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The Possibility of Utilizing Selfed Strains in Practical Corn Improvement

A.N. Hume

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Agronomy Department

Agricultural Experiment Station
of the
South Dakota State College of
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Summary of Bulletin No. 245

1. Hybrid vigor has been recognized . . . the difficulty in making practical use of it has not been lack of acquaintance with the principle itself, but of finding and outlining a way to utilize it. Page 3.

2. Continuous ear-row selection of corn for yield seventeen successive years (with the use of three separate systems) reinforced the idea that such selection is a means of picking out superior strains, but not in and of itself a sufficient means for genetic improvement. Page 4.

3. Continuous selfing (like any process of progressively close selection) tends toward separate genotypes and correspondingly diminutive yields. Page 6, Table 2.

4. The row yields produced in 1929 All Dakota Breeding Plot from near-hybrids (S_5 strains x Selection 1210) were 35 per cent higher than yields from selected strains. Tables 3 and 4, pages 8 and 9.

5. Similarly five out of six of the same near-hybrid strains planted in variety test yielded higher than the standard or "check" variety. Table 5, page 10.

6. A plan for perpetual crossing of selfed strains. Page 12.

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The Possibility of Utilizing Selfed Strains in Practical Corn Improvement

By A. N. Hume, Agronomist and Superintendent of Substations

Many people who are either actively or indirectly engaged in corn breeking are acquainted with the fact that so called hybrid vigor is brought about through crossing of strains of corn that have first been reduced by several generations of inbreeding or selfing. Hybrid-vigor has long been recognized and it is not the purpose of the present paper to discuss the fundamentals further than to call attention to it as a basis for corn improvement.

Some years ago in South Dakota bulletin 186, the writer referred to a number of earlier publications including "Hybridization Methods in Corn Breeding," by G. H. Shull, American Breeders Magazine (The Journal of Heredity, April-June, 1910, p. 98). Also in the bulletin the writer attempted to call attention to the apparent advantage of crossing strains that are selected—continuously—and whose sires and dams may have approached a homozygous condition.

It may be generally accepted as a fact that the difficulty in making practical use of hybrid vigor in getting higher yields and higher quality of corn during the past one or even two decades has not been lack of acquaintance with the principle itself but rather the practical difficulty of finding and outlining a way to utilize it. It is apparent to those who have studied and discussed the matter most seriously that corn breeders have arrived at considerable clarity in their own minds about how to proceed; within the short time of two years or even one year.

Part of the impetus given to utilizing the principle of hybrid vigor in corn breeding has been due to the apparent fact demonstrated from several different angles that mere selection of strains of corn by picking out desirable ears or by ear-row methods of testing formerly practiced is not a means for securing genetic improvement in corn. South Dakota experiment station pursued continuous selection of corn for yield for seventeen consecutive years by three different systems. The three separate systems of selection employed were as follows:

1.—Selection of the "best" seed ears—mass selection.
2.—Systematic ear-row selection with detasseling of alternate rows (as described in Illinois Bulletin 100).
3.—Selection of high yielding ear remnants (described in Ohio Bulletin 289).

The comparative yields of corn secured in successive trials by the three systems of selection indicated, are put down in the appendix of this bulletin. The summary of the yields is put down for examination in the following Table 1:

Table 1.—SUMMARY OF AVERAGE YIELDS OF CORN IN BUSHELS PER ACRE BY SUCCESSIVE PERIODS OF YEARS, COMPARING SEED DEVELOPED BY (1) MASS SELECTION, (2) ILLINOIS SYSTEM OF EAR-ROW SELECTION, (3) OHIO SYSTEM OF EAR-ROW SELECTION.

Period of years included	General average, bushels of ear corn, for periods indicated from seed of given selection system			
	Mass selected	Illinois	Ohio	Av.
1912-13	46.4	50.4	46.1	47.6
1914-18	49.7	47.9	47.4	48.3
1919-23	51.9	54.1	65.1	57.0
1924-28	43.4	45.2	47.4	45.3
General average of annual yields	48.1±2.2	49.2±2.2	52.5±2.5	

Selection Alone Had Some Effect

Selection of certain strains under the conditions where they have to grow may result in finding which ones are best adapted to those conditions. No amount of selection will chage the genetic constitution of the strains involved.

In the foregoing Table 1,* it may be seen that mass selected seed picked out of the "best ears" from progeny produced year after year, yielded as an average 48.1 bushels, whereas the same kind of corn resultant from systematic ear-to-row testing (with detasseling all alternate rows) yielded 49.2 bushels per acre. Again the average yield secured by the Ohio remnant system was 52.5 bushels, an increase of 4.4 bushels. Whether such increase be considered very significant or not, it may illustrate the result, usually considered beneficial, of resorting to some system or plan for picking out the kind of corn that is best adapted to the conditions under which such corn is to be produced. An old fashioned way of stating the same, is to say that it is important that corn be acclimated. Perhaps more scientifically it is to say that strains of corn need to be adapted to ecological conditions.

Apparently from Table 1 both the Illinois system of ear-to-row selection and the Ohio system of selecting remnants furnished a more rapid process of adaptation than the mere picking out of the best seed ears by mass selection. The experiments which furnished the data for Table 1 were started in the beginning with the idea of discovering which one of three separate systems of selection then in vogue would be most effective in corn improvement. The average yields of Table 1 might indicate indeed that the Ohio remnant system was somewhat more effective than either of the other two. This may be because that system is arranged purposely to provide for the direct utilization of ear remnants of high-yielding seed ears previously tested in an ear-to-row trial plot. The nature of these yields however and comparison with those unaffected by selection in the same seasons makes an estimate of the effect of selection difficult.

It Is Possible to Reach the Limit of the Beneficial Effect of Selection

Examination of the average yields in Table 1 will make it appear that the yields produced for the period 1914-18 were practically equal or higher than those for 1912-13 at the beginning of the period of

*See also Appendix, Table 1.

selection in all three systems. A comparison of the yields just indicated with those produced by ordinary assorted seed corn of the same variety in rotations at Brookings (see Appendix Table 3) reveals the fact that yields in general apparently due to seasonal causes were decidedly lower for the period 1914-18 than for 1912-13. It is a reasonable explanation therefore to say that selection with the use of one of the three several processes had the effect of increasing corn yields perhaps several bushels per acre through a period of several years.

This early increase in yield due to selection has been explained by supposing that the process of selection itself resulted in simply picking out the seed that was best adapted to conditions and discarding that which was not quite suitable.

It is possible also judging from Table 1 that some increase in yield due to selection continued for all three systems during the third period, 1919-23, because the yields for the period indicated are decidedly higher than those of the previous period. Nevertheless referring again to Appendix Table 3, reveals the fact that corn yields in general were somewhat higher for that period though not as decidedly as the increase noted in the yields of Table 1. It is a fair inference that the selection process in all three systems showed some effect in increasing corn yields at least up to the end of the period 1919-23.

Selection of seed corn begun in 1912, therefore apparently arrived at increased yields without notable exception until the close of approximately 12 years. After that a continuance of selection somehow resulted in reduced yields. The lowest average yields of corn within the three systems of selection were produced within the last five-year period.

Without attempting to discuss all theories it may be suggested that all three systems resulted in closer and closer selection. Accordingly ear-row selection at first beneficial to yield, seemed to result unfavorably if persisten in indefinitely. Seventeen years of selection by the three separate foregoing systems indicated that former methods of corn breding which were usually based upon some such selection system as the ones indicated were beneficial but not sufficient. Such experience in South Dakota and elsewhere has given rise to attempts to develop systems of corn breeding which not only provide for crossing in the ordinary sense but also produce actual hybrid strains and practically utilize the principle of hybrid vigor.

Hybrid Vigor

A hybrid is the "progeny of a cross fertilization of parents belonging to different genotypes"; meaning by genotype the hereditary constitution of any given individual. Mere crosses of two kinds of corn that both belong to the same genotype are not hybrids in a strict sense of the term. Crosses produced by detasseling alternate rows planted with different seed ears of the same variety may or may not be hybrids; not likely that they will be such in respect to all characters. Therein lies the reason why former systems of corn breeding even though they involved detasseling of alternate rows sometimes failed to arrive at hybrid vigor. The crosses which these former systems represented were not always made between individuals belonging to **separate** and **distinct** genotypes.

Continuous Selfing Produces Separate Genotypes

It may be assumed that a large number of people are able to produce inbred or selfed strains of corn by placing pollen of a given stalk on silk of the same stalk at a time when fertilization ensues. Practical methods for accomplishing inbreeding of corn will not be described at present. Such methods are known to involve time and labor. The production of large amounts of selfed seed corn by hand pollination methods is impossible. One of the practical difficulties of producing a sufficient amount of hybrid seed corn which is bound to be a cross of selfed strains is due to this difficulty of first securing the selfed strains. A good deal of progress has been made with methods of producing selfed strains or their equivalents and it is generally accepted that the most difficult practical problem in making further progress in corn improvement is finding out how to utilize selfed strains commercially after they are once developed at home or secured from outside sources.

Table 2.—EAR-TO-ROW YIELDS FROM ALL DAKOTA BREEDING PLOT, 1928, INCLUDING YIELDS FROM SELFED STRAINS

Row No.	Planted with ear number	Description of strain planted	Weight ears harvested pounds	Weight air dry ears	Weight shelled corn per row (lbs.) after air-dry	Bushels per acre computed
1	1210	*Close bred	14.8	10.3	8.00	14.5
2	D2-107 Bkgs. 86	**Selfed	12.4	8.75	2.65	4.8
3	1211	***Crossed	20.5	14.7	11.75	21.3
4	1210	Close bred	16.6	11.7	9.40	17.0
5	B3-111 Alta	Selfed	5.0	3.7	2.15	3.9
6	1209	Crossed	27.0	17.65	14.00	25.3
7	1210	Close bred	17.7	11.3	8.6	15.6
8	E4-108 Bkgs. 86	Selfed	6.0	3.8	2.95	5.3
9	1219	Close bred	19.3	11.35	9.1	16.5
10	1210	Close bred	18.7	11.4	9.05	16.4
11	A10-112 Alta	Selfed	3.4	2.35	1.25	2.3
12	1216	Close bred	18.0	10.3	7.8	14.1
13	1210	Close bred	16.5	9.7	7.25	13.1
14	C1-128A Bkgs. 86	Selfed	9.1	4.5	2.75	5.0
15	1207	Close bred	11.2	5.6	4.2	7.6
16	1210	Close bred	15.1	7.6	5.65	10.2
17	A10-112 Alta	Selfed	1.9	0.75	0.45	0.8
18	1204	Close bred	14.7	7.75	6.00	10.9
19	1210	Close bred	6.9	3.85	2.60	4.7
20	C12-106 Bkgs. 86	Selfed	0.0	0.10	T	T
21	1221	Crossed	12.8	5.8	4.25	7.7
22	1210	Close bred	2.3	1.5	0.95	1.7

*Close bred in this table means only that the plant was open pollinated from a plant from the same ear.

**Cross bred in this table means only that the plant was pollinated from a plant from another ear.

***The term selfed in this table means S_5 with the use of hand pollination.

(Strains produced by Franzke.)

Comparison of Yields Directly from Selfed or Inbred Strains and from Other Strains Selected More or Less Closely

The ear-to-row yields put down in Table 2 were produced by twenty-two separate breeding plot rows at Brookings. The separate seed ears planted in the several rows are numbered, and the numbers of these ears may be found in the second column of Table 2.

In general three kinds of seed ears were planted in the plot and these are designated in the third column of Table 2. (1) Ears which were produced by stalks that were open pollinated from other stalks growing from the same mother ears are called close bred, (2) ears that were produced from stalks that were detasseled and consequently pollinated by plants from a different ear are designated as crossed, (3) ears that are the result of hand pollination with putting pollen from a given stalk on silk of the same stalk are called selfed.

In Table 2 foregoing it is easy to note the relatively low yields produced by all rows planted with selfed strains. These **selfed** or inbred strains were developed at Brookings field by Clifford Franzke, with the use of either Brookings 86 or Alta. The yields from them are typical and they illustrate well enough that the immediate effect of inbreeding or close-breeding in corn is reduced yield. While discussing the subject of utilizing selfed strains in general these comparative yields serve as a demonstration that they have no practical use for direct planting when high yield is the objective.

The practical value of selfed strains is to be found in utilizing them for crossing—in such way that the hybrid vigor of their resulting progeny may be realized upon.

The selfed strains which were planted in the breeding plot in 1928 making low yields, as put down in Table 2, were all detasseled and pollinated from the rows planted with the close-bred ear No. 1210; the only rows in the plot in 1928, not detasseled. These were consequently side-rows, so called. Accordingly the corn produced in rows No. 2, 5, 8, 11, 14, 17, 20—planted with selfed strains was hybrid or near-hybrid corn in all cases.

This near-hybrid corn was planted in the breeding plot in 1929 for comparison with the other rows, the greater number of which were the result of ordinary ear-row selection.

The following Table 3, makes record of comparable yields from kinds of seed produced in 1929, including the near-hybrids mentioned:

In the fifth column of Table 3 the highest yielding rows are generally those planted with crosses produced in the breeding plot of 1928 between selfed strains x the selected strain 1210. It may be mentioned that ear No. 1210 itself is a close-bred selected ear produced from ear No. 1106, which was likewise pollinated from a stalk that grew from No. 1106. Thus it appears that in 1929 six different strains which were the progeny of ears produced by five generations of selfing, pollinated in turn from the ear No. 1210, apparently show a high degree of hybrid vigor. The mother ears or dam ears of these near-hybrid strains were selfed by hand-pollination methods. The sire was not strictly selfed but was produced by continuous ear-row selection with an exceptional degree of close breeding.

Table 3.—COMPARATIVE EAR-ROW YIELDS FROM ALL DAKOTA BREEDING PLOT (1929) INCLUDING NEAR-HYBRIDS PRODUCED IN 1928, AND OTHER HIGH YIELDING STRAINS SELECTED FROM ADJOINING ROWS.

Row No.	Planted with ear number	Description of strain planted	Wt. ears harvested pounds	Wt. air-dry ears harvested pounds	Pounds shelled corn per row	Bushels per acre shelled corn
1	1209	1106 / 1110	13.0	12.1	10.9	29.4
2	1211	1106 / 1118	27.0	25.3	20.8	56.2
3	1314	1210 / C-1-128A-B. 86	33.0	31.2	25.1	67.8
4	1209	1106 / 1110	20.5	19.4	15.9	42.9
5	1309	1210 / 1219	27.0	25.4	21.0	56.7
6	1311	1210 / A-10-112 Alta	33.0	31.3	26.0	70.2
7	1209	1106 / 1110	18.5	17.3	14.6	39.4
8	1310	1210 / 1210	26.5	24.0	20.0	54.0
9	1308	1210 / E4-108 B. 86	25.5	23.9	19.7	53.2
10	1209	1106 / 1110	12.5	11.4	9.5	25.7
11	1307	1210 / 1210	30.00	26.8	22.0	59.4
12	1305	1210 / B-111-Alta	29.5	28.1	21.8	58.9
13	1209	1106 / 1110	21.0	19.2	16.6	44.8
14	1301	1210 / 1210	33.0	30.9	25.7	69.4
15	1302	1210 / D-2-107-B. 86	33.5	31.0	25.6	69.1
16	1209	1106 / 1110	23.5	22.0	18.2	49.1
17	1312	1210 / 1210	29.5	27.4	22.5	60.7
18	1317	1210 / A-10-112 Alta	28.5	26.4	21 9	59.1
19	1209	1106 / 1110	22.0	19.7	16.7	45 1
20	1313	1210 / 1210	15.5	14.0	11.8	31 9
21	C-12-106-B. 86			0.9		
21A	Golden Bantam			5.9		
22	1209	1106 / 1110	16.3	15.9	12.7	34.3

Table 4.—EAR-ROW YIELDS OF 1928 AND 1929 INCLUDING THOSE FROM SELFED STRAINS (1928) AND NEAR-HYBRIDS FROM SAME (1929).

Kind of ear planted, 1928	Yield in 1928 Bu. per acre	Kind of ear planted, 1929	Yield in 1929 Bu. per acre
1106/1106	14.5	1210/1210	69.4
D-2-107-B. 86; S_5	4.8	1210/D-2-107, B. 86	69.1
1106/1118	21.3	1106/1110	44.8
1106/1106	17.0	1210/1210	59.4
B-3-111-Alta; S_5	3.9	1210/B-3-111-Alta	58.9
1106/1110	25.3	1106/1110	25.7
1106/1106	15.6	1210/1210	54.0
E-4 108-B. 86; S_5	5.3	1210/E-4-108-B. 86	53.2
1106/1106	16.5	1106/1110	39.4
1106/1106	16.4	1210/1219	56.7
A-10-112-Alta; S_5	2.3	1210/A-10-112-Alta	70.2
1106/1106	14.1	1106/1110	42.9
1106/1106	13.1	1106/1110	29.4
C-1-128 A-B. 86; S_5	5.0	1210/C-1-128A-B. 86	67.8
1106/1106	7.6	1106/1118	56.2
1106/1106	10.2	1210/1216	60.7
A-10-112-Alta; S_5	0.8	1210/A-10-112-Alta	59.1
1106/1106	10.9	1106/1110	49.1
1106/1106	4.7	1210/1210	31.9
C-12-106	T		
1106/1118	7.7	1106/1110	45.1
1106/1106	1.7	1106/1110	34.3
Average yield of S_5 strains	3.7		
Av. yield of all selected strains			46.6
Av. near-Hybrid strains			63.1

Table 5.—YIELDS OF CORN VARIETY TEST, BROOKINGS, 1929.

No.	Variety	Yields in pounds per plat	Per cent shrinkage	Yield of air dry ear corn in bu. per acre	Shelling percent	Yield of air dry shelled corn Bu. per acre	Yield in per cent check variety Minn. 13
1	Mercer Flint	68.2	9.3	49.1	75.3	46.2±1.08	96.3
2	Extra Early Northwestern Dent	52.6	7.2	38.7	79.4	38.7± .90	80.6
3	Northwestern Dent	58.5	7.2	43.1	77.8	41.9± .98	87.3
4	Early Minn. No. 13	57.8	6.5	42.9	80.4	43.1±1.00	89.8
5	Wisc. No. 25	52.5	7.2	38.7	80.2	38.8± .90	80.8
6	Minnesota No. 23 White Cap	51.3	7.1	37.8	83.4	39.7± .93	82.7
7	Longfellow Flint	63.5	6.3	47.2	80.5	47.5±1.11	99.0
8	Rustler White Dent	70.4	9.2	50.7	76.3	48.4±1.13	100.8
9	Wisc. No. 8 Early Yellow Dent	71.4	8.0	52.1	77.1	50.3±1.17	104.8
10	Minn. No. 13	70.2	10.1	50.1	76.7	48.0±1.12	100.8
11	Wisc. No. 12 Golden Glow	76.8	10.6	54.5	76.9	52.4±1.22	109.2
12	Wisc. No. 7 Silver King	51.7	13.2	35.6	75.4	33.6± .78	70.0
13	Murdock	82.3	11.0	58.1	76.4	54.5±1.27	113.5
14	Wimple's Yellow Dent	78.9	14.0	53.9	77.9	52.5±1.22	109.4
15	Alta	64.2	6.5	47.7	80.8	48.2±1.12	100.4
16	Wimple's Hybrid	79.0	11.6	55.4	76.1	52.7±1.23	109.8
17	Brookings 86	63.1	6.4	46.9	77.3	45.3±1.06	94.4
18	Perrines Early Yellow Dent	62.8	7.8	46.0	80.9	46.4±1.08	96.7
19	1210 / 1210	56.1	5.5	42.1	80.4	42.2± .98	87.9
20	1210 / D 107-B. 86	73.7	5.7	55.2	78.8	54.4±1.27	113.3
21	1210 / B_2-111-Alta	69.3	4.5	52.5	77.7	51.0±1.19	106.3
22	1210 / E_4-108-B. 86	69.2	6.8	51.2	81.8	52.4±1.22	109.2
23	1210 / A-10-112-Alta	63.1	7.0	46.6	79.9	46.9±1.09	97.7
24	1210 / C-1-128-B. 86	73.3	7.4	53.9	81.2	54.7±1.27	114.0
25	1210 / 1209	60.0	6.0	44.8	81.7	45.7±1.06	95.2

In connection with the yields produced by these near hybrids it is interesting to refer again to the reduced yields produced by the selfed strains which were their mother ears or dams. The latter are put down in Table 2, and are repeated, along with the yields of 1929, including those from the near-hybrids (Table 3) for direct comparison in Table 4.

It is possible to note that the foregoing yields for 1928 and 1929 are arranged usually in groups of three which represent the arrangement of the ear-rows in the breeding plot on the ground.

It appears that the average yield of six S_5 strains (i. e., selfed for five generations) in 1928 was 3.7 bushels per acre. The average yield in 1929 from all the selected strains, exclusive of the near hybrids in bushels per acre was 46.6. The yield of the rows planted with near hybrids in 1929 was 63.1 bushels per acre, an increase of 35.4% over that of the selected ears, which increase might be due to hybrid vigor.

Yields from Variety Test Plot (1929) Also Indicate Vigor of Near-Hybrids

Variety yields of corn at Brookings for 1929 have been computed by Dr. Klages, on a basis of yield in percent of that produced by the check variety Minnesota 13. Twenty-five varieties and strains of corn were included in the trial. Eleven of the strains yielded slightly more than 100% of the check strain Minnesota 13, and of the eleven, four of them were near-hybrids, as put down in the following Table 5. Only five of these near-hybrids were included in the test and four of them outyielded the "check"; the remaining one yielded roundly 98%. The foregoing results substantiate those secured from Table 3, and they indicate superiority in yielding capacity of hybrid or near-hybrid strains, due apparently to hybrid vigor.

The results of the foregoing Table 5 make it possible to compare yields at Brookings field for 1929 from ordinary standard varieties with the same near-hybrids developed in the All Dakota breeding plot of 1928, and further utilized in the row tests of All Dakota plot of 1929 (Table 3). It was necessary to move the near-hybrid seed of these strains from the conditions of the breeding plot under which they were developed to the conditions of the West Farm where the variety test was made in 1929.

The standard variety or check in the variety test plot for comparison was Minnesota 13. On a basis of computation and considering the yield of Minnesota 13 as 100, the highest yield produced by any of the near-hybrid strain was 114.0, obviously an increase of 14%. The near-hybrids with a single exception yielded higher than the standard variety in the test plot. The results in the variety test plots are more conservative for increasing yields due to hybrid vigor than those secured directly out of the breeding plot. The writer believes the difference in results may be due in part to the fact that in order to place the near-hybrid strains into the variety test it was necessary to move them out of the direct environment in which they had been developed.

The Practical Use of Selfed Strains

The foregoing part of this paper has been set down in order to furnish concrete data from South Dakota, which may serve as a tangible basis for what may be the next step in corn improvement. Also the writer would prefer that South Dakota corn improvers study these yields carefully on their own behalf, rather than accept any formula stated by the writer or anyone else without further criticism.

A Plan for Perpetual Crossing of Selfed Strains

A plan for utilizing selfed (inbred) strains of corn was proposed at the meeting of the Purnell Committee on Corn Improvement held in Chicago, by Professor T. A. Kiesselbach of Nebraska. Very briefly the proposal consisted of the following steps:

1—Secure selfed strains either from distant sources or from local productions.

2—Having selected two of these strains plant them in alternate rows in successive seasons.

3—Detassel one of these strains in one season and the other in the next season, thus carrying the two strains along in a single plot or field and securing crosses while at the same time maintaining pure seed of both strains.

4—Thus one would be able to harvest hybrid seed from the detasseled rows each year and these crosses between *sib progenies of inbred strains would be as good as crosses between the selfed strains themselves.

The foregoing plan offers possibilities. One of its strongest recommendations is that it is evidently possible of being carried out.

It may be announced by commercial seed companies or by growers that they will offer strains of strictly hybrid seed corn for sale. They could produce such seed in commercial quantity, provided they followed recognized principles; utilized two distinct selfed (inbred) strains to start with, which they would increase in isolated plots, up to whatever amount might be required; then produce crossed seed by planting these selfed strains in alternate rows as described and detasseling the rows of each strain in alternate years—saving a seed supply always from the tasseled rows.

Some Modification of Foregoing Method May Be Possible and Desirable

In connection with the foregoing plan for arriving at commercial quantities of hybrid seed it is necessary to know which two of many possible selfed strains present the desired combinations, not alone for the place where the combination is first made, but for the several places where the combination is to be utilized commercially for seed. That could possibly be found out by an accurate growing test; such a test as we have in Table 3, where our All Dakota near-hybrids were tried out in comparison with standard varieties. Apparently that

*Sibs—progenies of full brothers and sisters.

would be the only method of finding out whether such hybrid strains were indeed superior, over ordinary selected strains or varieties.

Incidentally, if and when such hybrid strains were found to be superior to all others under various conditions, the producers of such hybrids, would have if not a monopoly of them at least, an advantage in producing and offering them for sale. They could not only make a trade secret of their origin, but they could keep possession of the locality and the conditions of producing them. At least and at last the producer of superior seed could retain some proprietary interest in it, and possibly even realize upon part of the extra labor and intelligence he has put into it.

The Foregoing Method Is of Advantage to the Producer Who Is also a Seller

Growers of corn should emphasize in their own minds that the foregoing method of perpetually producing and at the same time crossing to selfed strains, produced hybrids. Hybrids, once they are planted are utilized so far as their hybrid-vigor is concerned, and in case the same is to be utilized again, new hybrid seed has to be produced or perhaps purchased. That means of course that the grower first has to find out for himself by test, that the given hybrid combination is exceptionally productive under just his conditions. It is to anticipate that the carrying out of a test which will prove the superiority on any given farm, of hybrid combinations made on another farm, while possible, will prove exacting and difficult.

Corn Producers May Take Advantage of Close-Bred Strains Already Produced by Them by Selection Methods

A number of corn breeders in South Dakota have been selecting varieties and strains of corn for many years. It is not likely that proposals emphasizing the vigor of hybrids will cause these growers rapidly to discard all that they already have, in order to plant great areas of hybrid seed. They should not do so—not suddenly.

Turning again to our Table 1, where there is evidence that there is a limit to increasing yield by "selection" in corn, there is also evidence that increased yields were produced in successive years merely by selection for a long time, perhaps for ten or fifteen years. It remains to be proved that the improvement thus to be arrived at by simple selection, can be dispensed with even with taking advantage of hybrid-vigor. Some sort of testing and selection are necessary in any event, to find what strains or combinations are superior on any given farm.

Corn Breeders May Utilize the Selection Plots They Now Have and Also Employ Them for Producing Near-Hybrids and Testing Them

There seems reason to believe that the selection which has already been pursued with corn, within the several conditions of environment has been and is a profitable and also a necessary process for finding which strains among many hundreds of possible ones, are best fitted and adapted to the environment. The evidence is that selection and especially the use of the ear-row test plot does more than furnish an ear-row test. (Look at the summary again in Table 1.) Persistent selection of corn on any farm, under a given set of conditions, with no introduction of outside strains, will surely result in producing a greater and greater degree of inbreeding or close breeding.

It is worth while to give careful consideration to using the ear-row breeding plot which may have been developed on any farm, through years of continuous selection, first, as a standard to go by, and second, as a source of pollen for selfed strains which may be planted with it in alternate rows. Selfed strains may be secured by making them year after year, with hand pollination methods, with the use of increase plots when desirable, or from other corn breeders in this or other states.

The placing of these selfed strains say in alternate rows of an ear-row selection plot, one which has itself been conducted so long that it is comprised of very closely selected strains, detasseling the selfed strains, thus permitting them to be pollinated from the rows of selected corn—such a process creates what may be called near-hybrids (such were produced in 1928, see Table 2). These hybrids by actual test in the ear-row plot itself (Table 3) and in variety test may be capable of producing increased yields over a standard variety, due to a degree of hybrid vigor.

Continuance of the Ear-Row Selection Plot Ultimately Develops Close-Bred or Inbred Sires That Are Known to Be Adapted to Conditions

The continuance of the ear-row test plot as indicated for the purpose of having it serve to pollinate detasseled selfed strains, in order to secure crossed seed, which will possess hybrid vigor (as in Tables 3 and 4) makes it possible also to test out any number of these selfed strains, all alike under similar conditions with the use of the same kind of row-tested close-bred pollen.

Having thus produced numerous crosses with the use of available selfed strains it is possible to test the hybrids thus produced by planting them again in detasseled rows of the ear-row selection plot the following year. Thus the yields produced by the crossed progeny of the several selfed strains can be compared with one another and likewise with the regular tasseled rows of the selection plot, and with any other strains which it may have seemed worth while to introduce into the alternate (detasseled) rows of the ear-row selection plot.

Such a process of inserting selfed strains into the regular ear-row selection plots which have long been conducted in a number of instances would virtually constitute a new system of corn breeding with the utilization of selfed strains. This would result in utilizing the principle of hybrid vigor, at the same time making it possible to realize upon the valuable adaptations which have been brought about in many instances by continuous selection within close-bred lines, for many generations of corn.

Possible Use of Close-Bred Ear-Row Selections from Breeding Plots Now Employed

The status of corn breeding seems to warrant the conclusion that hybrid-vigor should be recognized as a principle and utilized in practice. This paper has attempted to point out with a basis of fact that the progeny of ear-row selections, such as have been continued by well known methods for many years possess a degree of close breeding, and may accordingly serve as one parent, when hybrid vigor is desired.

If the foregoing assertion is well founded as seems to be the case then the following suggestion also is in order: It is possible to utilize the progeny of any one ear-row selection plot for one parent as indicated and likewise to utilize the progeny of another ear-row selection plot for the other parent. In short, the utilization of selfed strains within ear-row selection breeding plots that have been long continued should be encouraged, but in lieu of these absolutely selfed strains the progeny of another ear-to-row breeding plot should be employed. Thus the next possible conservative step in corn breeding, in a number of instances, should be crossing of the close-bred strains from separate carefully conducted ear-to-row selection plots.

Possible Steps in a System of Corn Improvement Utilizing Either Selfed or Closely Selected Strain for One Parent and a Closely Selected "Acclimatized" Strain Now Available from Ear-Row Plot for the Other

At the risk of some repetition it may be worth while attempting to summarize possible steps in a system of corn improvement which may at once (1) continue to utilize ear-row selection and thus serve to maintain adapted strains and varieties now generally recognized, and (2) utilize the principle of hybrid vigor and preventing losses from close breeding by introduction of selfed or other close-bred strains. It is possible that confusion may arise from a very general attempt to create and utilize hybrid strains of corn without first providing carefully for the introduction of such hybrids only after careful trial. The following steps apparently would provide a basis for such trials and even if further knowledge which may come from experimental work and the practice of corn breeders in general suggests a better plan or plans, the following will apparently be a procedure in the right direction:

1. Continue the ear-row selection plots which have been the basis for the best "varieties" for various localities and sections.

2. These selection plots will continue efective as ear-row test plots, and also serve in producing "acclimatized" strains with an increasing degree of close-breeding—the closer the better.

3. In order to secure hybrid vigor, introduce selfed strains, or strains from other established ear-row selection plots into the alternate, even numbered rows of these selection plots—carefully detasseling all rows thus introduced; making it necessary for all introduced strains to be pollinated from the rows of the ear-row selection plot.

4. Save seed from as small a number of the most productive tasseled rows as seems desirable for planting next year.

5. Save near-hybrid seed from as many of the introduced, detasseled strains separately as appear at all suitable.

6. Provide for testing the several near hybrid strains comparatively either in a separate test plot, or by planting it again in some of the detasseled rows of the ear-row selection plot previously mentioned.

7. As time goes on such introduction of selfed strains into the alternate rows of the present ear-to-row selection plots, and testing of near-hybrids therefrom, will make it possible to pick out the most fortunate selfed strain for combining in such manner. If and when it becomes possible to pick out the one single strain fulfilling that requirement, it will only remain to utilize it for the given locality by following the plan outlined on page 14.

8. Using the close bred strain of the ear-row selection plot for one parent; the chosen introduced strain for the other; planting them in alternate rows, and detasseling one strain one year and the other strain next year.

APPENDIX

Table 1.—*YIELDS OF CORN FROM SEED SELECTED FOR SEVENTEEN CONSECUTIVE YEARS BY THREE SYSTEMS: (1) MASS SELECTION (2) ILLINOIS (HOPKINS) SYSTEM, (3) REMNANT (WILLIAMS, OHIO) SYSTEM.

Year	Separate and Average Yields from Comparative Plots of South Dakota No. 86 Corn Planted with Seed in Given Years from Given Selection System. Bushels (70 lbs.) Ear Corn Per Acre.		
	Mass Selection	Illinois System	Ohio System
	47.4	62.4	48.4
	75.4	62.1	49.3
	32.1	48.4	45.4
	57.6	65.0	42.0
1912	43.0	56.9	47.4
	52.3	53.0	53.1
	49.6	65.3	54.3
	52.0	59.1	51.1
	45.1	65.3	54.7
	36.1	61.6	43.9
Average	49.1	59.9	49.0
	45.0	42.1	44.9
	42.0	41.2	42.9
	44.8	42.0	42.0
1913	39.7	36.2	39.5
	46.2	41.7	44.6
	44.3	45.1	44.4
	44.4	38.2	43.2
Average	43.8	40.9	43.1
	55.8	44.6	48.6
	55.7	54.2	53.7
	55.0	53.5	50.7
	55.5	54.0	54.5
	54.5	49.4	49.4
1914	52.9	52.1	50.0
	55.6	58.1	55.8
	54.3	50.3	54.2
	52.0	57.7	50.9
	49.5	48.2	47.5
Average	54.1	52.2	51.5

*Plot experiments for securing these ear-row yields were carried out by Matthew Fowlds.

Table 1.—(Continued)

Year	Separate and Average Yields from Comparative Plots of South Dakota No. 86 Corn Planted with Seed in Given Years from Given Selection System. Bushels (70 lbs.) Ear Corn Per Acre.		
	Mass Selection	Illinois System	Ohio System
	20.7	19.5	21.9
	27.8	31.6	28.7
	34.0	31.1	31.1
	32.8	26.6	30.8
	27.8	22.2	21.3
1915	28.5	22.2	25.8
	31.4	31.8	28.8
	33.7	29.0	29.6
	29.0	24.3	21.8
	24.2	17.7	19.2
Average	29.0	25.6	25.9
	40.7	49.5	47.9
	42.8	44.3	44.9
1916	46.1	47.4	47.5
	46.1		
Average	43.9	47.1	46.8
1917	61.2	50.7	53.3
1918	60.3	63.8	59.7
1919	25.6	42.8	58.4
	71.1	67.0	78.3
1920	68.1		
Average	69.6	67.0	78.3
	58.0	55.3	71.3
	66.9	59.7	78.3
1921	70.4	59.0	74.0
	63.6		
Average	64.7	58.0	74.5
	38.9	42.6	45.1
	46.9	41.4	42.0
1922	41.7	31.4	38.6
	47.1		
Average	43.7	38.5	41.9

Table 1.—(Continued)

Year	Separate and Average Yields from Comparative Plots of South Dakota No. 86 Corn Planted with Seed in Given Years from Given Selection System. Bushels (70 lbs.) Ear Corn Per Acre.		
	Mass Selection	Illinois System	Ohio System
	55.4	68.7	79.3
	60.1	63.6	71.7
1923	57.7	60.9	65.6
	51.4		
Average	56.1	64.4	72.2
	53.9	58.1	59.3
1924	54.7	56.7	55.6
	54.6	56.1	54.7
	49.6		
Average	53.2	57.0	56.5
	24.9	32.0	34.7
	34.0	31.0	28.4
1925	29.6	30.9	30.9
	23.6		
Average	28.0	31.3	31.3
	38.3	42.7	43.2
	38.5	35.5	36.7
1926	36.0	34.0	34.1
	28.0		
Average	35.2	37.4	38.0
	63.1	77.0	79.9
	83.1	67.3	77.4
1927	70.3	64.4	68.9
	46.4		
Average	65.7	69.6	75.4
	33.1	30.6	38.6
	35.6	30.4	36.8
1928	35.7	30.7	32.4
	35.8		
Average	35.0	30.6	35.9
General Average	48.1±2.2	49.2±2.2	52.5±2.5

Corn Yields Unaffected by Selection for Comparison with Table 1, and Appendix Table 1

The question arises whether variations in yield summarized in Table 1 are indeed affected by the process of selection or whether they may be seasonal. For instance the average yield of corn in the third period 1919-23 is highest by all three systems of selection. Specifically the yield for the Ohio system for that period (65.1) is decidedly higher. Again the corn yields of the fourth period for all systems are lower than those of the previous period, and it is pertinent to consider whether the cause entirely or in part may have been due to relatively poorer conditions for growth of corn, within the years of that period.

Some light on that question may be secured by examining yields of corn from crop rotations on contiguous experiment plots where selection is obviously not a factor in yield. Some such yields are made available in the following table, arranged according to the same periods of time as per the grouping of Table 1:

Table 2.—YIELDS OF CORN (BUSHELS OF EARS PER ACRE) FOR SEPARATE SEASONS, AND FOR SAME PERIOD AS INDICATED IN TABLE 1, FROM BROOKINGS FIELD.

Year	Corn Yield from Land in Given Rotation					
	Rotation 17	Rotation 7			Rotation 11	Rotation 22
	Corn, wheat	Corn, wheat, legume			Corn	Corn, oats, clover
	O	M	O	Av.	O	O
1912	34.2	45.8	40.5	43.1	50.4	58.0
1913	48.1	48.7	50.6	49.7	46.3	48.4
1914	34.8	59.5	55.1	57.3	47.7	46.7
1915	14.0	20.1	18.5	19.3	5.6	12.3
1916	37.6	38.0	37.7	37.9	43.8	39.8
1917	42.6	51.8	43.0	47.4	42.8	34.1
1918	47.3	57.2	53.4	55.3	—	47.6
1919	28.9	43.0	57.9	50.5	38.7	57.1
1920	1.7	18.7	26.4	22.6	31.3	65.3
1921	52.9	59.1	52.9	56.0	50.0	55.1
1922	51.0	52.1	50.0	51.1	50.0	38.9
1923	53.4	63.1	60.7	61.9	57.2	76.6
1924	36.7	52.8	34.3	43.6	36.3	42.0
1925	30.7	31.1	32.0	31.6	32.6	40.7
1926	51.2	57.9	51.4	54.7	51.1	33.3
1927	51.1	54.9	58.4	56.7	52.9	52.4
1928	39.4	35.4	39.3	37.4	31.1	38.6

Table 3.—SUMMARY OF FOREGOING TABLE 2. AVERAGE YIELDS OF CORN IN BUSHELS PER ACRE BY SUCCESSIVE PERIODS OF YEARS FROM FOUR SEPARATE ROTATIONS.

	General Average Yield from Corn in Rotaton Indicated				
	Rotation 17	Rotation 7	Rotation 11	Rotation 22	General
	Corn, wheat	Corn, wheat, legume	Corn	Corn,oats, clover	Av.
1912-13	41.1	46.5	48.4	53.2	47.3
1914-18	35.3	43.4	34.9	36.1	37.4
1919-23	37.6	48.4	45.5	58.6	47.5
1924-28	41.8	44.8	40.8	41.4	42.2

Some Earlier Experiments with Crossing Corn Varieties

In consideration of the general subject of hybrid vigor and especially of practical procedures for producing crossed or hybrid seed corn it is well to recall certain earlier experiments. That yields of corn could be increased by crossing of different varieties (not selfed strains) was demonstrated as early as 1878 by W. J. Beal, of Michigan Agriculture College, and results published in Annual Reports of Michigan State Board of Agriculture, and Farmers Review.

The classic experiments of Morrow and Gardner corroborating the foregoing results were reported in 1893 in Illinois Bulletin 25. This was and is so important as a basis for corn breeding that the following quotation is put down here:

(Copied from Illinois Bulletin No. 25)

Five plats were planted, each from a different ear. The accompanying table gives the date of ripening, number of ears, and bushels per acre for each parent, and their average, as compared with that of the cross. The first-named variety is in each case the female parent. In every instance the yield from the cross is greater than the average from the parent varieties; the average increase per acre from the five crosses being 9.5 bushels. The fact that increased yields can be obtained by crossing two varieties is pretty certainly established, and a few farmers are changing their practice accordingly. This is quite easily done, by planting in one row one variety, and in the next another variety, and removing the tassels of the one as soon as they appear. The ears forming on the rows having the tassels removed, will be fertilized with pollen from the other rows, thus producing a direct cross between the two varieties. The seed should be selected from the rows having the tassels removed, and the experiments indicate that it will pretty certainly give a larger yield than the average of the parent varieties, when planted under like conditions.

Results from Cross-Bred Corn

Plat	Variety	Date of ripening	Yield per acre No. of ears	Yield per acre Bu. air dry corn
22	Burr's White	Sept. 29	9960	64.2
82	Cranberry	" 29	9200	61.6
	Average	" 29	9580	62.9
117	Cross	" 29	7080	64.1
22	Burr's White	Sept. 29	9960	64.2
18	Helms Improved	Oct. 11	10880	79.2
	Average	Oct. [illegible]	10420	71.7
118	Cross	Sept. 29	11000	73.1
68	Leaming	Sept. 21	10440	73.6
8	Golden Beauty	" 29	8280	65.1
	Average	" 25	9360	69.3
123	Cross	" 29	11520	86.2
91	Champion White Pearl	Sept. 29	11080	60.6
68	Leaming	" 21	10440	73.6
	Average	" 25	10760	67.1
124	Cross	" 21	8760	76.2
22	Burr's White	Sept. 29	9960	64.2
110	Edmunds	" 21	9040	58.4
	Average	" 25	9500	61.3
125	Cross	" 21	10400	78.5

Some discussion of the possibilities of crossing varieties, e. g., flint and dent varieties, is put down in Minnesota Bu. 210, "Methods of Corn Breeding," Hayes and Alexander, April, 1924.

Commenting upon results of the foregoing bulletin and of other similar trials with varietal crosses, Dr. H. K. Hayes says: "Except for some special condition, it appears that F_1 varietal crosses are of no material value as a means of increasing yielding ability, provided a broad method of breeding is used by the corn breeder without too close selection to type." P. 284, Breeding Crop Plants—Hayes & Garber, McGraw-Hill Book Co.