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UNIVERSITY OF MINNESOTA
AGRICULTURAL EXPERIMENT STATION

METHODS OF CORN BREEDING

BY

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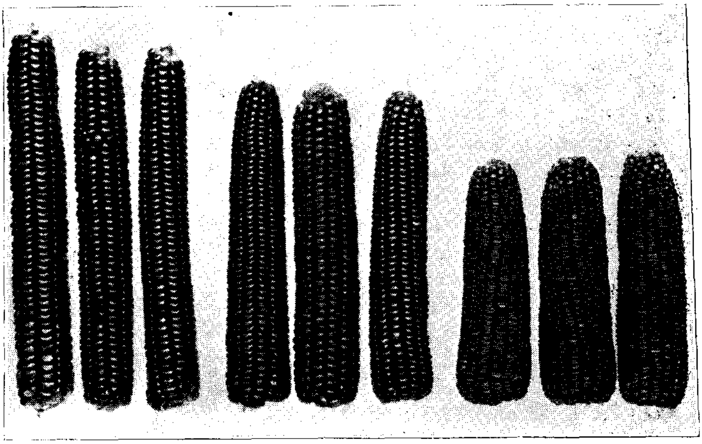
DIVISION OF AGRONOMY AND FARM MANAGEMENT



F_1 CROSSES AND THEIR PARENTS
At left, Longfellow. In center, F_1 Cross. At right, Minnesota No. 13.

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METHODS OF CORN BREEDING

By H. K. Hayes, Assisted by Lee Alexander

INTRODUCTION

The great economic value of the corn crop has led to the production of many varieties, and corn is now being grown in many regions where formerly the crop was a failure. These facts support the conclusion that the production of varieties adapted to various regions has been of great aid to the farmer.

Because of the importance of the crop, studies have been carried on in order to furnish accurate information regarding rates and dates of seeding, proper rotation, cultural methods, and systems of seed selection which will produce the greatest return per acre.

Adapted varieties are available for most sections of the corn belt, and for these regions it does not seem desirable or necessary to produce more varieties. The list of varieties is already much too long and what is needed is a standardization of varieties and the discard of the more undesirable ones. In many localities the more desirable varieties are known and the natural question in the minds of many corn growers is, "How can I keep my variety in a state of improvement and can it be further improved by selection?"

A series of experiments was outlined several years ago for the purpose of learning the value of different methods of seed selection for the corn grower or seedsman who produces his own seed. In order to solve the problem it was necessary to use methods which the corn grower could practice on his own farm. This bulletin is a report of (1) the comparative value of different methods of seed selection of an adapted variety, and (2) the value of first generation varietal crosses between standard varieties. Before presenting the Minnesota results, a brief history of corn improvement will be given.

BRIEF HISTORY OF CORN IMPROVEMENT STUDIES

The selection method of corn improvement was introduced into the United States between 1890 and 1896 by Hopkins, of Illinois. The method consisted in growing under comparable conditions a progeny row of each ear selection in order to determine the yielding ability of selected ears. Subsequent selections were made from the higher yielding rows. The method is known as the ear-to-row plan.

The ear-to-row method has been tried by many experiment stations, and various modifications of the original plan have been made. The main purpose of these modifications has been to overcome a tendency toward inbreeding, for it was realized that inbreeding resulted in a reduction of yield.

With an unadapted variety ear-to-row breeding may be the quickest method of adapting the variety to the conditions. When the present experiment was outlined in 1915 there was little available information regarding the value of ear-to-row breeding in an adapted variety. The lack of value of ear-to-row tests is well illustrated by data presented by Hume (1919), which was collected in South Dakota. A seven-year average yield of certain high-yielding rows exceeded the average of all ear-to-row tests by nearly 12 bushels per acre. From this it seems reasonable to suppose that continued selection from the higher yielding rows would improve the variety. Hume tested two methods: ear-to-row breeding, and selection of good ears from a seed plot. In the ear-to-row test alternate rows were detasseled to prevent inbreeding. When a comparison was made of yielding ability from seed saved from detasseled rows in ear-to-row plots and from seed saved in the experimental fields near by, the difference in yield was very small. Hume suggests the possibility that all corn on the farm was improved through cross-pollination with pollen from the ear-to-row test. In spite of the lack of experimental evidence, Hume suggested an ear-to-row plan for the South Dakota corn grower. Smith (1918), of Illinois, has likewise suggested two plans for improvement by selection. In the first method the ear-to-row test is used as a preliminary step in obtaining the better lines. The remnants of these better ears are mixed and planted in a seed plot. Good ears are selected from the seed plot for use in the following year's seed plot. This method was first suggested by Montgomery (1909). The other method suggested by Smith is not widely different from the plan suggested by Hume except that Smith recommends growing check rows in the ear-to-row test and detasseling every plant in the check rows and all undesirable plants in the plot. Alternate ends of each ear-to-row plot are detasseled and seed is saved from the detasseled rows.

Kiesselbach (1922) has recently presented data which indicate that ear-to-row breeding is of little value as a means of improvement of an adapted variety. At the Nebraska station, Hogue's Yellow Dent has proved, on the average, the highest yielding variety. The following table presents the results obtained by Kiesselbach:

TABLE I

EFFECT OF EAR-TO-ROW BREEDING ON YIELD OF HOGUE'S YELLOW DENT CORN (AFTER KIESSELBACH)

Kind of breeding	Average yield per acre Bu. 1911-17
Original Hogue's Yellow Dent	53.6
Continuous ear-to-row selection since 1903	53.3
Increase of single high-yielding row selected in 1906	47.7
Increase from 4 strains selected in 1906	55.0

The original Hogue's was carried on by selecting well-developed ears for seed. The continuous ear-to-row breeding appeared to be of no value. The increase of the high-yielding strain and subsequent isolation of the strain resulted in a reduction in yielding ability which presumably was a result of inbreeding. The increased yield obtained from the isolation of four high-yielding strains was not very large. Similar results were obtained from Nebraska White Prize except that the increase and subsequent selection from eight high-yielding strains yielded on the average three bushels less than the original corn. These experiments of Kiesselbach certainly cause one to doubt the value of ear-to-row breeding as a means of increasing yields of adapted corn varieties.

No problem of corn improvement has been more carefully studied than the relation of ear type to yield. The results of many of these studies have been summarized in a previous bulletin of this station. (See Olson, Bull, and Hayes, 1915.[1]) The conclusion was reached that selection of ears on the basis of score card type was of no particular value as a means of increasing yield. The opinion was advanced that close selection to type, if long continued, might lead to a reduction of yield because of the tendency toward inbreeding.

Certain results of Kiesselbach, as well as the data reported later in this paper, prove that some ear types are better adapted than others for certain conditions. Thus at Lincoln, Neb., and likewise at University Farm, St. Paul, Minn., it appears from the seed standpoint that medium smooth ears of dent corn are more desirable than rough ears. Kiesselbach observed a correlation between rough and smooth ears and plant type. The rough ears produced plants that matured later and had higher leaf area than those produced when seed from smoother ears was used for planting. The earlier maturity and low leaf area were desirable under conditions at Lincoln. Close selection for ear type was not the cause for the higher yielding ability of the progeny of smooth ears.

[1] Out of print, no longer available for distribution.

Hutcheson and Wolf (1918) observed that higher yielding rows of ear-to-row tests, on the average, produced ears which scored higher than ears from low-yielding rows. This led them to conclude that perhaps after all there was a relation between ear type and yield, and that the seed producer was probably justified in selecting seed on the score card basis. Data are presented in this paper which indicate that the better yielding rows of the ear-to-row tests carried on at University Farm were higher yielding because of general vigor, rather than because of close agreement with certain score card standards.

The difficulty of all methods of selection under open-pollinated conditions arises from the fact that every ear results from the union of egg cells of one plant with pollen grains of many other plants. Most of the undesirable characters of corn are covered up by desirable characters,, i.e., most undesirable characters are recessive. The undesirable germ plasm is carried along in a heterozygous condition. While close selection for desirable characters may eliminate some of the undesirable characters, at the same time the variety is frequently injured by inbreeding. Instead of being improved, the yielding ability of the variety may be reduced by the selection which it has undergone.

It is now realized that a corn plant is the end result of the interaction of many inherited factors and environment. From the breeding standpoint the best method of selection appears to be selection in self-fertilized lines.[2] Self-fertilization, however, results in great reduction in vigor and the method of selection in self-fertilized lines appears to be one which is not well adapted to the average farmer or seedsman. A knowledge of laws of heredity is almost necessary to a correct carrying out of the self-fertilization method of breeding. The Minnesota stations are carrying on rather extensive work along this line and nearly all of the Corn Belt experiment stations have similar work under way.

The purpose of this paper, however, is not to present data on selection in self-fertilized lines, but rather is a report of the comparative value of methods of seed production which can be carried out by the corn grower.

[2] For statements of the method and literature on the effects of inbreeding plants, see East and Jones, 1921; Jones, 1920; Hayes and Garber, 1919; Hayes, 1922.

SEED SELECTION OF AN ADAPTED VARIETY

Methods of selection used.—Rustler White Dent was chosen for the study as it was a variety which showed considerable deviation in ear type and as it had not been selected previously by the ear-to-row method. It had the advantage of being adapted to the climatic conditions of Central Minnesota, which was necessary, as the problem was planned as a means of learning how best to select seed of an adapted variety.

The methods used in the Rustler selection test were as follows: As far as possible, the field in which each method of selection was carried on was separated from other fields of corn, selection being continuous from year to year. The selected seed, for the different methods, was stored in a comparable way, except as noted later, and only seed from ears which showed high germination ability by actual trial was used for planting. The comparable yield trials for the different methods of selection were made on the same field. Three-row plots, each row approximately 36 hills long, were used, the central row being used for the yield comparison. Three systematically distributed plots were used each year except in 1920, when four plots were grown. The methods of selection used are as follows:

1. Selection of good ears at husking. Three seeds were planted in each hill and the corn was cut and shocked when mature. Later in the fall the better appearing ears were thrown into a pile when the corn was husked and reserved for seed. This method was isolated from other corn fields.

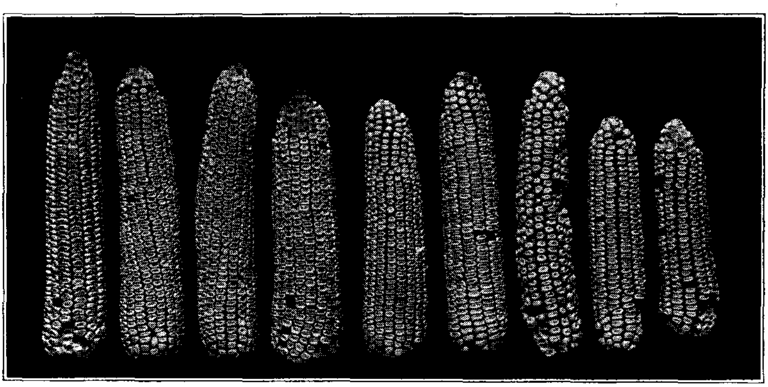

Fig. 1. Average Variation in Ear Type Obtained from Ear-to-Row Plot No. 80, 1921

2. Selection during seed corn week[3] from perfect stand hills and vigorous stalks. Only well-matured ears were chosen but no close selection to ear type was made. The ears were stored immediately in a well-ventilated room, each ear having individual space for proper curing. The lower series on Field X was used each year and similarly selected seed was used to plant the adjacent series on which silage corn was grown. This method was isolated from other methods.

3. As in method 2 except that the selected stalks were shocked and the ears husked later in the fall.

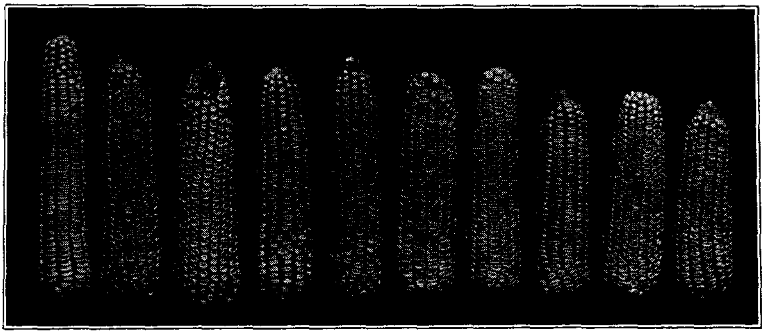

Fig. 2. Selection from Vigorous Plants in Perfect Stand Hills; Method 3, 1918

4. Selected as in method 3 in the field during seed corn week. After husking, the ears were carefully examined for ear type. Only ears of high score card type were used for planting the following year. Selection was made for good butts, medium denting, straight rows, cylindrical ear, 14 to 16-rowed ears, and good ear length. Field C, the manured half-acre, was used for this method through cooperation with the farm crops section. Some cross-pollination may have occurred between the plants on this field and those in the ear-to-row plot, altho the fields were a considerable distance apart.

5. Method 5 is called "Montgomery's method" as the plan was suggested originally by Montgomery. It consists of an ear-to-row test the first year followed by a mixture of seed of the remnants of the 25 better yielding ears as determined by the ear-to-row test. Approximately 100 ears were used for the original ear-to-row selection. In subsequent years the method pursued is similar to plan 3. By selecting from that part of the field which was the farthest from the ear-to-row plot the isolation was fairly good.

[3] The period set by the Agricultural Extension Division for selection of seed under field conditions.

6. Williams' method. The purpose of this plan is to isolate high-yielding ears by the ear-to-row plan, cross the remnants of the three highest yielding ears the following year and multiply the crosses in a seed plot the following year. The seed plot is considered the place to produce commercial seed. The ear-to-row plot, the crossing plot, and the multiplying plot are used each year. The crossing plot and multiplication plot were well isolated from other corn fields.

From Williams' plan two sorts of seed have been used for the yield trial: (1) F_1 crossed seed produced by crossing the remnants of the three higher yielding ears. (2) Increase plot seed obtained by planting F_1 crossed seed. Field T was used for this increase through co-operation with the farm crops section.

Before presenting the results obtained for the different methods of selection, some data will be given so that a comparison can be made of the ears produced in high-yielding, medium-yielding, and low-yielding ear-to-row plots.

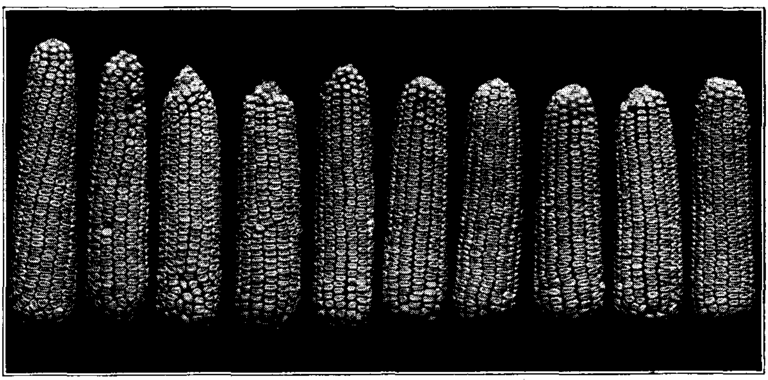

Fig. 3. Selection from Vigorous Plants in Perfect Stand Hills, and Later Selection for Ear Type; Method 4, 1918

Comparison of results obtained in high-, medium-, and low-yielding rows of the ear-to-row tests.—Between 80 and 100 ear-to-row plots were grown each year. The seed of each ear was grown in two rows of 18 hills each and systematic distribution of the rows was made in order to overcome soil heterogeneity. Five or six seeds were planted per hill and these were thinned to a three-stalk basis. Selection of ears to plant the following year's ear-to-row test was made from the ten highest yielding rows.

After the ears were harvested they were taken to the seed room and allowed to dry until January, when the yield data were taken. The ten highest, the ten lowest, and the ten medium-yielding rows were selected and comparative data were taken on the ears of these rows for the purpose of learning what characters were chiefly responsible for the differences in yield. Table II gives averages for percentage stand, number of ears, yield per acre, and shelling percentage.

TABLE II

AVERAGES FOR PERCENTAGE STAND, NUMBER OF EARS OBTAINED PER ROW, YIELD PER ACRE, AND SHELLING PERCENTAGE OF THE TEN HIGH-YIELDING, THE TEN MEDIUM-YIELDING, AND THE TEN LOW-YIELDING ROWS OF THE EAR-TO-ROW TRIALS, 1918 TO 1923 INCLUSIVE

Class for yield	Year grown	Percentage stand	Average yield	No. ears per row	Shelling percentage
High	1918	98	69.9	112	..
"	1919	97	76.6	98	..
"	1920	96	70.9	111	84
"	1921	98	72.8	108	85
"	1922	94	63.0	119	..
"	1923	91	70.5	120	84
Average	....	95.7	70.6	111	84.3
Medium	1918	96	60.9	101	..
"	1919	89	64.1	89	..
"	1920	95	63.2	104	83
"	1921	94	63.5	99	84
"	1922	93	57.0	112	..
"	1923	90	63.5	111	84
Average	....	92.8	62.0	103	83.7
Low	1918	95	55.3	97	..
"	1919	86	54.2	80	..
"	1920	85	54.8	95	82
"	1921	94	57.7	94	84
"	1922	93	50.6	108	..
"	1923	83	56.8	98	83
Average	....	89.3	54.9	95	83.0

Table II indicates that some of the yield differences were probably due to differences in stand. It appears, however, that all the differences can not be explained by this means. In average number of ears produced per plot there was an average of 111 ears produced in the high-yielding rows, 103 in the medium-yielding, and 95 in the low-yielding rows. The production per stalk on the basis of actual stand was, for the high-, medium-, and low-yielding rows, 1.08, 1.04, and 0.99 ears, respectively. The slight difference in shelling percentage in the three groups is in favor of the high-yielding rows.

Table III gives averages for length of ear and for number of rows per ear, together with measures of variability for ear length and row number. The higher yielding ear-to-row plots exceeded both the medium- and low-yielding rows in average ear length. The difference in favor of the high-yielding over the medium- and low-yielding rows is $.17 \pm .04$ and $.37 \pm .04$, respectively. These are significant differences in the light of their probable errors.

In number of rows per ear the differences between the three groups are rather small. During the period of ear-to-row selection no selection for ear type has been made with the exception of straight rowed ears of good size and maturity and from vigorous stalks under competition. Apparently there has been a gradual reduction in number of rows per ear which indicates that this type of ear is adapted for University Farm conditions. The variability for ear length and row number is not significantly different in the three groups.

TABLE III

AVERAGES FOR LENGTH OF EAR IN INCHES, NUMBER OF ROWS PER EAR, AND COEFFICIENTS OF VARIABILITY FOR THE TEN HIGH-YIELDING, THE TEN MEDIUM-YIELDING AND THE TEN LOW-YIELDING ROWS OF THE EAR-TO-ROW TESTS, 1918 TO 1923, INCLUSIVE

Class for yield	Year grown	Length of ears	C. V. for ear length	No. of rows per ear	C. V. for row number
High	1918	6.79±0.05	11.27±0.57	14.8±0.12	13.37±0.62
"	1919	7.97±0.07	12.37±0.61	13.9±0.12	12.89±0.63
"	1920	7.10±0.07	14.76±0.68	13.9±0.11	12.51±0.58
"	1921	7.71±0.07	13.84±0.65	14.5±0.12	12.54±0.59
"	1922	7.08±0.07	16.79±0.75	13.8±0.11	12.10±0.54
"	1923	7.43±0.08	17.71±0.80	13.2±0.10	12.90±0.59
Average	....	7.35±0.03	14.46±0.28	14.0±0.05	12.72±0.24
Medium	1918	6.73±0.05	11.52±0.57	14.7±0.13	12.83±0.62
"	1919	7.67±0.07	12.83±0.66	13.6±0.12	12.30±0.62
"	1920	6.92±0.07	14.51±0.69	13.5±0.12	12.97±0.62
"	1921	7.52±0.08	14.63±0.71	13.7±0.11	12.24±0.60
"	1922	6.90±0.07	16.16±0.74	13.7±0.11	12.83±0.59
"	1923	7.31±0.08	17.10±0.83	13.5±0.11	12.99±0.64
Average	....	7.18±0.03	14.46±0.29	13.8±0.05	12.69±0.25
Low	1918	6.47±0.06	11.89±0.58	15.3±0.14	13.30±0.66
"	1919	7.49±0.07	14.10±0.76	13.9±0.14	13.02±0.64
"	1920	6.82±0.07	15.80±0.79	13.7±0.11	11.87±0.59
"	1921	7.41±0.08	14.74±0.75	14.2±0.12	12.65±0.64
"	1922	6.57±0.07	17.48±0.83	13.7±0.12	13.65±0.65
"	1923	7.15±0.08	17.32±0.86	13.1±0.11	12.14±0.64
Average	....	6.98±0.03	15.22±0.32	14.0±0.05	12.75±0.26

Table IV records the average differences obtained when the three groups were compared on the basis of score for butts. The small differences obtained are in favor of the higher yielding rows.

The percentage of rough and smooth dented ears is given in Table V. Selection of ears for the following year's planting was made on the basis of vigor and maturity of plant under field conditions without selection for any particular ear type. This selection has led to a gradual reduction in the percentage of rough ears without a corresponding increase in the percentage of smooth ears. In other words, without selecting for uniformity the general uniformity of type has been increased rather than decreased. The three groups do not markedly differ in the production of number of ears of the different types. It should be remembered, however, that the seed for both the high- and low-yielding rows was selected from the ten high-yielding rows of the previous year.

TABLE IV

COMPARATIVE PLACING FOR BUTTS SCORE OF TEN HIGH-YIELDING ROWS, TEN MEDIUM-YIELDIING ROWS, AND TEN LOW-YIELDING ROWS OF EAR-TO-ROW TESTS FOR THE VARIETY RUSTLER WHITE DENT, 1918 TO 1921, INCLUSIVE

Class for yield	Year grown	Range for butts score	Average butts score
High	1918	75–95	82.0
"	1919	68–90	85.0
"	1920	80–85	80.5
"	1921	75–85	80.5
"	1922	80–90	83.5
"	1923	80–85	82.0
Average	....	.....	82.3
Medium	1918	50–90	79.5
"	1919	80–95	85.0
"	1920	75–85	79.0
"	1921	75–85	80.5
"	1922	80–85	83.0
"	1923	75–80	78.5
Average	....	.....	80.9
Low	1918	60–95	80.5
"	1919	75–90	82.0
"	1920	75–85	79.5
"	1921	75–90	80.0
"	1922	75–85	80.0
"	1923	70–80	74.0
Average	....	.....	79.3

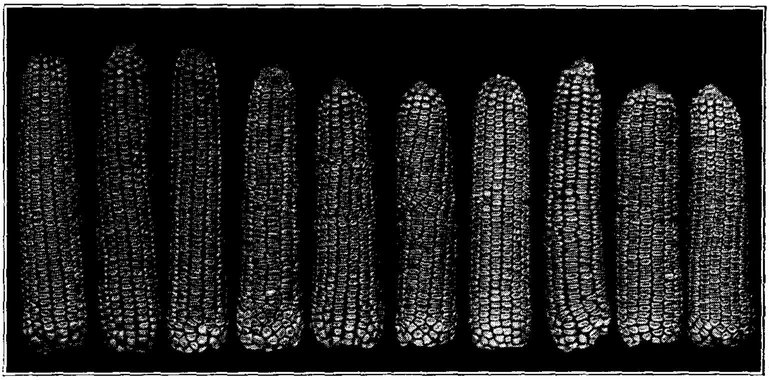

Fig. 4. Selection from Vigorous Plants in Perfect Stand Hills, no Selection for Ear Type; Method 3, 1921

TABLE V

COMPARATIVE PERCENTAGE OF VERY SMOOTH AND VERY ROUGH EARS IN THE TEN HIGH-YIELDING, THE TEN MEDIUM-YIELDING, AND THE TEN LOW-YIELDING ROWS OF RUSTLER EAR-TO-ROW TESTS, 1918 TO 1923, INCLUSIVE

Class for yield	Year grown	Range in percentage rough	Average percentage rough	Range in percentage smooth	Average percentage smooth
High	1918	3.3–41.6	20.0	3.7–29.3	9.0
"	1919	4.5–40.0	14.2	3.0–12.6	8.9
"	1920	4.4–12.9	7.5	0.0– 6.1	3.9
"	1921	0.9–23.5	6.2	1.8–19.8	10.1
"	1922	1–5	3.3	2.0–13.0	7.4
"	1923	1–6	2.2	3.0–10.0	5.8
Average	....	......	8.9	......	7.5
Medium	1918	1.9–48.4	14.0	4.2–22.1	13.9
"	1919	1.1–27.6	11.9	1.1–20.8	9.7
"	1920	0.0–12.4	5.9	1.8–19.5	7.7
"	1921	0.0–11.4	5.1	3.9–22.1	11.8
"	1922	3.0–11.0	5.5	7.0–15.0	10.4
"	1923	0.0– 4.0	2.1	2.0–13.0	7.6
Average	....	......	7.4	......	10.2
Low	1918	1.0–46.1	18.3	5.1–14.1	8.4
"	1919	8.0–21.0	13.3	3.5–17.7	8.9
"	1920	0.0–17.7	7.3	0.0– 8.2	2.6
"	1921	1.2–10.8	5.1	3.2–21.7	6.8
"	1922	3.0–27.0	9.8	4.0–26.0	9.9
"	1923	0.0– 5.0	1.3	2.0–27.0	8.7
Average	....	......	9.2	......	7.6

The results of this test indicate that the chief differences between high- and low-yielding rows in ear-to-row tests are dependent upon characters which in general are correlated with vigor of growth. To argue from this result that selection for ears of uniform type and of good vigor—in other words, that selection of score-card characters is desirable—is to overlook the genetic side of the subject. Selection for vigorous ears of good score-card type is probably much more desirable than selection of non-vigorous ears of uniform type. Perhaps the better method would be to select for vigorous ears, without too great regard for close selection of type, with the assurance that ear type in general will take care of itself if the selection is made on the basis of vigor of plant and maturity of ear.

Yield trials.—As has been already noted, careful yield tests were made each year under comparable conditions. The results of these tests are given in Table VI.

TABLE VI
METHOD OF SELECTION OF SEED OF RUSTLER DENT CORN IN RELATION TO YIELD

Method of selection	Yield in bushels per acre				
	1920	1921	1922	1923	Ave.
1. At husking	50.2±1.6	64.1±1.3	48.9±1.3	54.9±1.9	54.5±0.8
2. Perfect stand hills for yield, seed stored immediately.	47.9±1.5	64.1±1.3	49.2±1.3	56.5±1.9	54.4±0.8
3. Perfect stand hills for yield, seed cured in shock	48.1±1.5	63.7±1.3	48.9±1.3	56.5±1.9	54.3±0.8
4. As in 3 in field, selection later for score card ear type	46.6±1.4	63.7±1.3	47.2±1.2	55.1±1.9	53.2±0.7
5. Montgomery's method	49.5±1.5	66.0±1.3	49.5±1.3	55.9±1.9	55.2±0.8
6. Williams' method, F_1 crossed seed	47.0±1.4	65.7±1.3	49.1±1.3	60.3±2.1	55.5±0.8
7. Williams' method, increase plot	....	60.9±1.2	48.2±1.2	52.3±1.8	....

The probable errors for yield were obtained by a method which has been explained previously (Hayes, 1923). In brief, it consists in obtaining the average yield of each three plots planted from a particular method of seed selection. The deviations, obtained by subtracting the yield of each plot from the respective mean yield of each group of three plots, are placed on the percentage basis and the standard deviation is computed by the formula $\sqrt{\frac{\Sigma(d^2)}{n}}$ where d represents each deviation in per cent and n the number of deviations. The result of this calculation is the standard deviation for the yield of a single plot expressed in per cent. For three plots the probable error in per cent is obtained by the formula $\frac{S.D. \times .6745}{\sqrt{3}}$.

The differences in yield for the various methods are very small. Comparing methods of selection 4 and 5 gives the following average difference, 2.0±1.1. The chances are only 3.45:1 that this difference is significant.

A new method, called "Student's method"[4] has been strongly recommended as a means of comparing on a probable error basis such comparable trials. By this method, Montgomery's method (5) is compared with selection for yield and score card type (4).

Method 4	Method 5	Deviation	D'	(D')²
46.6	49.5	+2.9	0.8	0.64
63.7	66.0	+2.3	0.2	0.04
47.2	49.5	+2.3	0.2	0.04
55.1	55.9	+0.8	1.3	1.69
		8.3		2.41
		4 =2.1		4 = .6025
				$\sqrt{.6025}$=.78

$$\frac{M}{S.D.}=Z=\frac{2.1}{.78}=2.7$$

[4] See Love, 1923, 1924; Love and Brunson, 1924.

With Z = 2.7 and n = 4, i.e., the number of comparison, P equals .9908. Therefore the chances are 107:1 that method 4 yields significantly less than method 5.

It likewise appears desirable to compare methods 3 and 4. These methods differ only in the fact that in method 4 there is continuous selection for score-card type. By the Student method, P =.9737 and the chances are 37:1 that selection for score-card type has led to a reduction in yield.

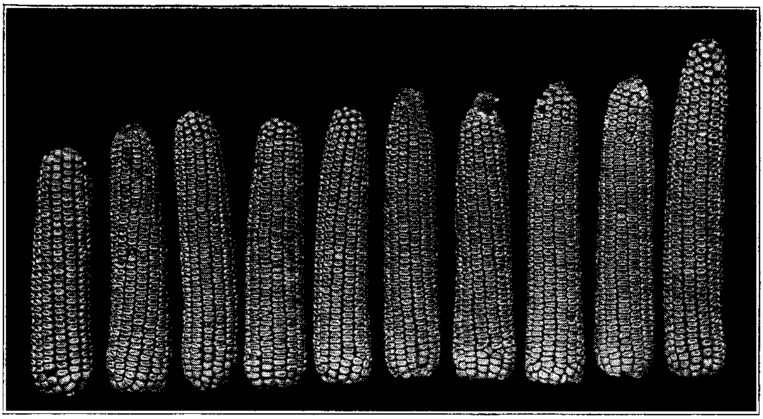

Fig. 5. Selection from Vigorous Plants in Perfect Stand Hills; Method 4, 1921

The conclusions appear fairly obvious.

1. The use of F_1 crossed seed obtained by crossing the remnants of the higher yielding ears of the ear-to-row test led to a slight increase in yield over selection in perfect stand hills and from vigorous stalks. However, after making an increase of the F_1 cross seed and selecting seed from the multiplication plot, the yields obtained were slightly less than those obtained from selection in perfect stand hills.

2. By the Student method the chances are 37:1 that selection for score card type of ear has led to a slight reduction in yield even tho the plants were first selected on a yield basis from perfect stand hills.

3. Seed selected at husking did not have essentially different yielding ability from seed selected from vigorous stalks in perfect stand hills. It is only fair to point out, however, that the plot in which selection at husking was practiced produced nearly perfect stands each year.

4. The yielding ability of seed stored immediately, when selected during seed corn week, was not essentially different from the yielding ability of seed selected at the same time which was cured in the shock before storing.

5. There seems to be little or no value from the farmer's standpoint in using the ear-to-row plan. Under any circumstances its continuous use appears undesirable.

F_1 CROSSES BETWEEN STANDARD COMMERCIAL CORN VARIETIES

The value of using first generation crossed seed was suggested originally as early as 1876, by Beal. A review of the experiments, in which the yield of F_1 crosses have been compared with the yield of their parents, has been made (Hayes and Garber, 1921). Every cross did not prove equally vigorous, however, some crosses yielding more than their higher yielding parent. In many of the tests one or both of the parents was an unadapted variety. This led to a study, which was started in Minnesota in 1915, for the purpose of learning the comparative value of first-generation crosses between standard adapted varieties. A report of this investigation has been made (Hayes and Olson, 1918). In these crosses Minnesota No. 13 was used as one parent and selected flints and dents were used as the other parents. The flint and dent varieties, except Minnesota No. 13, were obtained from neighboring corn growers and from the same source each year. The Minnesota No. 13 variety was a stock which for ten years previous to the experiment had been grown at University Farm and after husking, the ears of desirable type and vigor (good score-card type) were selected to plant the following year's seed plot. This is the variety which has been previously distributed by the Minnesota station. The crosses between the flint varieties and Minnesota No. 13 proved most productive and during the period from 1915 to 1918 these F_1 crosses yielded 15.8 per cent more shelled corn than either parent. During this same period the flint varieties yielded practically as well as Minnesota No. 13.

The Rustler variety (selection method No. 3) yielded 12 per cent more than Minnesota No. 13 during this period, which led to the selection of Minnesota No. 13 for seed by selection in perfect stand hills, according to the method outlined under (3) for the Rustler selection experiment. Since 1918, Minnesota No. 13 has been selected by this plan.

The method of producing F_1 crossed seed is to grow the varieties to be crossed in alternate rows, and detassel all of one variety by pulling out the tassels before any of the silks of this variety show. Seed from the detasseled variety is used for the commercial crop. In crossing an early with a later variety it is necessary to plant the varieties at different times so that both reach maturity at nearly the same time.

In 1919 F_1 crosses between Rustler and the selected flints were added to the trials. The results from 1919 to 1923, inclusive, are presented in Table VII.

The F_1 crosses yielded about as well as the dent parents but no better on the average. Squaw × Minnesota No. 13 yielded as well as Minnesota No. 13. Such a cross appears to be of some promise as a silage corn for northern sections.

The dent parents yielded more than the flints for this period. The seed for the flint parents was obtained from the same source as in previous years. During the period 1915 to 1918, previously mentioned, the flints yielded practically as well as Minnesota No. 13. It would appear that Minnesota No. 13 has been somewhat improved during the last six years by the method of selection used. This is further brought out by the fact that from 1915 to 1918, inclusive, Rustler yielded 12 per cent more than Minnesota No. 13, while during the period from 1919 to 1923 Rustler exceeded Minnesota No. 13 by only 4 per cent.

It is of considerable interest to compare the F_1 cross between Rustler and Minnesota No. 13 with its parents. In this case the parents were both selected for yield. The cross exceeded Minnesota No. 13 in yield by 8.7 per cent and Rustler by 4.3 per cent. On the Student method basis the chances are only 7.5 : 1 that the cross is a significantly better yielder than Rustler.

The following points seem of importance:

1. F_1 varietal crosses yield more than their parents, providing the parent varieties have been closely selected for ear type. If the parents have been selected on a yield basis the better crosses yield somewhat more than the average of their parents but not necessarily more than the better parent.

2. The only promising cross for Minnesota appears to be one between an early flint and a later dent. Such a cross matures considerably earlier than the dent parent and yields about as much. A cross of this kind appears to be of promise for northern Minnesota conditions.

3. The results of this experiment have a bearing upon methods of saving seed by farmers. The results appear to be conclusive that close selection for ear type is undesirable. The conclusion is reached by a consideration of the following facts:

(a) During the early period of this experiment (1915 to 1918) Rustler yielded 12 per cent more than Minnesota No. 13. From 1919 to 1923 Rustler yielded only 4 per cent more than Minnesota No. 13. For many years prior to 1915, Minnesota No. 13 had been selected closely for ear type. Since 1918, Minnesota No. 13 has been selected for yield.

TABLE VII

YIELD OF SHELLED CORN PER ACRE OF F_1 CROSSES AND THEIR PARENTS, 1919 TO 1923, INCLUSIVE

Variety or cross	Yield in bushels per acre					5-year average	3-year average
	1919	1920	1921	1922	1923		
Minnesota No. 13	69.6 ± 0.5	32.6 ± 1.1	56.0 ± 0.8	37.8 ± 0.6	50.8 ± 1.3	49.4 ± 0.41	48.2 ± 0.55
Longfellow × No. 13	63.0 ± 1.0	35.7 ± 1.6	48.5 ± 1.0	39.4 ± 1.1	55.7 ± 2.4	48.5 ± 0.68	....
Longfellow	59.7 ± 0.7	25.8 ± 0.9	41.0 ± 0.6	36.5 ± 1.0	42.6 ± 1.9	41.1 ± 0.50	....
King Phillip × No. 13	68.6 ± 1.1	30.1 ± 1.4	52.4 ± 1.1	40.5 ± 1.1	50.2 ± 2.2	48.4 ± 0.65	....
King Phillip	59.7 ± 0.7	30.3 ± 1.1	40.2 ± 0.6	31.7 ± 0.9	45.9 ± 2.0	41.6 ± 0.52	....
Squaw × No. 13	72.8 ± 1.2	36.0 ± 2.4	49.6 ± 1.0	37.0 ± 1.2	55.1 ± 2.4	50.1 ± 0.79	....
Squaw	....	....	39.7 ± 0.6	30.9 ± 0.8	49.4 ± 2.2	....	40.0 ± 0.85
Rustler × No. 13	75.7 ± 1.2	38.1 ± 1.8	57.3 ± 0.8	40.6 ± 0.8	57.0 ± 1.8	53.7 ± 0.61	....
Rustler	68.9 ± 0.8	33.7 ± 1.2	59.4 ± 0.9	38.8 ± 0.7	56.7 ± 1.8	51.5 ± 0.51	51.6 ± 0.71
Longfellow × Rustler	74.1 ± 1.2	35.6 ± 1.9	55.3 ± 1.2	....	51.1 ± 2.2	....	....
King Phillip × Rustler	70.6 ± 1.1	37.4 ± 2.0	52.1 ± 1.1	39.3 ± 1.1	57.4 ± 2.5	51.4 ± 0.75	....
Squaw × Rustler	....	....	50.1 ± 1.0	35.8 ± 1.0	55.9 ± 2.4	....	47.3 ± 0.93

Four-year average for Rustler = 54.7 ± 0.62.
Four-year average for Rustler × Longfellow = 54.0 ± 0.84.

(b) A second proof of a change in the yielding ability of Minnesota No. 13 may be noted. From 1915 to 1918, Longfellow and King Phillip yielded as much as Minnesota No. 13 while from 1919 to 1923 Minnesota No. 13 yielded approximately 16 per cent more than the flint parents. The results prove the undesirability of closely selecting corn for score-card ear type.

CONCLUSION

The experiments appear to show that an adapted variety of corn can be kept in a constant state of improvement by selection on the basis of vigor without close selection for score card ear type. By this we do not mean to infer that it is necessary or desirable to have a mixture of different colors of seeds but that ear type will take care of itself if selection is made, under conditions of competition, on the basis of vigor of plant. The chief value of selection in the field is that type of plant may be noted. It appears desirable to select plants which are green when the ear approaches maturity, i.e., those which do not ripen prematurely.

SUGGESTIONS FOR THE FARMER WHO PRODUCES HIS OWN SEED

The result of these experiments, together with other studies, lead to the following suggestions:

1. It is important to grow a variety of corn which is well adapted to your locality.

2. Corn seed should be selected from perfect stand hills and from vigorous healthy stalks. Plants which are green when the ear approaches maturity insure normal maturity of the ear.

3. Close selection for ear type leads to a reduction in yielding ability. For this reason no close selection to ear type should be made.

4. Proper storing of seed ears is fully as important as methods of seed selection.

5. A first-generation cross between an early flint and a later dent appears of promise for northern Minnesota.

6. In order to obtain benefit from a first-generation cross the crossed seed must be produced each year. Crossed seed can be obtained by planting the varieties in alternate rows and detasseling all of one variety before the silks of that variety appear. To cross an early with a later variety it is necessary to plant the late variety several days before the early variety is planted so that both mature at about the same date.

The only type of first generation varietal cross which proved to be of much value was the cross between an early flint and a later dent. Such a cross appeared of promise for northern Minnesota. If selection to ear type is not closely followed, the conclusion is reached that the use of first-generation crosses between standard varieties will not lead to a material increase in yield.

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