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In the January issue of The Visitor a summary of the scientific investigations of the relation between ear characters and yield was presented. The February issue reviewed some of the more important investigations of the reliability of several methods of corn breeding and suggested what the farmer can do to improve his corn yields. In this issue Dr. H. K. Hayes, professor of plant breeding, University of Minnesota, reviews briefly the corn breeding methods that are at the present time receiving the attention of the plant breeders at the various experiment stations. The purpose of presenting the materials on corn investigations is to furnish the teachers of agriculture with present investigational methods which Agricultural Experiment Station men are using in studies of corn improvement.—A. M. F.

INVESTIGATIONAL METHODS IN CORN BREEDING

Introduction

The development of the practice of breeding cross-pollinated plants by some method of controlled pollination has been a gradual one. The method originated as a result of intensive studies of the effects of self-fertilization in cross-pollinated species and throughout this study the work with corn has been of fundamental importance. The studies which were initiated over 15 years ago by Dr. E. M. East at the Connecticut station, by Dr. G. H. Shull at Cold Springs Harbor, and by various workers of the Bureau of Plant Industry, and others, had as their aim the development of a more intensive knowledge of the physiology of inheritance of the corn plant, with the belief that such studies were essential to the development of better methods of breeding. In 1910 Dr. Shull emphasized the value of isolating pure lines and of using F_1 crosses between pure lines for maximum production. He makes the significant comment "I feel quite sure that the results of such investigations will lead to some hybridization method in the breeding of this crop."

Summary of Methods

The purpose of the newer methods is to enable the breeder to control the factors of inheritance. A brief summary of the main steps is given here. Numerous plants of a desirable adapted commercial variety are self-pollinated. This is accomplished by covering the ear with a paper bag before the silks appear. The tassel is covered with a separate bag and after the silks are well out the pollen is poured from the tassel bag over the silk. The ear is protected from foreign pollen by again covering the ear shoot with the bag. The seed for each subsequent generation is obtained by self-pollinating plants which seem desirable. Such self-fertilized lines rapidly become uniform and remain so as long as self-fertilization is continued. No selfed strains have been obtained yet which are as vigorous as normal varieties. By the method used undesirable germ plasm is eliminated and desirable germ plasm made known. Selfed strains differ widely from each other. Some of the more important differences are:

1. Resistance or susceptibility to ear, stalk, and root rots and to smut.
2. Height of plant, length, shape of ear, and ear production per plant.
3. Size of seed.
4. Strength of stalk.
5. The number and sort of striking abnormalities present.

This method allows the breeder to discard strains which are highly inferior. The best appearing strains which approach homozygosis are selected for further breeding operations. These can be selected after the strains have been selfed for four or more generations. Three general plans for the use of such strains are being tried out. These are (1) single crosses, (2) double crosses, and (3) synthetic recombination of several selfed strains.

In the single cross plan two selfed strains are crossed and the F_1 (first) generation grown as the commercial crop. Certain difficulties are involved in this. The low

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yield of seed which is usually obtained from closely inbred lines will result in increased cost of seed production. In many inbred lines the size of seed is smaller than that of the commercial variety from which the inbred line was obtained. This results in some handicap for the young plant when single crosses are used for the commercial crop. With the production of better selfed strains it is possible that the single cross plan may prove more feasible.

The double cross plan overcomes some of these difficulties, altho instead of making one cross to obtain commercial seed three crosses must be made. A double cross is really a first generation cross between two single crosses. Four selfed strains which combine well together are used. The double cross plan has the advantage that vigorous F_1 crosses are used as parents. The variability of the individual plants of a double cross will be greater than in a single cross. This will result in a prolonged period of pollination which, under certain environmental conditions, is an advantage.

If either the single or double cross plan is used, F_1 seed must be produced each year, as the selection of seed from F_1 crosses leads to marked reductions in yielding ability in later generations.

The production of improved varieties synthetically, by a cross of several selfed lines and subsequent selection, aims at the improvement of the variety without the necessity of making an F_1 cross each year. It appears probable, however, that it will be very difficult to obtain a variety which will be as vigorous as certain F_1 crosses. When a single character, such as disease resistance, is of outstanding importance the plan appears to be a sound one.

Extensive studies are under way at nearly all of the Corn Belt experiment stations and, in general, there is close co-operation between the different workers.

RESULTS SUMMARIZED

Single Crosses

In Minnesota crosses between lines highly resistant to attacks of corn smut have been highly resistant and very vigorous. Similarly at other stations (Indiana, Illinois, and Wisconsin) selfed lines resistant to corn, stalk, and ear root rotting organisms have been isolated and F_1 crosses between them have proved resistant and have given high yields.

Investigations at the Nebraska Experiment Station.—Eight F_1 crosses of selfed strains were tested in Nebraska and compared for four years with the original variety. The average yields secured from these tests are shown in Table 1.

Table 1. F_1 Crosses of Selfed Lines Compared with the Original Variety on Basis of Yield

	Bushels per acre shelled corn				
	1913	1915	1916	1917	Average
Average 8 crosses	23.3	66.9	51.7	59.3	48.3
Best yielding cross	21.9	73.6	58.0	59.4	53.2
Original variety	11.4	73.1	34.5	46.0	41.2

Results from the Iowa Experiment Station.—In the South Central Section of Iowa Corn Yield Contest, 4 of the 5 highest yielding varieties were crosses in which selfed strains were involved. The highest yield, 51.3 bushels, was from a cross. The average of 4 crosses in which inbred strains were involved was 44.2 bushels and of 34 commercial varieties of Reid's Yellow Dent 34.5 bushels.

Extensive trials have been conducted at the Iowa Experiment Station. The quotation from Professor Hughes summarizes the results: "From the results secured thus far it is entirely evident that decidedly better yields can be secured from hybridizing pure lines than can be had from the best standard varieties of which we know. The data would also indicate that extensive ear-row breeding with subsequent crossing of the best lines even when carried thru a long period of years can not be expected to give

the results to be had from the production of pure lines and the use of F_1 (first generation crossed) seed."

Double Crosses

One double cross of 4 selfed lines grown in Connecticut in 1924 illustrates the possibilities. Century and Leaming are two of the best varieties. Century $F_1 \times$ Leaming F_1, which means the first generation cross of 2 selfed strains of Century crossed with a first generation cross of 2 selfed strains of Leaming, yielded 37% more than the better standard variety.

Results from investigations at the Minnesota Experiment Station.—Crosses in which selfed strains were used have been grown at University Farm, St. Paul, Minnesota, for several years. Rather extensive field plot trials of double crosses were made in 1924 and 1925. During these two seasons the selfed lines used were isolated previously from standard high-yielding Minnesota varieties. Two such varieties recognized as standard for Central Minnesota, Minn. No. 13 and Rustler White Dent, have been grown at University Farm for many years, the seed being selected in the field from perfect stand hills and from vigorous, healthy stalks. Close selection to score-card type of ear has not been practiced in recent years. Seed for three other varieties has been purchased yearly from a seed company in Minneapolis and represents the better selections for these varieties.

The selfed strains used for the crosses were picked out on the basis of yield and the absence of striking abnormalities. Each F_1 cross was made by crossing two selfed strains within a variety which appeared unlike each other and the double crosses of these F_1 crosses were made at random. It is recognized that it would be more desirable to determine the strains which would combine to produce the better yielding crosses, and this method is being tried out. In the meantime, however, it appears of interest to see what the results would be from combining on the basis of observable characters alone. The results for the two crop seasons are presented in Table 2.

Table 2. Percentage Yield of Double Crosses Obtained by Crossing F_1 Crosses Between Selfed Lines Where 100 Is Taken as the Yield of the Higher Yielding Standard Variety. University Farm. 1924-1925

1924 Results	Percentage yield classes								Number of crosses	Average percentage yield
	70	95	100	105	110	115	120	125	130		
Dent crosses			1	2	1	1		1	1	7	113.3
Flint-dent crosses		2		3	2	3	1	1		12	109.4
Flint crosses	1						1			2	95.5

1925 Results	Percentage yield classes										Number of crosses	Average percentage yield
	80	90	95	100	105	110	115	120	125	130		
Dent crosses			1	2	1	1	1	2		1	9	110.1
Flint-dent crosses				1	1		1				3	107.3
Flint crosses	1		1				2	1			5	105.5

In 1924, of a total of 21 double crosses tested, three yielded less than the higher yielding commercial varieties. One double cross exceeded the better commercial variety by 30 per cent. The 7 double crosses, in which dent inbred strains were used, yielded 13 per cent more on the average than the better variety, while 12 flint-dent crosses averaged 9 per cent more than the better variety. Of two flint double crosses one gave a low yield and the other yielded rather well. The results in 1925 were similar and certainly indicate that double crosses in which desirable appearing selfed lines are used may be expected to yield more than the present standard varieties.

Synthetic Combination of Several Selfed Lines

The production of improved varieties thru the recombination of several selfed strains has one advantage over either the single or double cross plan in that the farmer can save his own seed from the yearly crop and that yearly crosses need not be made. Little data regarding the value of this method are available.

At University Farm several recombinations of selfed strains within a variety were made in 1923 and the F_2 recombinations were compared with commercial varieties in 1925.

The methods used were as follows: Selfed strains were selected which appeared superior to the average and which were free from striking abnormalities. The recombination of selfed strains was obtained by pollinating several plants of each strain of a variety with a mixture of pollen from other strains of the same variety. An equal

number of seeds from each such cross of each strain was bulked and planted the following year. Seed for later generations within each recombination was obtained by pollinating 50 plants with a mixture of pollen of 50 other plants. The comparisons of yielding ability of the standard varieties and of the F_2 recombinations are given in Table 3. According to genetic theory, yields in later segregating generations should be as good as in F_2.

Table 3. Yield of Synthetic Varieties Compared with Commercial Varieties. Univ. Farm. 1925

Variety	Strains used for recombination		Yield bushels per acre	Per cent increase or decrease
	Years selfed	Number		
Minn. No. 13	..	..	51.3	
Minn. No. 13 F_2 Recomb.	1	5		
	3	3	45.3	−11.7
	8	1		
Rustler	..	..	44.8	
Rustler F_2 Recomb.	1	2		
	2	7	47.5	+6.0
	3	5		
	4	3		
N. W. Dent	..	..	51.9	
N. W. Dent F_2 Recomb.	1	2		
	3	8	60.5	+16.6
King Phillip	..	..	40.3	
King Phillip F_2 Recomb.	3	11	43.3	+7.4
Longfellow	..	..	43.9	
Longfellow F_2 Recomb.	3	8	40.1	−8.7

For the five comparisons there were three F_2 recombination families which yielded more than the standard variety and two which yielded less. The Northwestern Dent F_2 recombination yielded 16.6 per cent more than commercial Northwestern Dent and appeared superior to Northwestern Dent in the field.

What Are the Possibilities?

Further extensive study is needed and is being conducted co-operatively by corn belt stations. Fairly extensive studies are being conducted at University Farm and Waseca. Studies have been started at Crookston and Morris.

It appears evident that the newer methods are worth extensive study. As knowledge of the genetic and physiologic properties of the corn plant become known, it will be possible to produce results which by the older methods could not be obtained.

If root rots are harmful, and in some seasons and sections they surely are, what better control could be suggested than the use of resistant varieties?

It appears probable that corn of better quality and of 20 to 30 per cent higher yielding ability can be obtained by the newer breeding methods.

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