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THE RELATIONSHIP BETWEEN CERTAIN MORPHOLOGICAL CHARACTERS AND LODGING IN CORN[1]

D. M. HALL[2]

INTRODUCTION

Lodged corn seriously interferes with harvesting operations and it assumes a new importance as the use of mechanical pickers increases. That lodging is the result of the interaction of the various environmental and inherited factors has been indicated by previous studies. No doubt corn is lost and the yield thereby reduced under farming practices when lodging occurs. However, the evidence does not indicate that a lodged stalk necessarily yields less than an erect one if none of the kernels are lost or rendered unfit for feed by being on the ground.

There are two types of lodging, the broken stalk type which occurs generally after the plants are mature and which is serious in areas where corn is picked from standing stalks, and the leaning type which results from weak anchorage and generally occurs between the last cultivation and harvesting time. The leaning stalk type is of particular importance in Minnesota where much corn is cut, and this study was limited to that type of lodging. Particular attention was paid to the various root structures which were assumed to be of importance in holding a plant erect in the face of wind and rain. It was important that these root characters be studied if synthetic lines of non-lodging corn were to be developed.

LITERATURE REVIEWED

One of the first problems was to find a satisfactory method of classification for different degrees of lodging. Koehler (9) recorded plants leaning 30° from the vertical as lodged and disregarded those leaning less. Hayes and McClelland (4) placed plants in four classes, those leaning 0°, 20°, 40°, and 60°, and calculated a lodging index by multiplying the number of plants in each class by the angle lodged and dividing this sum by the total number of plants.

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[2] The writer wishes to thank the Division of Agronomy and Plant Genetics of the University of Minnesota for making it possible for this study to be conducted and to acknowledge the assistance of Dr. H. K. Wilson as advisor, Dr. H. K. Hayes for critical analysis of the manuscript in preparation, and Dr. F. R. Immer for plans and procedures in the statistical treatment of the data, also Drs. Hayes and I. J. Johnson for furnishing the seed and previous lodging data.

Lodging has been attributed to disease by Hoffer and Holbert (5) and Koehler (9). Later Koehler (10) began a more extensive study of lodging because he felt that root rots were not necessarily the principal cause. He found that late planted corn lodged more than early planted corn, thick planting increased lodging, there was less lodging on virgin fields, and lime and rock phosphate reduced lodging. Pettinger (12) found that lodging decreased as fertilizers were added and the amount of lodging was influenced directly by the amount of rain and the velocity of wind.

Using selfed lines and F_1 crosses between these lines, Hayes and McClelland (4) demonstrated that "lodging was dependent to a considerable extent upon inherited differences." Holbert (6), Koehler (9, 10) Wilson (15), and Pettinger (12) demonstrated that lines differ in the pounds necessary to pull the plants from the soil. The pull was negatively correlated with the lodging of the strains.

Both Koehler (9) and Wilson (15) showed positive relationships between lodging and the number of brace roots. Holbert (6) found a positive relation between lodging and the number of roots and the amount of branching of the roots. Wilson (15) reported that short lower internodes were associated with erect plants.

Holbert (6) found strong plants to have roots with large oval tracheids and large pith cells thickened at the corners, which made the cells appear angular. In contrast he reported weak plants to have small round tracheids, small round pith cells, and no thickening at the corners.

Jenkins (7) has found a rootless (rt) line which was unable to hold itself erect because of the scarcity of roots. Jenkins and Gerhardt (8) reported a "lazy" gene that slowed up the deposition of structural materials. In July normal plants contained 3.5 times as much structural material as "lazy" plants and slightly less than twice as much in September. "Lazy" plants were lodged.

Koehler (9, 10) from crosses of erect x weak lines believed that the inheritance of strong or weak roots was not based on a single genetic factor but was more complex.

The work up to this time indicated that lodging was the result of a certain unfavorable environment acting upon a certain inherited complex, which appeared to result in a decrease in yield. Koehler, Dungan, and Holbert (9) stated "on the whole, differences in percentage of leaning plants are not very closely associated with differences in yield." But Pettinger (12), using a selected open pollinated strain, found a positive correlation between erect plants and yield and between pounds needed to pull the plant and yield. In Pettinger's case the storms came before August 15.

Hayes (2) published correlation coefficients for many selfed lines which showed very little or no correlation between lodging and yield.

MATERIALS AND METHODS

Selfed lines and F_1 crosses from the plant breeding cultures of the Minnesota Experiment Station were selected on the basis of lodging notes that had been taken for several years previous, as shown in Table 1. They were arbitrarily classified for this particular study as strong (S), intermediate (I), and weak (W) as follows:

	Group	Range of lodging angle in degrees from perpendicular	Lodging index
Strong	(S)	0-22.5°	0-1
Intermediate	(I)	22.6-45.0°	1.1-2.0
Weak	(W)	45.1-67.5°	2.1-3.0
Weak	(W)	more than 67.5°	3.1-4.0

Table 1

Lodging Index of Corn Cultures, 1927-33

Culture	Average angle of lodging			Index of lodging							Index average of years recorded
	1931	1932	1933	1927	1928	1929	1930	1931	1932	1933	
9-29 P	0.0	0.0	0.0	..	..	1.0	..	0.0	0.0	0.0	0.25
8-29 O	8.2	0.0	0.0	..	..	..	1.0	0.5	0.0	0.0	0.37
64 N	21.8	0.0	0.0	0.0	1.0	1.0	0.5	1.0	0.0	0.0	0.58
15-28 R	9.5	0.0	0.0	..	..	1.0	1.0	1.0	0.0	0.0	0.60
49 M	8.2	0.0	0.0	0.0	1.0	1.5	2.0	1.0	0.0	0.0	0.78
41 M	5.0	0.0	2.8	1.0	2.0	2.0	1.0	1.0	0.0	0.5	1.14
51 R	43.9	..	0.7	1.0	1.0	..	..	3.0	..	0.0	1.25
14 M	15.9	0.0	0.0	0.0	2.0	3.0	1.0	3.0	0.0	0.0	1.28
53 R	29.7	21.6	0.7	..	2.0	2.0	2.0	2.0	1.0	0.0	1.50
43 M	33.2	7.9	6.9	1.0	2.0	3.0	2.0	2.0	0.5	0.5	1.57
48 M	0.0	49.9	0.0	2.0	1.0	3.0	2.0	0.0	3.0	0.0	1.57
44 M	12.5	0.0	0.7	2.0	3.0	3.0	1.0	1.0	0.0	0.0	1.43
50 M	24.0	1.5	2.8	2.0	3.0	1.5	2.0	2.0	0.5	0.5	1.64
56 R	30.6	2.1	7.1	..	2.0	2.5	2.8	2.0	0.5	0.5	1.71
11 M	41.3	4.0	18.9	2.0	2.0	2.0	3.0	2.0	0.5	1.5	1.80
42 M	44.1	1.0	1.5	2.0	2.0	2.0	3.0	3.0	0.5	0.6	1.85
20 R	24.4	0.5	26.5	2.0	2.0	3.0	3.0	2.0	0.0	1.5	1.93
16 R	41.1	7.3	16.5	2.0	3.0	3.0	3.0	2.0	0.5	1.0	2.07
15 R	40.4	45.0	15.8	4.0	2.0	3.0	3.0	2.0	2.0	1.5	2.28
19 R	25.2	48.7	9.1	3.0	3.0	3.0	3.0	1.0	3.0	0.5	2.35
57 R	41.5	59.5	53.2	4.0	3.0	3.0	4.0	2.0	3.0	2.5	3.07

Index of lodging 1927-30, 0 = no lodging, 4 = severe lodging.
Index 1931-33, as explained in tabulation above.

R = Rustler
M = Minn. 13
N = Northwestern Dent
O = Osterland Dent
P = Purdue Dent

Crosses between these lines were selected to give the various combinations as SxS; SxI; SxW; IxI; IxW; and WxW. The parent lines had been selfed from 8 to 15 years.

Fig. 1. The Pulling Machine Used in Harvesting the Strains Used in This Study

The field used for the experimental studies was a part of the regular station rotation. All seed was treated with ceresan and planted in rows 42 inches wide, with plants approximately one foot apart in the row. Two replications were grown of each culture and these were planted in randomized blocks. The field was shallow cultivated and hilling was avoided.

Fig. 2. Machine Used to Lodge the Plants Artificially

In 1931 the data were collected before frost during the first week in September. The plants were pulled by the machine illustrated in Figure 1. A leather thong fitted with an iron ring at each end was wrapped about the base of the stalk. The rings were then fastened into the hook on a spring balance which was attached to a block and tackle as shown in Figure 1. The pounds required to pull the plant out of the ground were recorded. The brace roots were counted, and the cross section of the stalk at the surface of the ground was inked on a stamping pad and an impression made on cross-section paper. The root part was cut longitudinally so as to enable the easy measurement of the portion of the stalk below the surface and to note disease discoloration of the nodes.

In 1932 a few plants were dug at two different times during the season. At the same time a few plants were pulled over (artificially lodged) by the machine shown in Figure 2. These operations were done immediately after a heavy rain, while the soil was still muddy. The pounds of pull were recorded and the plants were left until the final harvest in September.

During 1933 certain refinements were made in the technic of artificial lodging and the field was provided with water so that the soil could be thoroly soaked before the plants were pulled down. At intervals of 15 days seven plants were artificially lodged and seven were dug from each culture.

During the period of the study measurements were taken as follows:

1. Ear height in inches to tip of upper ear.
2. Stalk height in inches.
3. Green weight of ears harvested from 7 stalks.
4. Anchorage—the length in millimeters of the underground part of the stem.
5. Internodal length—the distance in millimeters from the surface of the soil to the third node.
6. Disease on stalk—as indicated by discolored rotted spots on the leaves and behind the leaf sheaf.
7. Disease on roots—brown or pink discolored and rotted spots on roots and underground stem, with discoloration at node tissue as seen when stem was split longitudinally. Disease notes were: 0 = no infection to very light; 1 = light, 2 = heavy infection. To distinguish between discoloration caused by disease or the accumulation of iron at the node, the potassium thiocyanate test as outlined by Sayre (13) was applied to a number of stalks. No iron accumulation was found. None was expected to be found as complete chemical fertilizers including potash had been applied.
8. Area of cross section, in square centimeters, at surface of ground as measured by planimeter from inked imprints.
9. Amount of suckering.
10. Lodging angle—degrees from the vertical.

11. Pull up—the pounds needed to pull the plant from the ground.
12. Pull down—the pounds needed to pull the plant over to an angle of 45°. The direction of pull was at an angle of 45° from the middle height of the plant. The plant was slowly pulled over to an angle of 45° from the perpendicular.
13. Number of brace roots—those roots arising from nodes above the surface of the ground.
14. Length of brace roots—in millimeters.
15. Size of brace roots: 1 = 2.5 — 3.5 m.m.; 2 = 3.5 — 4.5 m.m.; 3 = 4.5 — 5.5 m.m.; 4 = 6.0 — 8.0 m.m.
16. Angle at which brace roots project from the stalk: 1 = 0 — 22.5°; 2 = 22.5° — 45°; 3 = 45° — 67.5°; 4 = 67.5° — 90°.
17. Depth of root clump—average depth at which roots broke when dug or pulled, in mm.
18. Width of root clump—average of two width measurements in mm. at approximately 3 inches below surface of ground, when plants were dug or pulled.
19. Volume of root clump. Cylindrical volume calculated from average width and length measurements. $(\text{Ave. Diameter})^2 \times \frac{\text{pi}}{4} \times \text{Depth} = \text{Volume}$.

Certain of these measurements were dropped because they were found to be of little value.

Three definite problems and the calculations designed to answer them were:

1. Did the plant material differ and were the differences inherited? This was determined through an analysis of variance and by inter-replicate correlations.
2. Did a relationship exist between the measurements of the characters and lodging angles such that the characters measured could serve as an indication of lodging? This was determined by correlation of the angle of lodging with the characters measured.
3. How were these characters expressed in crosses? A set of frequency tables was prepared to show this.

Much of the data were analyzed by the analysis of variance as devised by R. A. Fisher (1). This assumes the squared standard deviation to be the best measure of variability. This statistic, called variance or mean square, can be compared with other mean square values through Fisher's tables of "Z" and a level of significance obtained. An obtained "Z" value greater than the "Z" value in Fisher's 5% point table is explained, as a deviation as great or greater than that obtained could only happen by chance one time in 19 similar trials.

Fisher calculates the sum of squares value for the entire trial which includes all the variability regardless of whether it is caused by varietal differences, differences in treatment, or experimental error. The formula common to all standard deviation calculations $S(X-\overline{X})^2$ is shortened into $SX^2-S(X)\overline{X} =$ sum of squares. In a like manner, the sums of squares due to varieties, blocks, treatments, etc., are calculated and the total of these subtracted from the total sum of squares leaves the remainder as uncontrolled error. The plan below gives the manner of arranging the calculations for a simple analysis of variance.

Variability due to	Sum of squares	Degrees of freedom	Variance
Varieties	$\frac{SX^2V}{b} - S(X)\overline{X}$	$V-1$	$\frac{SX^2V}{b} - S(X)\overline{X} / V-1$
Blocks	$\frac{SX^2b}{V} - S(X)\overline{X}$	$b-1$	$\frac{SX^2b}{V} - S(X)\overline{X} / b-1$
Error	Remainder	$(b-1)(V-1)$	Remainder $/ (b-1)(V-1)$
Total	$SX^2 - S(X)\overline{X}$	$N-1$	$SX^2 - S(X)\overline{X} / N-1$

In each case it is important that the sum of squares be calculated on the single plot basis. Thus the sum of squares for varieties is divided by the number of items that go into the figure for each variety before $S(X)\overline{X}$ is subtracted. The same is true for blocks and treatments. Since single plot calculations are used to obtain the sum of squares for total, this item is divided by one. Degrees of freedom is used in the sense of independent comparisons. Thus with N quantities whose mean is fixed there will be in general N-1 degrees of freedom.

EXPERIMENTAL RESULTS AND THEIR INTERPRETATION

The Determination of Inherited Differences and the Uniformity of the Expression of the Characters in Replicated Plots

A prime consideration was to determine whether significant variability was to be found in the data, which consisted of many measurements of characters for both selfed lines and F_1 crosses between them. Further study would not be worthwhile unless individual character differences were discovered.

The analysis of variance method as outlined by Fisher (1) was considered a convenient method of attacking this problem. Consequently, the first step was the analysis of individual character differences within the material selected for this study. This analysis is presented in Table 2 for the characters of selfed lines used in these experiments.

Table 2

Mean Square Values for the Final Measurements of the Selfed Lines for 1931-33 as Obtained From an Analysis of Variance

1932, '33	D.F.	Depth of root clump	Ave. width of root clumps	Volume of root clump
Blocks	2	508.95	35.88	101,194.95
Cultures	14	1,071.70*	1,022.44*	942,041.50*
Years	1	608.02	2,815.35*	2,021,803.27*
Cultures × Years	14	243.16	257.49*	293,159.73†
Error	28	223.45	101.81	131,133.15

1932, '33	D.F.	No. of brace roots	Length of brace roots	D.F.	Ear height (1931, 1933)
Blocks	2	245.40	28.62	2	1,044.38
Cultures	15	2,225.89*	1,651.38*	16	9,136.98*
Years	1	120,062.25*	32,942.25*	1	1,040.52
Cultures × Years	15	471.75	518.85	16	653.78
Error	30	829.60	342.55	32	756.62

1932, '33	D.F.	Size of brace roots	Angle of brace roots	Disease	Suckers
Blocks	2	33.33	6.70	32.41	35.53
Cultures	14	82.42*	105.15*	144.05*	99.38*
Years	1	792.06*	1,135.35*	252.15†	299.26*
Cultures × Years	14	31.63†	45.56*	57.18	27.26
Error	28	15.44	12.21	36.23	16.67

1931, '32, '33	D.F.	Lodging angle	Pull up	Stalk Height	D.F.	Weight of ears (1933)
Blocks	3	2,159.27	356.50	1,896.29	1	76.80†
Cultures	14	44,795.00*	8,779.93*	9,845.22*	14	126.74†
Years	2	456,537.90*	17,154.03*	68,666.06*	..	.....
Cultures × Years	28	17,888.15*	2,178.65*	4,319.52*	..	.....
Error	42	7,316.10	288.19	676.64	14	21.30

* Exceeds 1% point Fisher's tables of Z.
† Exceeds 5% point Fisher's tables of Z.
D.F. = degrees of freedom.
Note: Weight of ears taken for 1933 only, ear height for 1931 and 1933, others for years as indicated.

The data given in Table 2 show degrees of freedom and mean squares for blocks, cultures, years, error, and the interaction of cultures in different years. The measurements for some characters were taken one, two, or three years, as indicated in the table.

The significant differences of the mean square values for years indicate that some characters were more influenced by different seasons than others. This more uniform reaction in different seasons was observed for depth of root clump and ear height. Less uniform expression in different years was noted for width and volume of root clump, number, length, size and angle of brace roots, disease, number of suckers, lodging angle, pounds to pull the plant from the ground, and stalk height.

The selfed cultures were significantly different with a "Z" value exceeding the 1% point for all 14 characters measured. Thus the selfed lines appeared satisfactory material to use in continuing the study.

This same conclusion, with one exception, can be drawn for the F_1 crosses. When the mean squares for cultures was compared with that for error, a "Z" value which exceeds the 1% point was found in each case except one. No explanation is offered for this one exception. The mean square values are shown in Table 3 below.

Table 3

Mean Square Values for the Final Measurements of the F_1 Crosses for 1933 as Obtained from an Analysis of Variance

	D.F.	Depth of root clump	Ave. width of root clump	Volume of root clump
Blocks	1	1,404.50*	537.92	12,960.50
Cultures	24	885.57*	371.34	8,126.19*
Error	24	104.87	258.33	3,106.75

	D.F.	Size of brace root	Angle of brace root	Disease	Suckers
Blocks	1	0.32	2.42	144.50*	109.52
Cultures	24	12.58*	54.62*	87.31*	5,469.87*
Error	24	5.02	16.12	23.58	1,521.56

	D.F.	No. of brace roots	Length of brace roots	Ear height
Blocks	1	212.18	1,693.62*	46.08
Cultures	24	2,211.23*	1,174.12*	5,069.41*
Error	24	1,146.84	232.16	1,267.83

	D.F.	Stalk height	Pull up	Weight of ears
Blocks	1	890.42	744.98	54.08
Cultures	24	9,269.44*	3,674.78*	128.00*
Error	24	1,319.87	957.43	27.49

* Exceeds 1% point Fisher's tables of Z.
D.F. = degrees of freedom.

Having found these characters variable enough to warrant further study, it seemed desirable to determine the extent of their uniformity of expression by correlating the two replicates. The correlation coefficients for selfed lines and F_1 crosses are given in Table 4.

Considering the small number of cultures used in these calculations, it was rather remarkable that the coefficients were as high as those obtained. They were significant for the most part, which indicated that the cultures reacted in a similar manner in the two replicates. The coefficients for height of ear, pounds needed to pull the plant from the soil, and the area of cross-section of the stem need no explanation. These characters appear most stable. However, several exceptions were noted, and considering that only about 25 plants were measured in each replicate it was not surprising to find some exceptions. Reasons given below for these low correlations for certain characters may point the way for a modification of method to obtain more reliable data in future studies.

Table 4
Coefficients of Correlation Between Duplicated Rows for the Characters Measured the First Week of September, 1931-32 for Plants Pulled from Dry Soil

Characters	Correlation coefficients: Selfed lines 1931 N = 21	Selfed lines 1932 N = 17	F1 crosses 1931 N = 15	F1 crosses 1932 N = 11
Height of ear	.6704*	....	.5833*	....
Stalk height	.9654*	.5873†	.1018	.8063*
Pull up	.9577*	.4393†	.7304*	.8660*
Length underground stem	.0653	....	.4593	....
Internodal length	.5896*	....	.1591	....
Area cross-section	.9600*	....	.9291*	....
Disease on stalk	.3972	....	.1913	....
Disease on roots	.5707*	.5541†	.4629	.7158†
Angle of lodging	.6195*	little lodging	.3891	little lodging
Depth root clump	....	.3137	....	.6797*
Width root clump	....	.3491	....	.9043*
No. of brace roots	....	.4330	....	.5485
Length brace roots	....	.5282†	....	.1072
Size brace roots	....	.6596*	....	.4458
Angle brace roots	....	.3164	....	.6939†

* Exceeds 1% point Fisher's table of V.A.
† Exceeds 5% point Fisher's table of V.A.

Stalk height showed a low correlation for the F_1 crosses in 1931. No explanation, except small numbers, was available.

The low correlation for length of underground stem part is explained on the basis of other tests made on the depth of planting. Five cultures were planted at 1, 2, and 3 inches in depth in both June and July in 1932 and 1933 in the field. The seedlings were dug and the length of the underground stem measured. (See Fig. 3.) A comparison of the mean square values obtained from an analysis of variance showed the cultures differed in the length of the underground stem, depending upon the depth of planting as indicated by the following tabulation:

	D.F.	Mean squares
Depths	2	552.4*
Cultures	4	292.0*
Dates	1	16.1
Cultures x dates	4	212.9*
Depths x dates	2	40.5
Error	15	37.5

* Exceeds 1% point Fisher's tables of Z.
D.F. = degrees of freedom.

The mean square value for cultures was highly significant, indicating that the five cultures differed in length of underground stem. Also, the figure for depths was highly significant, which indicated that the length differed within cultures depending upon the depth of planting. The interaction of the cultures at different dates gave a significant mean square (212.9) which showed that the underground stem reacted in a differential manner on different dates. Only one culture (64) showed a tendency to form the secondary roots at the same depth in the soil regardless of the depth of planting. The statement often found in botany textbooks that the depth of planting bears no relation to the depth at which the secondary roots are formed does not agree with these studies except for Culture 64.

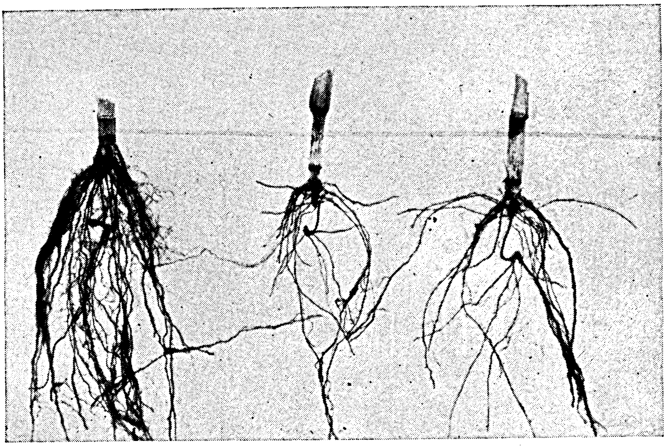


Fig. 3. Plants of the Same Culture Planted at Different Depths Showed the Length of the Underground Stem Depended Upon the Depth of Planting

The length of the lower internode seems to vary in the same manner. The ground level is indicated by the line drawn across the cut.

The ability to resist attacks of disease organisms seemed to be fairly constant between replicates, altho the attacks were more severe in lodged than in erect plants. The one low correlation, disease on roots for F_1 crosses in 1931, almost reached the 5% point. Very little disease was noted on the stalks, so low coefficients were expected.

A high interreplicate correlation was found for lodging in the selfed lines, but for the F_1 crosses it was low. The F_1 lines showed less lodging, and this with the fact that the gusts of wind did not uniformly lodge the plants in the same row could account for this low figure. It therefore seemed necessary to plan a method of artificial lodging to replace the uncertainties of natural lodging.

The summer of 1932 was very hot and dry, and the plants suffered considerably. Following a short heavy rain, a pool of water stood for a short time over a large part of the second replications. Thus these rows obtained more water than the others, and this may be the reason for the low correlations between replicates throughout 1932 and account for those inconsistencies in the calculations for depth and width of root clump and the number, length, size, and angle of brace roots.

For the most part, the data indicated that the cultures selected possessed inherited differences in each of the characters studied and that there was a similarity in the reaction of these characters when the plants were grown in different replicated rows.

The Correlations Between the Angle of Lodging and the Characters Studied

The search for plant characters that might serve as indicators of lodging led to the measurement of plant structures that theoretically should give strength to resist wind and rain. It was assumed that plant height and root anchorage were the main characters that should be studied. First it was believed necessary to devise a uniform standard for measuring lodging. Lodging most often occurs between the final cultivation and harvesting. Most stalks after being lodged straighten in the shape of a curve, making it possible to record almost any angle depending on the place the measurement was taken. The lodging notes prior to 1931 were taken by a skilled observer, by estimating the average deviation of the plant row from the vertical, and were supplied by the Division of Agronomy and Plant Genetics of the Minnesota Agricultural Experiment Station. The cultures were classified as 0 = no lodging to 4 = severe lodging.

Fig. 4. The Protractor Used to Measure the Lodging Angle and the Height

In 1931 the measurements were taken at the base of the stalk, where the angle was the greatest, but this plan was discarded as too severe since the disadvantage of lodging came at the time of the harvest.

For the remainder of this study the angle at which a plant would interfere with harvesting machinery was calculated. It was determined that the ordinary wagon offered greater interference with slightly lodged corn than either the corn picker or corn binder. On this basis, a protractor with a 20-inch radius (the height of an ordinary wagon hub) was constructed (Figure 4) to measure the lodging angle.

Correlation coefficients between the extent of lodging and the measurements of the various characters are given in Table 5. The mean angle at the base of the stalk was used for 1931. The mean angle measured by the 20-inch protractor was used for 1932 and 1933. In the table for column headed 1927-33 the mean index of lodging was used as obtained from Table 1.

Table 5

The Correlations Between Amount of Lodging and the Characters Studied

Characters	Correlation coefficient: Parent lines 1931 N = 21	Parent lines 1932 N = 18	Parent lines 1927-33 N = 15	F_1 crosses 1931 N = 15	F_1 crosses 1932 N = 14	F_1 crosses 1933 N = 25
Ear height	—.0342	....	.3476(a)	.2367	....	.1676
Stalk height	.2728	.4842*	.5099*	—.3117	—.3698	.0952
Pull-up	—.4439*	—.3531	—.5151*	—.4443	—.5853*	—.0953
Length underground stem	.3055	....	....	.1513	....	....
Internodal length	.6950†	....	....	.4481	....	....
Stalk cross-section	—.0197	....	....	—.0534	....	....
Disease on stalk	.0889	....	....	—.0321	....	....
Disease on roots	.5358†	.1101	.5964*	.4421	—.5336*	—.1995
Depth root clump	....	—.5040*	—.5294*	....	—.5027*	—.3512
Width root clump	....	—.9571†	—.6394†	....	—.3572	—.1811
Volume root clump	....	....	—.6451†	....	....	—.3015
Number brace roots	....	—.2288	—.2828(b)	....	.6601†	.2253
Length brace roots	....	—.3053	—.5906(b)†	....	—.5000*	—.3170
Size brace roots	....	—.1013	—.3373	....	—.1364	—.1592
Angle brace roots	....	—.2807	—.5442*	....	—.1924	—.1276
Number suckers	....	....	—.0327	....	—.1612	.0491
Lodging angle for 1933	....	....	.9182†	....	....	....
Weight of ear	....	....	.1909	....	....	.1452

* Exceeds 5% point Fisher's tables of V.A.
† Exceeds 1% point Fisher's tables of V.A.
a, N = 17 b, N = 16.
Note: The mean angle of lodging was used in each case except for the average of 1927-33 for the parent lines. In this case the average index of lodging as obtained from Table 1 was used.

Since the expression of the characters in the various cultures was similar in different years, as indicated previously, it seemed desirable that they be correlated with the average index of lodging for a period of years. This was even more desirable in view of the fact that natural lodging conditions were very variable in different years. Thus the calculations for 1927-33 were considered most satisfactory.

From Table 5 it appeared that no relationship existed between the amount of lodging and ear height, length of underground stem, stalk cross-section, disease on stalk, size of brace roots, number of suckers, or weight of ear.

The other character reactions with lodging were explained as follows: Stalk height was related to a certain extent with lodging angle in the selfed lines but not significantly related in the F_1 crosses. This may be due to the greater variability in the height of the plants in the selfed lines. On this basis, as indicated by the coefficient of variability shown below, higher correlations would be expected in the selfed lines. This difference could also be due to the fact that the selfed lines lodged more than the F_1 crosses.

		Average stalk height	S.D.	Coefficient of variability
Means of selfed lines	1931	46.45	17.84	38.37
" " " "	1932	43.90	6.84	15.58
" " F_1 crosses	1931	65.60	6.78	10.35
" " " "	1932	56.05	5.06	9.02

Average index of lodging of 17 selfed lines = 1.44
" " " " " 25 F_1 crosses = 1.03

Significant negative correlations were secured between the pounds required to pull the plant from the soil and lodging by many workers using various selfed lines and open-pollinated varieties. This study showed a significant relationship for two years in selfed lines and for only one of the three years in the F_1 crosses.

Disease on roots was correlated positively and pull-up was correlated negatively with lodging in the same years for both selfed lines and F_1 crosses. This would indicate that a large amount of disease would so weaken the roots that the pull would be low. When low correlations were found between lodging and disease, the correlations between lodging and pull-up were low also.

Significant relationships were found in selfed lines for internodal length, depth, width, and volume of root clump. Only depth of root clump in the F_1 crosses gave a significant coefficient.

The number of brace roots appeared to have no relationship to lodging in the selfed lines, but a highly significant coefficient was found in the F_1 crosses in 1932.

The length of brace roots was correlated in somewhat the same manner as the depth of root clump. The one exception approaches the 5% point, however.

A significant correlation with the average of 1927-33 was found for the angle of brace roots in the selfed lines. All others were too low to be significant.

On the whole it seems safe to conclude that stalk height, pull-up, disease, depth, width, and volume of root clump, and length and angle of brace roots are of value as indices of lodging.

It became apparent that the work of any single season might be lost if one depended entirely upon natural conditions to affect lodging. To overcome this difficulty, a machine (See Fig. 2) was constructed to lodge the plants artificially. This machine was designed so that the point of pull would be at the middle height of the stalk, and its direction was at an angle of 45° from the stalk regardless of the stalk height. The machine was in two parts. The first part was an upright piece securely tied to the stalk. This served to keep the plant from bending and to direct the strain of pulling toward the roots. The point of attachment was adjustable to the middle of the plant, and a guide served to direct the pull at the proper angle. The second part of the machine was a milk scale mounted on a sharp piece that could be stuck into the ground at the proper distance so as to make the angle of pull always the same. A rope was arranged over a suitable pulley, so that the measurement of the pull could be read on the milk scale. The ground was soaked with water and the plants were slowly pulled over to an angle of 45° from the vertical and the maximum pounds required in the pulling recorded.

In 1932 rains on August 17 and August 26 provided the water, and lodging was done immediately afterward. In 1933 the plots were artificially watered. About the equivalent of one inch of rainfall was applied and enough added each day during the pulling to keep the moisture about equal. The plants were artificially lodged during the weeks of July 15 and August 1.

Table 6

The Mean Square Values for the Pounds Needed to Lodge Corn Plants Artificially to an Angle of 45° from the Vertical

	19 selfed lines		17 selfed lines	
	D.F.	1932	D.F.	1933
Blocks	1	10.3	1	1,991.6*
Cultures	18	1,690.8*	16	1,304.3*
Dates	1	0	1	1,601.5*
Blocks x dates	1	76.2	1	152.9
Cultures x dates	18	8,013.5*	16	401.6†
Error	36	351.9	32	195.3
	14 F_1 crosses		**23 F_1 crosses**	
	D.F.	1932	D.F.	1933
Blocks	1	1,028.5	1	400.7
Cultures	13	5,828.1*	22	931.8*
Dates	1	2,696.1	1	2,961.8*
Blocks x dates	1	900.1	1	375.9
Cultures x dates	13	649.7	22	1,909.8*
Error	26	1,004.8	45	333.8

* Exceeds 1% point Fisher's tables of Z.
† Exceeds 5% point Fisher's tables of Z.
D.F. = degrees of freedom.

The data for 1933 were considered more valuable because of more uniform moisture. When summarized by the analysis of variance the data gave highly significant differences for both selfed lines and F_1 crosses, as shown in Table 6 for the different cultures.

In 1933 there was a highly significant difference in the reaction at different dates for both selfed lines and F_1 crosses. This reaction was not found in 1932. The plants were lodged about one month earlier in 1933 than in 1932, and this may explain the difference. In three cases a differential reaction of the cultures at different dates was noted. This may have been the result of a differential rate of root growth.

It was possible to check the rate of growth as measured on different dates in 1932. An analysis of variance for these data revealed the significance of the differences when the volume of root clump was used as a measure of root growth. The volume was calculated for plants dug at three different dates at intervals of 15 days. The mean square values and significant differences as determined by the "Z" test were as follows:

	D.F.	Mean square values
Cultures	12	1,230,666.17*
Dates	2	814,283.50*
Error	24	52,164.04

* Exceeds 1% point Fisher's tables of Z.
D.F. = degrees of freedom.

Some lines lost in volume between the second and third recordings. These lines were most heavily diseased, and the loss may have been the result of the disease pathogene.

In order to determine whether the pull down was a satisfactory measure of lodging, the lodging indices for 17 selfed lines (Table 1) were correlated with the pounds needed to pull the plant down. The coefficients are given below:

	Correlation coefficient
Plants lodged July 15, 1933	—.5117
Plants lodged August 1, 1933	—.3760
5% point Fisher's Table of V.A. (1)	.4821

This indicated a possibility of using artificial lodging as a measure of the ability of plants to resist wind and rain. However, it would seem that high-pressure water equipment could be used to effect this artificial lodging. A stream at constant pressure directed against the row would lodge it much as it would be naturally lodged. The soaking of the ground and the force of the water should have much the same effect as the rain and wind.

Because, theoretically, stalk height and root volume should correlate highly with lodging, it was decided to determine whether there was any relationship between root volume and stalk height. The following tabulations showed a positive relationship early in the season, but none later.

Correlation Coefficients Between Height of Plant and Volume of Root Clump, 1933

	16 selfed lines	25 F_1 crosses
July 15 plants dug	.6162	.4090
Aug. 1 " "	—.0914	—.0701
Sept. 1 " pulled	—.1188	.2036
5% point Fisher's Tables V.A.	.4973	.3809

Weaver and Bruner (13) indicate a similar lack of relationship in stating, "This illustrates the fallacy of judging root extent by top growth. After years of study of scores of native and cultivated plants it has been fully demonstrated that such a criterion is entirely untrustworthy."

The Reaction of the Characters in F_1 Crosses

Examination of the data from crosses of strong, intermediate, and weak lines, selected on their ability to withstand natural lodging, was made possible by classifying the F_1 crosses on the basis of measurements of their characters. The frequency tables given below show the quantitative distribution of the various root and plant characters as obtained from F_1 crosses of S x S (strong x strong), S x I (strong x intermediate), S x W (strong x weak), I x I (intermediate x intermediate), I x W (intermediate x weak), and W x W (weak x weak) parent lines. Thus the distribution of ear height for the mean of 7 F_1 crosses of S x S selfed lines ranged from 24 to 38 inches, with a mean value of 31.6 inches. The mean for 1931 was 32.4 inches, while that for 1933 was 30.7 inches. The 8 F_1 crosses of S x I selfed lines showed a distribution from 16 to 33 inches. In the same manner, other crosses were distributed in Table 7 for the various characters studied.

The table reveals a definite trend for S x S F_1 crosses to have lower ears than W x W crosses. No apparent difference was observed in the height of stalk, whether the cross was between strong parents or weak ones.

The depth and width of root clump resulting from crosses of S x S parents was greater than from crosses of W x W on the average. A definite trend was noted from large root volume when S x S parents were used to smaller root volume when one or both parents were I or W.

On the average, more pounds were required to pull the plants from the ground when one parent was S than when one or both parents were I or W.

Table 7

The Frequency Distribution for the Measurements of the Various Characters Studied in F_1 Crosses. Parental Lines Going Into the F_1 Crosses Were Classified as S (strong), I (intermediate), and W (weak) on the Basis of the Average Lodging Index as Obtained from Table 1

	Ear height				Total	1933	1931
	16	24	32	40	mean	mean	mean
S x S	..	3	4	..	31.6	30.7	32.4
S x I	1	5	2	..	29.3	26.4	31.9
S x W	..	3	1	1	31.8	31.8	...
I x I	..	6	5	1	32.8	37.3	34.4
I x W	..	2	3	2	34.8	33.8	41.7
W x W	1	2	3	1	33.7	33.2	34.9

	Stalk height							Total	1933	1932	1931
	45	50	55	30	65	70	75	mean	mean	mean	mean
S x S	..	1	3	3	2	1	1	63.2	60.8	58.0	69.5
S x I	..	..	3	2	2	1	..	62.8	64.0	59.0	65.4
S x W	..	..	..	2	..	..	3	69.6	69.6	...	...
I x I	2	2	4	5	3	1	..	50.9	63.5	54.5	63.9
I x W	..	1	1	2	2	2	1	66.2	67.7	58.0	58.0
W x W	..	1	3	2	2	2	..	62.3	64.6	53.7	64.3

	Size brace roots							Total	1933	1932
	22	24	26	28	30	32	34	mean	mean	mean
S x S	..	..	..	1	5	..	..	28	29	30
S x I	..	..	1	1	5	..	..	29	29	29
S x W	..	..	..	2	3	..	..	29	29	..
I x I	2	..	2	4	3	..	1	28	30	26
I x W	1	2	1	..	4	..	..	27	29	24
W x W	..	1	3	3	1	..	..	27	28	25

	Angle brace roots						Total	1933	1932
	12	16	20	24	28	32	mean	mean	mean
S x S	..	..	..	1	5	..	29	30	28
S x I	..	1	1	1	3	..	24	23	27
S x W	..	..	..	1	4	..	29	29	..
I x I	1	2	4	3	1	1	23	25	20
I x W	1	1	1	2	2	..	23	23	19
W x W	..	..	5	3	..	..	23	23	23

	Disease							Total	1933	1932
	0	60	90	120	150	180	240	mean	mean	mean
S x S	4	..	..	...	...	1	1	86	72	100
S x I	2	1	..	1	...	2	1	134	138	125
S x W	1	1	..	...	...	1	2	181	181	...
I x I	4	3	..	4	...	...	1	141	113	170
I x W	1	3	..	1	...	2	1	128	117	200
W x W	1	3	..	1	...	3	...	136	112	210

	Suckers						Total	1933	1932
	0	40	80	120	160	200	mean	mean	mean
S x S	1	1	..	3	1	...	114	75	120
S x I	3	..	1	3	1	...	94	89	110
S x W	2	1	2	...	...	...	53	53	...
I x I	..	5	2	1	2	...	125	92	156
I x W	..	4	1	...	2	1	110	100	180
W x W	..	1	3	1	3	1	136	128	100

Table 7—Continued

	Depth root clump 90	110	130	150	170	Total mean	1933 mean	1932 mean
S x S	..	...	2	2	2	155	152	159
S x I	..	1	3	3	...	142	142	142
S x W	3	...	2	...	...	120	120	...
I x I	..	4	5	2	1	138	140	137
I x W	..	2	5	1	...	141	139	148
W x W	1	2	5	...	...	125	120	141

	Width root clump 115	135	155	175	195	Total mean	1933 mean	1932 mean
S x S	...	3	1	1	1	167	152	181
S x I	...	2	4	1	...	158	153	170
S x W	1	3	1	...	...	150	150	...
I x I	2	6	4	...	...	147	150	150
I x W	2	5	1	...	...	141	142	134
W x W	3	4	1	...	...	141	139	147

	Volume root clump 125	200	274	350	425	500	575	Total mean	1933 mean	1932 mean
S x S	...	2	1	1	1	...	1	355	282	429
S x I	1	3	4	...	...	...	...	273	259	317
S x W	1	3	1	...	...	...	...	231	231	...
I x I	3	6	2	1	...	...	...	242	251	234
I x W	3	3	...	...	...	...	...	225	216	289
W x W	4	4	...	...	1	...	...	204	193	238

	Pull up 95	155	215	275	335	Total mean	1933 mean	1932 mean	1931 mean
S x S	2	4	3	3	...	218	257	233	177
S x I	1	1	3	3	1	261	283	231	237
S x W	..	2	2	1	...	225	225	...	...
I x I	7	5	4	2	...	187	232	177	153
I x W	2	4	2	...	1	201	225	198	138
W x W	2	5	2	...	...	187	206	174	142

	Number of brace roots 85	125	165	205	245	Total mean	1933 mean	1932 mean
S x S	1	3	1	1	...	159	188	130
S x I	1	1	1	2	2	182	218	137
S x W	..	2	3	...	...	165	165	...
I x I	3	5	1	3	...	156	183	129
I x W	1	2	3	1	1	181	192	102
W x W	2	1	3	2	...	167	189	102

	Length of brace roots 80	110	120	140	160	180	Total mean	1933 mean	1932 mean
S x S	..	...	1	2	...	1	152	163	142
S x I	..	1	1	2	2	...	149	152	139
S x W	..	...	1	2	2	...	155	155	...
I x I	1	3	3	4	1	...	129	140	102
I x W	1	...	5	1	1	...	131	132	123
W x W	1	2	3	1	1	...	129	123	144

Note: All decimals have been dropped since they make no difference in the comparisons.

In number and size of brace roots there was no difference in crosses of S lines and crosses of I or W lines, but both the length and angle of brace roots were greater in the case of S x S than in W x W crosses on the average for both years.

Wide distribution was noted for disease. Most S x S crosses had little disease, but some were as heavily infected as the crosses with one W parent. However, the average was for S x S crosses to have less disease than others. In 1932 the increase in the amount of disease was quite uniform from S to I to W crosses. In 1933 the S x W crosses averaged heavier disease infection than any other crosses, and even in this case the range of distribution was wide. No W x W crosses were classified as being free from disease.

The number of suckers showed a wide distribution in all crosses, but the average was less in S x S crosses than in W x W. Strong lines used as one or both parents averaged less suckers than where I or W lines were used as parents.

On the average, S x S crosses showed lower ears, longer brace roots with wider angle, deeper and wider root clumps, larger root volume, less disease, fewer suckers, and more pounds to pull the plant from the soil than W x W crosses. There was individual variability, however, in different crosses, and in some cases S x S and W x W crosses gave similar results for the various characters. No particular difference could be observed between S and W crosses in height of plant and number and size of brace roots.

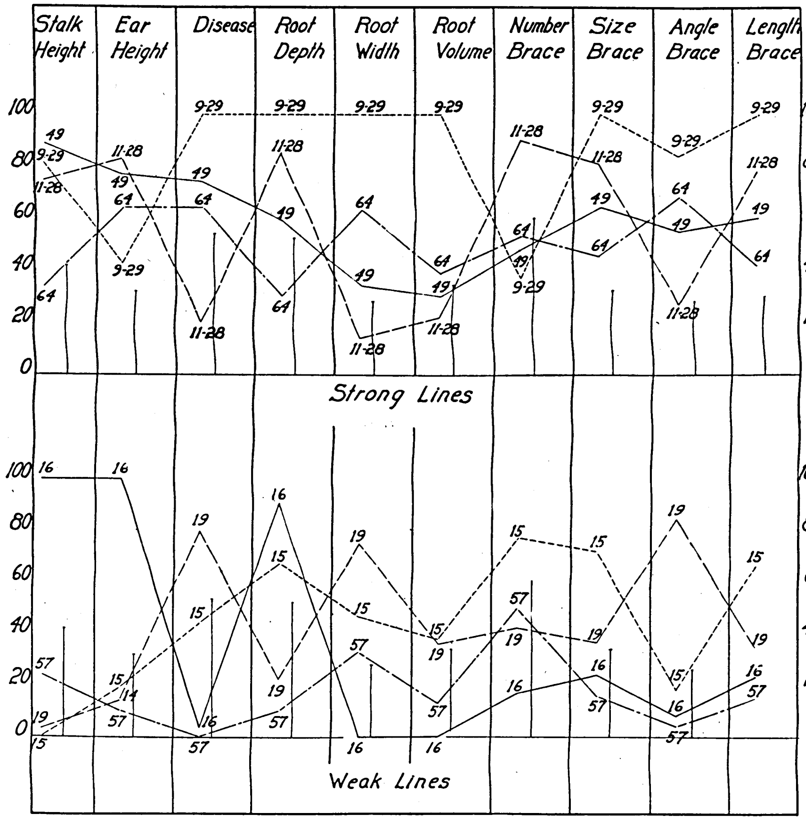
It was apparent that lodging was the result of a composite of causes, and a study of the characters classified on the basis of the index of natural lodging was not sufficient. It was considered worthwhile to study each character in more detail and especially so if synthetic non-lodging cultures were to be developed. Thus the selfed lines were distributed according to the magnitude of the measurement of each character studied. Theoretically a strong culture should have a short stalk, a low ear, little disease, deep and wide root clump, many large brace roots of considerable length and extending at a wide angle from the stalk.

On this assumption, a distribution was made on a scale with 100% equal to difference between the highest and lowest datum. From the previous study and based on what seemed reasonable, the characters were so arranged that those which should give a plant the ability to resist lodging appeared at the top of each column.

After all the cultures were distributed, those which had been previously determined as strong, intermediate, or weak (Table 1) were drawn off separately, as shown in Tables 8a and 8b. The bar drawn up from the bottom of each chart indicates the percentage range of the significant differences as calculated from the actual measurements through the analysis of variance according to the formula 2 S.D. of difference of 2 means $= 2\sqrt{\text{variance}}$. This was placed on the percentage basis before being added to the charts and means that two cultures must be at least as far apart as the length of the bar before they can be said to be significantly different.

Table 8a

A Distribution of Strong and Weak Lines Classified on Basis of Lodging Index for the Characters Studied, Cultures Scaled on the Basis of 100 Per Cent for Difference Between Maximum and Minimum Datum for Each Character

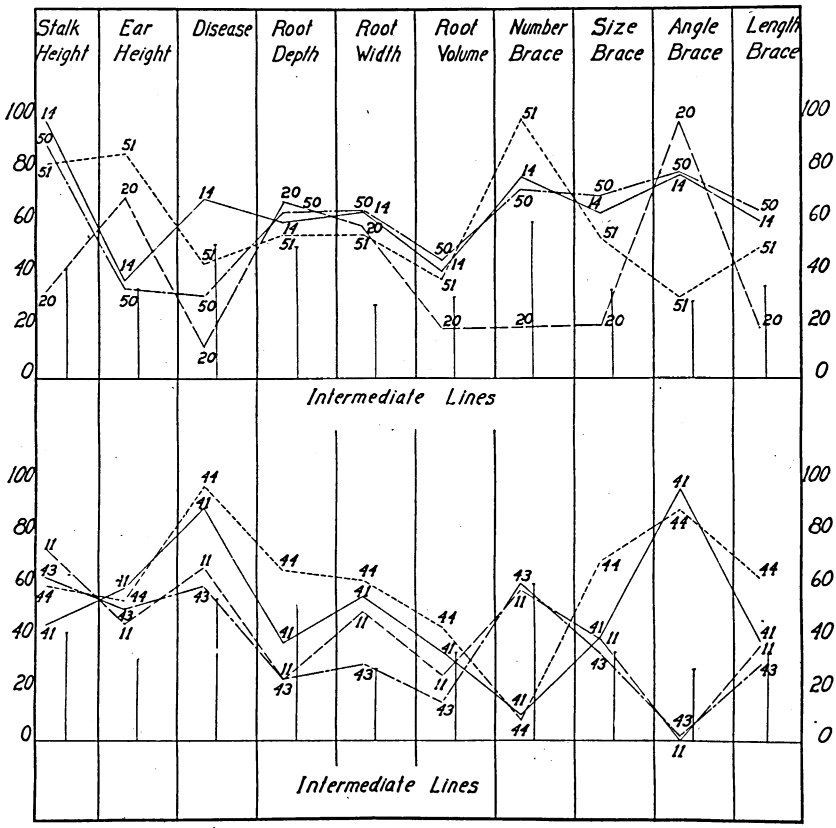


Note: The bar drawn up from the bottom of each column = significant difference = 2 S.D. of difference of two means.

These tables show that, while for the most part strong lines were found near the top of each column, it was not always the case. For example, Culture *9-29*, the strongest culture in the test, is near the top in all except two cases, and here it drops to near the 40% mark in ear height and number of brace roots. Another example, Culture 16, a weak line, was found near the top in three instances. It is noteworthy that 49 and 64 paralleled each other so closely. This would indicate that these two cultures were of similar genotypes for these characters, as would also be the case with Cultures 14 and 50, 44 and 41, and 11 and 43.

Table 8b

Distribution of Intermediate Lines Classified on Basis of the Lodging Index for the Characters Studied, Cultures Scaled on the Basis of 100 Per Cent for Difference Between Maximum and Minimum Datum for Each Character



Note: The bar drawn up from the bottom of each column = significant difference = 2 S.D. of difference of two means.

These tables indicate that lodging vs. non-lodging was not inherited as from the effects of a single factor and that strong lines were strong because they possessed one or more characters that correlate highly with erect plants and in spite of the fact that they also possessed certain characters that might be associated with weak lines. These tables also show which of the cultures might be used in backcrosses to synthesize strong lines. Stalk height, disease, depth and width of root clump, length and angle of brace root were correlated significantly with natural lodging. A synthetic strong line should rank high in each of these characters.

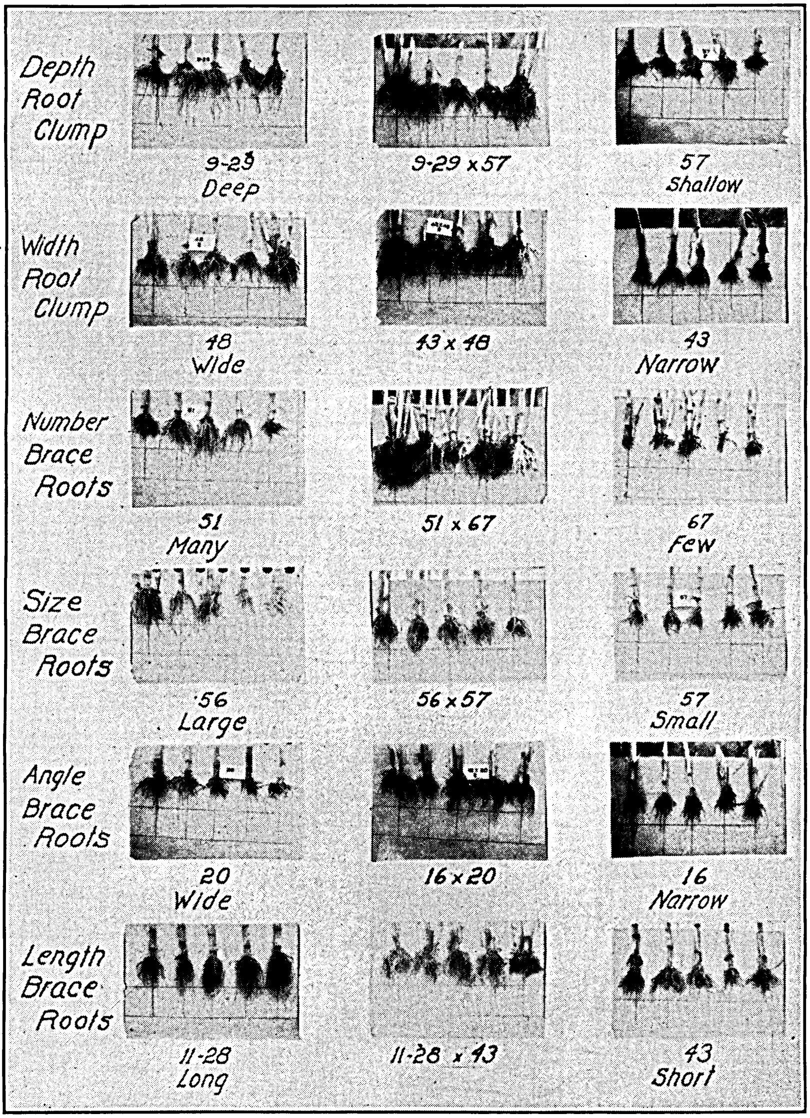
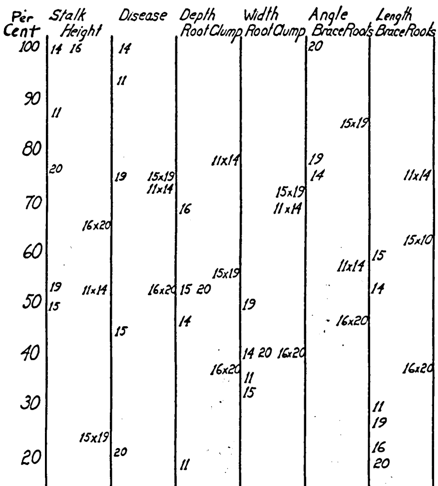


Fig. 5. Selected F_1 Crosses, Showing Reaction of Various Characters Studied

Certain of the cultures have proven to be good yielders when used in crosses. The Cultures 11 x 14 = E, 15 x 19 = K, 16 x 20 = I are being used in the Minnesota double crosses. These lines might be expected to show outstanding vigor in the F_1 generation. When they were distributed in a table similar to Table 8, only in one instance was the F_1 above the 80% point. In Table 9 100% is equal to the difference between the minimum and maximum datum when the range of both selfed lines and F_1 crosses were thrown together. The expression of the characters in the F_1 crosses was variable, which indicated that each line must be studied for each character before the parent material could be selected to synthesize new non-lodging lines. The lines shown in Table 9 were considered sufficient to illustrate this variability.

Table 9

Distribution of Selfed Lines and F_1 Crosses Used in Synthesizing Minnesota Double Cross Corn Cultures Scaled on Basis of 100 Per Cent for Difference Between Maximum and Minimum Datum for Both Selfed Lines and F_1 Crosses



Another arrangement of the data was undertaken in which the parent lines were divided into three classes, A, B, and C. The A class included all lines falling within the top third of the scale of Tables 8a and 8b. The B class included the middle third and the C group the lower third. The F_1 crosses were grouped into six groups, composing all the possible combinations of A, B, and C classes. Then the F_1 crosses were distributed into frequency classes, the center of each class being significantly different or approximately so. This set of frequency tables indicated a similar variability as was shown by Table 9, and it was not considered necessary to present these tables.

However, they indicated for the most part, tho not without exception, that there was a relationship between the parental lines and the F_1 crosses for height of ears, height of stalk, number of brace roots, size of brace roots, and volume of root clump. There appeared to be an increase in the F_1 crosses over the parent lines in most cases for height of ear;

height of stalk; number, size, angle, and length of brace roots, and the volume of the root clump.

SUMMARY

This study was undertaken to determine if there were characters that could be used as indices of lodging in selfed lines of corn and in F_1 crosses between the selfed lines. It was concerned mainly with the measurement of root characters that theoretically should give a plant the ability to withstand attacks by wind and rain. The first step was to discover if the plant material differed in its inheritance, after the difference due to environment had been taken into account. The second step was to determine if any relationship existed between the characters studied and the natural lodging of the cultures. The third step was to discover the reaction of the selfed lines when they entered into F_1 crossed material.

By the analysis of variance the selfed lines were shown to be different, with a "Z" value exceeding the 1% point in each case. This meant that these cultures possessed inherited difference in depth, width, and volume of root clump; in number, length, size, and angle of brace roots; in stalk and ear height; in weight of ears; in lodging angle, and in the pounds necessary to pull the plants from the ground. The F_1 material showed similar differences, except in the case of the width of root clump which did not show a significant "Z" value. Interreplicate correlation coefficients showed a striking similarity in the reaction of the selfed lines and F_1 crosses in the different replicates. It was surprising, considering the small number of plants used, to find as high coefficients as were found. One notable exception was the length of underground stem, which was found to vary in relation to the depth of planting. Since secondary roots arise from the underground stem, the depth of their formation was dependent upon the depth of planting.

From correlation coefficients between the average index of lodging and the character measurements of the various lines, it was found that little or no relationship existed between the amount of lodging and the ear height, the length of underground stem, the stalk cross-section, the amount of disease on the stalk, the size of brace roots, the number of suckers, and the weight of the ears.

Stalk height was related to lodging angle in selfed lines but not in F_1 crosses. Pounds to pull the plant from the soil were corrrelated significantly with lodging in most cases. A similar relationship was found for disease and lodging. Internodal length, disease on roots, depth, width, and volume of root clump, and length and angle of brace roots were associated with lodging to a certain extent in the selfed lines. The coefficients were for the most part not significant in the F_1 crosses.

Because of the uncertainty of natural lodging conditions each year, plants were artificially lodged and the pounds required were recorded. These data analyzed by the variance method showed that the selfed lines and F_1 crosses differed significantly in the pounds needed to pull the plants over to an angle of 45° from the vertical. Correlation coefficients between index of lodging for 17 selfed lines and the pounds required to pull the plants down showed significant negative relationship when plants were pulled down on July 15 but little relationship when pulled on August 1.

A differential response of the selfed lines in pounds to pull down on different dates indicated a different rate of root growth. This was checked by measuring the volume of dug root clumps at three different dates. These data when analyzed showed significant cultural differences and showed different volumes on different dates.

Both selfed lines and F_1 crosses showed a positive significant relationship between volume of root clump and height of plant when the data were taken on July 15, but showed no relationship at later dates.

Frequency tables showing the distribution of F_1 crosses from strong, intermediate, and weak parent lines, classified on the basis of the index of lodging, permit the following conclusions: On the average, strong x strong crosses showed lower ears, longer brace roots, with wider angle, deeper and wider root clumps, larger root volume, less disease, fewer suckers, and more pounds to pull the plant from the soil than the W x W crosses. There was individual variability, however, and in some cases S x S and W x W crosses gave similar results for the various characters. No particular difference could be observed in the height of plant nor in the number and size of brace roots between the strong x strong and weak x weak crosses.

When the parent lines were ranked on the basis of their actual measurements for each character, rather than on the basis of the lodging index, it became apparent that lodging was a complex of characters and that these characters were inherited separately.

The distribution of the F_1 crosses on this same basis and compared with the parent lines that entered into each cross gave an idea of the dominance or the expression of hybrid vigor. Hybrid vigor was expressed rather generally throughout the character classifications. A type of partial dominance was evident for high vs. low ears, tall vs. short plants, many vs. few brace roots, wide vs. narrow angle of brace roots, and no vs. several suckers. In several cases, however, a reverse dominance seemed to occur. The other characters measured were not statistically significant.

The study indicated that characters desired in F_1 crosses, which theoretically would give a plant ability to resist lodging, must be selected from a study of the individual parent culture, since certain lines have low lodging indices in spite of the fact that they stand high on the scale in certain characters which are associated with lodging.

LITERATURE CITED

1. Fisher, R. A.
   1930 Statistical Methods for Research Workers. Oliver & Boyd. London. 3rd Edition.
2. Hayes, H. K.
   1926 Present-day methods of corn breeding. Jour. Am. Soc. Agron. **18**:344-63.
3. Hayes, H. K., and Garber, R. J.
   1927 Breeding Crop Plants. McGraw-Hill Co., New York, 2nd Edition.
4. Hayes, H. K., and McClelland, C. K.
   1928 Lodging in selfed lines of maize and in F_1 crosses. Jour. Am. Soc. Agron. **20**:1314-17.
5. Hoffer, C. N., and Holbert, J. R.
   1918 Selection of disease-free seed corn. Purdue Agr. Expt. Sta. Bull. 224.
6. Holbert, J. R.
   1924 Anchorage and extent of corn root system. Jour. Agric. Res. **27**:71-78.
7. Jenkins, M. T.
   1930 Heritable characters in maize—Rootless. Jour. Heredity **21**:78.
8. Jenkins, M. T., and Gerhardt, Fish
   1931 A gene influencing the composition of the culm in maize. Ia. Res. Bull. 138.
9. Koehler, Benj., Dungan, G.H., and Holbert, J. R.
   1925 Factors influencing lodging in corn. Ill. Agr. Expt. Sta. Bull. 266.
10. Koehler, Benj., and Holbert, J. R.
    1930 Corn diseases in Illinois. Ill. Agr. Expt. Sta. Bull. 354.
11. Matsura, Hajime.
    1933 A Biographical Monograph in Plant Genetics. Sapporo, Japan. 2nd Edition.
12. Pettinger, N. A.
    1933 Effects of fertilizers, crop rotations and weather conditions on the anchorage of corn plants. Va. Agr. Expt. Sta. Tech. Bull. **46**:1-36.
13. Sayre, V. C.
    1930 Accumulated iron in nodes of corn plant. Plant Physiology **5**:393-98.
14. Weaver, John E., and Bruner, William E.
    1927 Root Development of Vegetable Crops. McGraw-Hill Co., New York.
15. Wilson, H. K.
    1930 Plant characters as indices in relation to the ability of corn strains to withstand lodging. Jour. Am. Soc. Agron. **22**:453-58.