollinated by B pollen produce hybrid seed only. Rows planted to strain B produce pure seed of B. Thus, this plan provides for the production of hybrid seed each year, as well as the production of pure seed of the two parental lines. Also, hybrid seed is produced on two-thirds of the total acreage while only one-third is devoted to continuing the strains.

Hybrid Seed Not Unduly Expensive

A plan similar to the above should permit the production of hybrid seed at relatively little increase in cost over that for ordinary seed corn.

The increased cost of planting would be negligible, especially if an arrangement were perfected whereby two extra planter boxes could be carried along and substitution made when a different strain was to be planted. The largest item of expense, and one not encountered in ordinary seed corn production, is the labor of detasseling. For a period of two or three weeks it would be necessary to go thru each field every other day to remove the tassels. Especial care is required at the beginning and end of the period, as few tassels may come out and shed pollen quite early, and others, particularly those on suckers, quite

FIG. 9.—MISSING HILLS RESULTING FROM THE EARLY DEATH OF BLIGHTED AND BADLY DISEASED PLANTS

Some inbred strains become so weakened that they can be propagated only with difficulty, particularly if grown on soil infested with the corn-rot organisms.

late. However, since all plants would not tassel at the same time, one could cover a considerable acreage in a day.

The cost of harvesting would be no greater than for ordinary seed corn. Some pains would be required, however, to keep the pure types separate from each other and from the hybrid seed. Finally, the expense involved in the subsequent handling and care would be practically the same as the seed corn grower must now bear for seed of any of the standard varieties.

On the other hand, there are some compensating features that largely make up for any extra cost encountered in hybrid seed-corn production. A larger proportion of the total crop would probably be sound corn than that of the ordinary corn crop. Furthermore, all sound corn produced by the detasseled rows could be used for seed, since all kernels have the same genetic constitution. It would appear therefore, all things considered, that the matter of keeping down the seed cost would not be serious.

Double Crosses

Since it is improbable that all desirable qualities will be found in any two lines, it would appear that the combination of several lines would produce a hybrid type superior to any single cross that could be made. That this result may reasonably be expected in certain cases is indicated by the work of Jones[1] on double crosses.

Let A, B, C, and D represent separate lines which have been rendered practically pure by inbreeding, and which possess individually one or more characters of outstanding importance, such as a strong root system or resistance to root and stalk rots. These strains would be combined into single crosses first and then into a double cross according to the following diagram:

Strains..............	A B	C D
Single crosses........	A x B	C x D
Double cross.........	(A x B) x (C x D)	

If the parent strains are pure, the plants of either single cross would show marked uniformity because they would all have the same genetic constitution. Variations among them would be due to environmental conditions. This cannot be said of the double cross, however. While in one sense it can be considered a first-generation hybrid, in another sense it represents, in its relation to the previous crossing, a second-generation hybrid. It will show therefore, considerable variation because it consists of plants which differ genetically. Indeed, so great is the possible number of factors in which the parent lines may differ, that it is not far from the truth to state that scarcely any two plants would have exactly the same genetic constitution. This is believed to be a desirable situation. Numerous types, with varying capacities for utilizing the plant food and moisture at their disposal, often will produce better collectively than if the population consisted of but one type, all the plants of which were uniform in their capacity for development. It is likely, also, in view of the large amount of crossing that is continually taking place under field conditions, that the population might be continued for a few years, by careful selection, without any very noticeable decrease in yield.

Multiple Crosses

Since good results have been obtained by combining four selfed lines into a double cross, probably still better results may be secured

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[1]Jones, D. F. The Productiveness of Single and Double First Generation Corn Hybrids. Jour. Amer. Soc. Agron. 14:241-252. 1922.

FIG. 10.—A GOOD CROSS OF TWO INBRED STRAINS

First-generation corn of the inbred strains illustrated in Figs. 6 and 7. Note the vigor and productivity.

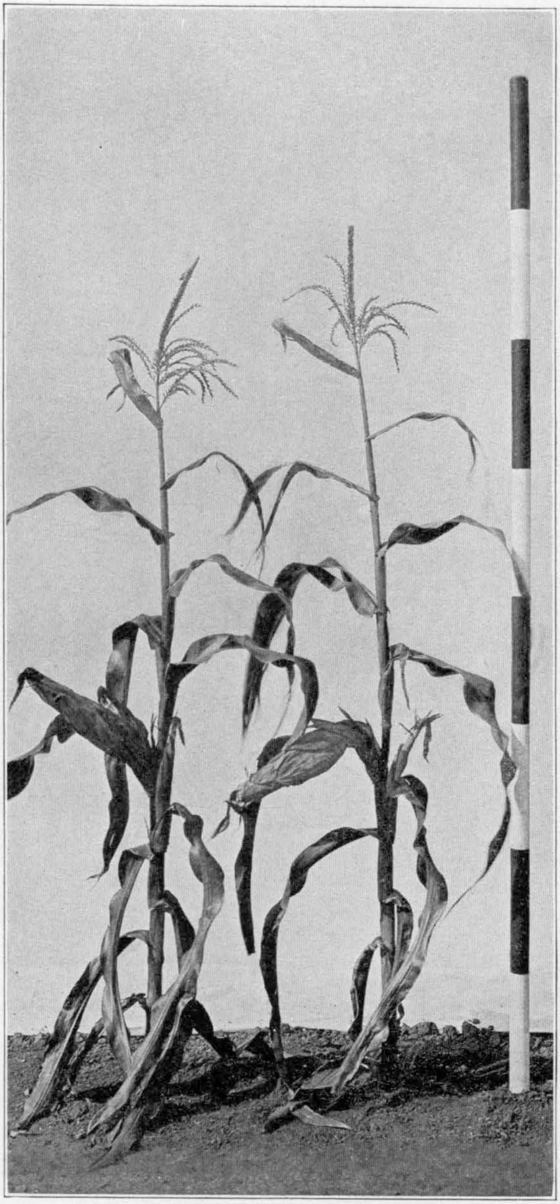
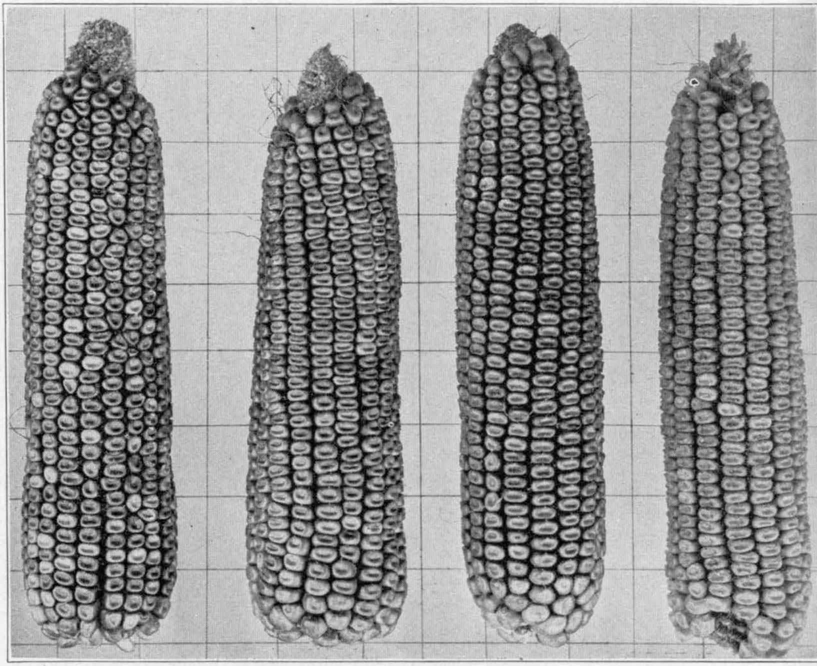
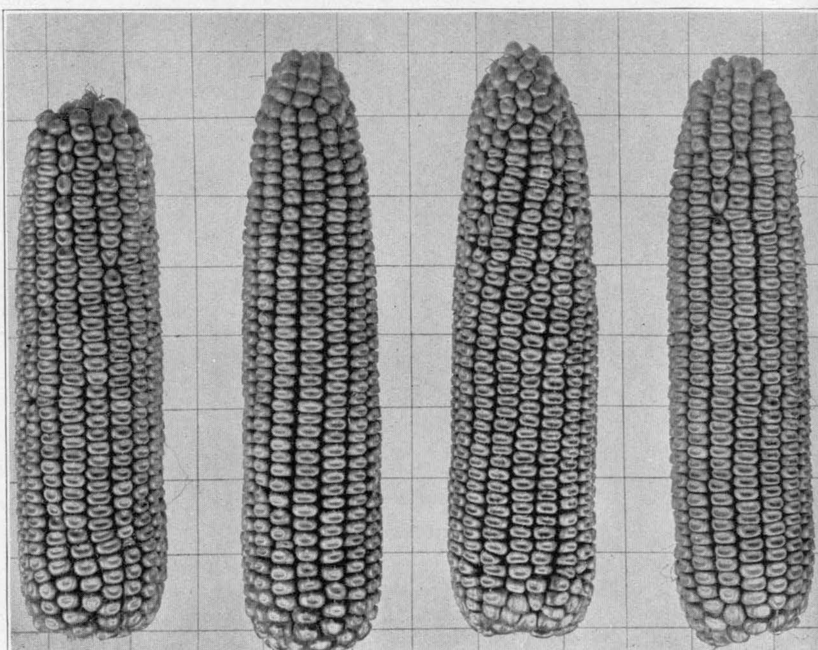


FIG. 11.—ANOTHER GOOD CROSS

Note the low stalks and large ears. These plants represent a first-generation cross between the strain illustrated in Fig. 6 and an inbred strain of the Illinois High Yield.





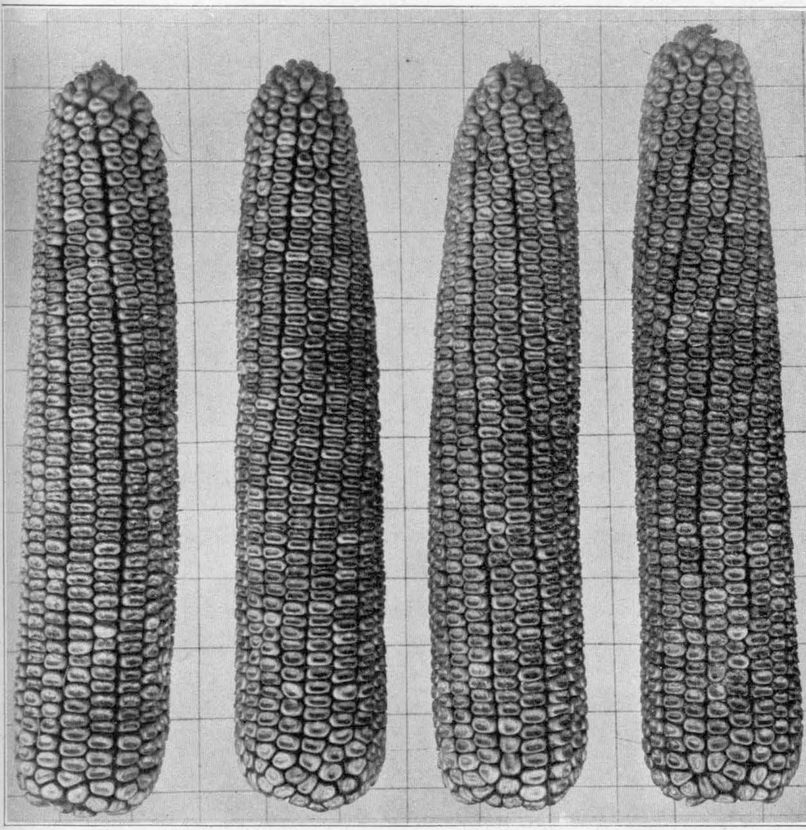


FIG. 12.—EARS PRODUCED BY THE PURE-LINE METHOD OF CORN BREEDING

Representative ears of inbred strain A (upper left), inbred strain B (lower left), and the single cross of A×B (above). This single cross yielded at the rate of 117.2 bushels per acre. (The ears were photographed on 1-inch mesh screen.) Bloomington, 1923.

The pure-line method of corn breeding is fundamentally sound in theory, but the practical benefits from its use are, in the main, still to be realized. Tho many problems remain to be worked out in regard to the utilization of inbred and hybrid strains, it is felt that enough is already known to justify considerable confidence in the importance and ultimate value of the method in corn production.

by combining many more such lines into what might be called a multiple cross. This is only suggestive, as no experimental data are available on this point. However, it would seem that the more lines there are entering into the cross, the better, because the result would be greater genetic diversity and variation, and consequently better response to seasonal, soil, and other conditions. Furthermore, the general superiority of the multiple cross could probably be continued for a considerably longer period by selection.

In the practical utilization of double or multiple crosses, the Experiment Station or the professional plant breeder must cooperate with the corn grower, the former furnishing the double or multiple crossed seed, the latter continuing it by selection. After several years it may become necessary for the grower to return to the original supply for his hybrid seed because in spite of careful selection the proportion of plants possessing the genetic constitution of the original hybrids is likely gradually to decrease, and the yield will accordingly be reduced. The general average yield of the hybrid seed in this period, however, would probably be enough in excess of that given by ordinary varieties to warrant its use.

The method proposed above would have several advantages from the practical point of view. It would permit a fairly rapid increase of seed for general distribution. It would not be necessary for the seed-corn producer or corn grower to maintain isolated seed plots. There would be little danger, for some time at least, of securing uniformity at the sacrifice of productiveness because of the hybrid origin of the seed stock and the consequent recurrence of varying hereditary combinations. And finally, abundant material would be at hand at all times for selection.

Probable Use of the Two Methods of Corn Improvement

The pure-line method is of incalculable value to the investigator. It provides him with a tool by means of which he can resolve the corn crop into its component elements and analyze them, saving what appears useful and discarding the rest. He can isolate and recombine the genetic factors which affect root development and thus build up a type with a superior root system particularly adapted to drouth conditions.

Self-fertilization may be likened to the analytical method employed by the chemist. It is a breaking down process according to which the investigator takes the corn crop as Nature has given it to him and determines of what it is made up. Then he takes the parts he wants and builds up, synthetically, the particular type desired, by hybridization. Hence, *analysis* and *synthesis* are the keynotes of this method.

For a considerable time, probably, the method of careful *seed selection* will be largely used by the majority of seed producers and farmers in improving their corn. This must necessarily be the case, because of the length of time required to obtain tested lines for use in producing hybrid seed. However, as the superiority of hybrid seed becomes more firmly established, and information concerning it spreads among corn growers, there will result an increased demand for it. To meet this demand, hybrid seed production will have to be put on a commercial basis. While practical difficulties which have always been urged against this method are not believed to be insurmountable, the utilization of hybrid seed in corn production will be most efficient only when there is complete cooperation between the Experiment Station, the professional plant breeder, the seed producer, and the corn grower.