A STUDY OF THE RELATION OF SOME MORPHOLOGICAL CHARACTERS TO STRENGTH OF STRAW AND LODGING IN WINTER WHEAT

by

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INTRODUCTION

Lodging of wheat, as well as other small grains is an important factor in the final yield of grain produced on farms in the more humid sections of the country. The problem is of more importance on rich soils or following applications of fertilizer than on thin worn-out soils. Furthermore, soil management methods which are desirable for increasing crop yields tend to produce conditions favorable for lodging. From the farmers' standpoint, the development of varieties resistant to lodging would aid in reducing one of the hazards of crop production.

For the plant breeder, an accurate evaluation of the resistance to lodging of new strains or varieties is difficult to obtain. Lodging occurs in most localities so irregularly that much time and effort may be spent on new strains before information is gained as to their resistance to lodging.

At various times in the past, efforts have been made to secure some satisfactory method of testing new strains in comparison with known varieties for their resistance to lodging. In some instances, these tests have consisted of mechanical laboratory devices, while other attempts have been concerned with morphological characters of the plant which might be associated with resistance to lodging.

The studies reported in this paper were made at Texas Substation No.6, Denton, Texas as a part of the wheat improvement program carried on cooperatively by the Texas Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture. In 1931 strength of straw determinations were made on only a few varieties. In 1932 a larger number of varieties were studied but the number of plant characters studied was small. In 1933 and 1934 a large number of characters were studied on a comparatively large number of varieties of hard and soft winter wheat.

REVIEW OF LITERATURE

The effect of lodging on the yield of grain and the difficulty of harvesting lodged grain have been recognized by nearly all writers on the subject of lodging. Immer and Stevenson(24), in a study of factors affecting the yields of oats, report markedly reduced yields as a result of lodging of grain.

The influence of fertilizers and plant nutrients upon lodging in grain has been observed and studied for many years. As early as 1789 Sir Humphrey Davy(11) associated lodging of grain with low silica content of the straw. This opinion was also held by Liebig(32), and more recently by

Headden(20), Davidson and LeClerc(9), Davidson and Phillips (10), and Phillips, Davidson, and Weihe(37). Contrary to this view Sachs(42) and others have questioned the importance of silicon and pointed out that lodging was due to deficient lignification of the supporting tissues. The importance of lignin in strength of straw has recently been studied by Phillips, Davidson, and Weihe(37), who found high lignin content in fertilized or lodged straw in contrast to lower lignin content in the straw from unfertilized areas.

Rivera(41) and Welton and Morris(54) report a lower percentage of dry matter in lodged straw compared to erect straw. They state that the reduction in dry matter may be brought about by environmental factors or by thick stands.

Kraus(27)(28)(29), Ziehe(58), and Stuch(48) report that applications of potash aided in producing stiff straw as compared with nitrogen or phosphorus. Tubbs(52) also found that potash was essential for the production of strong mechanical tissue and that a deficiency of nitrogen increased the strength of the lower internodes. Harcourt(18) analyzed the soil on which lodged and standing grain were grown and found that the soil on which grain had lodged contained more nitrogen and less lime than the soil on which the grain did not lodge. Stuch(48) studied the morphological and anatomical characters of oats plants grown with different applications of fertilizers and found that an optimum supply of nitrogen resulted in strong culms but if there was an excess or abundance of nitrogen the culms were weak with thin cell walls and lax tissues. Heavy phosphorus applications as well as heavy applications of potash served to increase the strength of straw but heavy phosphorus applications as well as heavy applications of nitrogen produced conditions favorable for mildew, which in turn was favorable for the development of weak straw.

Lack of sufficient light as a result of shading, thick stands, or heavy stooling were mentioned as contributing factors to lodging by Kraus(27), Rivera(41), Percival(36), and Welton and Morris(54).

The influence of diseases as a factor in lodging has been reported by Dombrovski(12) and the United States Department of Agriculture, Plant Disease Reporter(5).

Morphological and anatomical characters of the plant in relation to lodging and strength of straw have been studied by a number of investigators. Kraus(27)(28)(29) after extensive studies was unable to find any one character which he believed could be used as an index of standing power. Albrecht(1), on the other hand, found a close correlation between strength of culm and weight per unit length of culm near the base of the plant. This he believed to be the most accurate indication of the strength of the culm. He also found a relationship between strength of culm and diameter of culm, and between strength of culm and length of lower internode. He concluded that any one of the three measurements are accurate enough to be used in selecting plants resistant to lodging.

Kirsche(25), as a result of a study of length and strength of internodes, advised breeding for short, strong lower internodes as a means of overcoming lodging. Moldenhawer(35) found varietal differences in number of vascular bundles and recommends this as a good measure of strength of straw. Garber and Olsen(17) found no correlation between the characters they studied and lodging except in the case of thickness of the lignified cell walls. Welton and Morris (54) found differences in solidity and size of culm between varieties but pointed out that size of culm was influenced by stand and tillering. Brady(4) after extensive studies of external and internal anatomy of three varieties of oats concluded that thickness of culm wall, number of vascular bundles, width of lignified tissue and width of sclerenchema were all closely associated with varietal differences in resistance to lodging but that external characters such as height, length and diameter of lower internodes were equally as good indices of standing power. He concluded that all characters were so subject to soil variation that their use for the isolation of lodging resistant strains could be used only on a relative basis.

Lange(30) reports that wheat varieties having strong standing power had shorter stiffer stems, thicker ears, and tillered less than those weaker in standing power. Prutzkova et al. state that wheats resistant to lodging had shorter stems and especially shorter first and second internodes than non-resistant varieties.

Date of maturity has been studied in relation to lodging in several localities. Donald(13) recommends early planting of oats in Scotland as an aid to prevent lodging. Florell(16) found less lodging in certain varieties of wheat, oats, and barley in California when planted late in the season than when planted early but lower yields were obtained. Grading of seed as an aid to more uniform stands and stronger plants is suggested by Donald(13) and by Welton and Morris(54).

Very little work on the inheritance of strength of straw has been reported, although improved lodging resistant varieties as a result of transgressive segregation have been reported by Schribaux(45), Berg(2), Biffen and Engledow(3), Crepin(7), Harlan and Hayes(19), Howard and Howard(22), Hunter(23), Strampelli(47), and Tschermak(51). Ramian and

Dharmalingam(40) found only a single factor difference in crosses between two lodging varieties of rice and a non-lodging variety. It seemed that the non-lodging nature of the straw was linked with poorer tillering and later maturity.

A number of mechanical devices have been reported for measuring the strength of straw of cereals. In many instances results of strength of straw tests have not agreed with lodging behavior of the varieties under field conditions. Helmick(21) describes apparatus used at Cornell University, New York, for testing strength of straw and gives results obtained on a weak and a strong strawed variety of wheat. Willis(55) describes an apparatus which he states has been used successfully. More recently Salmon(43) devised an instrument which has been used at a number of experiment stations in the United States. He reports agreement between results obtained on the machine and lodging behavior in the field at the Kansas Experiment Station. This machine has also been used and results reported by Davis and Stanton(8), Salmon and Laude(44), and Leidigh, Mangelsdorf, and Dunkle (34).

Studtmann(49) describes two forms of measuring strength of straw, one of which measures the whole plant, and the other measures the resistance to lodging of several plants together. Both apparatus were used in the field upon the plant in its original position. Kraus(28) also describes apparatus for testing strength of straw. Draghetti(14) found that the flexibility of the first internode is directly correlated with degree of resistance to lodging and worked out a formula for its measurement. Zade(56) does not consider that stiffness of straw is an adequate guide to resistance to lodging. He regards length of straw and leaf area as important factors which must be considered in connection with resistance to bending. Zavada(57) states that resistance to lodging is dependent upon the elasticity of the culm, length of culm, and extent of leaves and other plant characters.

MATERIALS AND METHODS

The results herein reported have been obtained during the 1932,1933, and 1934 crop seasons, with a small amount of data secured in 1931. The varietal material used in the study was grown at Texas Substation No.6 located in Denton County in north central Texas. For the 1934 season a special planting was made of 129 varieties of wheat used in the study, while previous to that time, material was taken from the guard rows of the regular nursery plots. In 1934 a single 3 row, 8 foot plot of each variety was planted and material for the study taken from the center row. Planting rates were the same for each variety and no allowances were made for differences in size of seed. Varieties varied considerably in their stooling ability so that the number of culms per unit area, which was determined at harvest time, was different for each variety.

For the study of influence of stand on strength of straw and other characters, a special planting was made using four varieties. Planting rates were varied from twice the normal rate of 16 grams per 16 foot row, to one-fourth the normal rate. In making this planting, varietal differences in size of seed were taken into consideration and planting rates corrected so that approximately the same number of seed of each variety was planted.

Material for studying the influence of fertilizers upon strength of straw was obtained from a fertilizer test of wheat which has been conducted at the Substation for a number of years.

The strength of straw determinations were made with a machine devised by Salmon(43). Figure 1 shows this machine with straws in position for operating. Lodging notes were taken in the field whenever possible. In addition to the Denton notes on lodging, some data were secured from other experiment stations. By using the data from several stations it was hoped to get a more accurate evaluation of the standing power of a variety.

Figure 1. Machine used to determine strength of straw.

Strength of straw tests were made in all seasons after the material had been cured under cover. In 1931 and 1932 plants were pulled up by the roots, tied in bundles and hung up to dry. Later it was found that cutting the culms at the surface of the ground with a cycle was just as satisfactory thus eliminating the roots and reducing the size of the bundle. Strength of straw determinations were made on 100 culms for each variety. The strength of a variety is reported as average of 20 determinations of 5 straws each. No culms were used which failed to head but otherwise no selection was practiced in picking material for testing. Tests were made in all instances on the first straight internode above the crown of the plant.

With the exception of measurement of height of plant, 100 straws were used in determining each morphological character. To facilitate the work and reduce the error, the number of individual measurements was reduced as much as possible. Weight of heads, weight of grain, weight of culms, and weight of culm sections were taken on 100 culms. Height of plant measurements were taken in the field in 1932 but in 1933 and 1934 they were determined by measuring 20 culms after removing the head.

Measurements of diameter of culm, length of internode, and weight per unit of culm near the base of the plant, were taken during the process of testing for strength of straw. After each 5 culms were tested for strength, the internodes tested were laid end to end and the total length of 5 internodes recorded. A 10 centimeter section was then cut from each culm. The five culms were placed side by side so that the width of the five could be measured at one time with a vernier caliper. The sections were saved as they were measured and the 100 sections from each variety was weighed as a unit. This weight of 100 10-centimeter sections is used in this study as a unit or measurement of the size and solidity of the stem at the base of the plant. In the tables and discussion it is refered to as " weight per unit of culm at base of plant".

In 1933 determinations of strength of straw and plant measurements were recorded for the rate of planting test and the fertilizer test at two stages of growth before harvest. In these studies, samples of green material were taken to the laboratory where all measurements and tests were made as rapidly as possible. In all instances the tests were completed before the plants wilted appreciably.

Statistical treatment of the material has been confined mostly to measures of variability of the breaking strength. In this the method of Analysis of Variance as explained by

Snedecor(46) was used. Simple correlation coefficients were determined for all possible combinations among the characters studied. Partial correlations were determined in a few instances were it was thought they might be of value.

EXPERIMENTAL DATA

Results in 1932

The results of breaking strength determinations, as well as measurements of diamter of culm, length of lower internode, height of plant, field observations on lodging, date of maturity, notes on leaf rust and stem rust are recorded in table 1. The 65 varieties used in the study in 1932 were taken from the regular nursery and although no counts were made, the stands appeared to be uniformly good. Differences in number of culms per square foot of area prevailed due to varietal differences in stooling.

Notes on leaf rust(<u>Puccinia triticina Eriks.</u>) and stem rust(<u>Puccinia graminis tritici Eriks. and Henn.</u>) are given for each variety as it was thought desirable to determine whether either of these diseases influenced the breaking strength of the straw. Correlation coefficients were calculated to determine this influence. Leaf rust is an important factor in wheat production every year in North Texas and no doubt influences the development of the plant. In general, the hard wheat varieties are more susceptible to leaf rust than the soft wheat varieties grown in this study. Likewise, the hard wheats are normally smaller in stature, producing shorter, smaller culms, and having lower breaking strength than the soft wheat varieties. Thus, there is an association of weak straw and susceptibility to rust in the hard wheats and strong straw with resistance to leaf rust in the soft wheats. This combination resulted in the significant correlation of -.360 between breaking strength and leaf rust in 1932. While it is admitted that leaf rust probably has some influence in a general stunting of the plant, it is believed that where tests of strength are made near the base of the plant as in this study the influence of leaf rust can be ignored.

In a similar manner the soft wheats are in general more susceptible to stem rust than the hard wheat varieties grown. Stem rust infection in 1932 reached a maximum of 50 per cent on the varieties Sutton and Clarkan. The infection occurred late in the season and probably did not influence the maturing of the crop to a great extent as all grain filled well. It would be expected that heavy stem rust infection would weaken the stem of the plant, especially in the upper portions. However a positive correlation of .589 was found between breaking strength and stem rust. As with leaf rust this is believed to be an association of the stronger soft wheat varieties with susceptibility to stem rust rather than an effect of the rust on breaking strength. Therefore the influence of stem rust as well as leaf rust is not considered further in this study.

Detailed measurements were made on breaking strength of straw, diameter of culm, and length of lower internode. Measurements of height of entire plant were made in the field. Date of first head, rather than date of ripening, was used as a measure of date of maturity since in some seasons hot winds cause rapid ripening with little difference between varieties.

Varieties tested in 1932 ranged in strength of straw from 6.06 pounds required to break 5 culms of Clarkan, to 3.26 pounds required to break five culms of Turkey Selection C.I. 11015. In general the soft wheats were stronger strawed than the hard wheats. This is in close agreement with field observations on resistance to lodging.

Data recorded in the 1932 season are given in table 1.

Table 1. Data recorded on 65 varieties of hard and soft winter wheat, 1932.

Variety or strain	C.I. No.**	Date of first head	Per cent Leaf rust	Per cent Stem rust	Plant height in inches	Length of lower inter-node cm.***	Diameter of culm mm.***	Estimated field lodging Per cent	Pounds required to break 5 culms Avg. 20 tests
Clarkan	8858	4-28	45	40	42	8.78	3.03	T	6.06
Harvest Queen	6199	4-29	83	35	43	9.16	2.95	1	5.89
Ohio, T.N. 1047, T.S.* 18567	-	4-29	71	50	41	7.76	2.87	1	5.80
Kawvale	8180	4-27	21	18	39	8.05	2.85	1	5.25
P.1066-1 x Burbank	10087	4-25	63	18	38	6.80	2.66	9	5.23
Mediterranean, T.S.* 5933-36	-	4-24	13	24	42	10.00	2.87	24	5.17
Fultz	3416	4-22	79	9	36	7.25	2.83	4	5.08
Mediterranean, T.S.* 5933-32	-	4-23	26	35	40	9.03	2.63	34	4.92
Mediterranean, T.S.* 5933-7	-	4-23	21	18	40	9.86	2.71	38	4.91
Fultz-Mediterranean, Col. Row 358	-	4-27	75	8	39	8.21	2.82	3	4.84
Fulcaster	6471	4-29	78	43	42	8.40	2.62	8	4.81
Sutton	10053	5-1	24	50	40	8.25	2.54	13	4.80
Smithsonian	10022	5-2	20	30	41	7.07	2.57	64	4.79
Sibley 81	10084	4-27	45	10	39	7.95	2.52	18	4.76
Early Blackhull	8856	4-20	83	T	35	8.63	2.59	2	4.71
Denton (Average of 6 check plats)	8265	4-27	15	24	40	8.42	2.53	9	4.70
Kanred x Fulcaster, Ks.1928 R.93	-	4-26	26	15	40	9.05	2.76	3	4.69
Mediterranean, T.S.* 5933-35	-	4-23	11	21	43	9.68	2.68	36	4.64
Kanred x Marquis	11374	4-24	36	3	35	7.58	2.51	8	4.46
Quivira	8886	4-23	30	5	37	7.54	2.44	9	4.45
Mediterranean, T.S.* 5933-23	11525	4-25	4	16	42	8.19	2.67	10	4.44
Mediterranean, T.S.* 5933-38	-	4-23	13	25	42	10.30	2.70	30	4.37
Mediterranean, T.S.* 3015-105-1	11587	4-27	14	40	41	9.11	2.61	21	4.36
White Mediterranean	10023	4-23	68	41	40	9.26	2.47	10	4.36
Kanred x Marquis, Ks. 2644	10090	4-29	13	14	39	10.17	2.65	29	4.34
Minturki	6155	5-1	82	10	42	7.75	2.45	2	4.30
Mediterranean, T.S.* 3015-63	-	4-26	6	23	39	9.57	2.50	9	4.20
Kanred x Marquis, Ks. 2640	-	4-27	23	9	38	9.37	2.56	4	4.14
Kanred x Fulcaster, Ks. 1928 Row 73	-	4-27	31	23	41	9.33	2.56	21	4.12
Mediterranean, T.S.* 3015-130	-	4-26	21	24	40	8.71	2.44	9	4.07

Table 1 (continued)

Variety or strain	C.I. No.**	Date of first head	Per cent Leaf rust	Per cent Stem rust	Plant height in inches	Length of lower internode cm.***	Diameter of culm mm.***	Estimated field lodging Per cent	Pounds required to break 5 culms Avg. 20 tests
Blackhull	7172	4-29	80	8	39	8.73	2.38	20	4.06
Kanred x Fulcaster, Ks. 1928 Row 72	-	4-28	18	13	41	9.39	2.63	8	4.05
Beloglina Selection	8884	5-2	74	13	38	7.38	2.37	35	4.03
Kanred x Hard Federation	10092	4-22	48	10	34	7.77	2.50	4	4.02
Turkey Selection	10100	4-30	88	26	36	7.39	2.34	50	4.02
Tenmarq	6936	4-29	44	9	39	8.13	2.48	11	3.93
Mediterranean, T.S.* 5933-20	10085	4-24	15	11	39	9.13	2.30	13	3.92
Mediterranean, T.S.* 5933-34	11526	4-24	24	11	39	9.68	2.32	9	3.90
Red May Selection, T.S.* 7250-1	-	4-27	30	25	35	8.94	2.44	9	3.90
Mediterranean, T.S.* 3015-81	10086	4-26	33	16	38	7.82	2.29	33	3.90
Kanred Selection	10099	5-1	76	10	39	8.89	2.48	28	3.90
Cheyenne	8885	5-1	78	10	37	8.14	2.51	6	3.87
Oro	8220	5-1	75	8	39	8.81	2.53	6	3.85
Kanred x Hard Federation	11373	4-21	51	8	34	7.68	2.47	4	3.79
Tenmarq Selection	10089	4-29	35	8	39	8.58	2.56	11	3.77
Turkey Selection	10094	5-1	96	8	35	7.24	2.26	4	3.70
Nebraska 60	6250	5-1	88	14	38	8.00	2.36	19	3.66
Kharkof	1442	5-1	81	11	38	7.12	2.26	10	3.64
Mediterranean, T.S.* 3015-72	11567	4-27	48	23	39	8.82	2.29	39	3.59
Kanred x Hard Federation	10093	4-19	46	6	33	7.78	2.39	0	3.58
Fulhard	8257	4-26	80	11	38	9.43	2.35	5	3.54
Turkey Selection	10098	4-28	94	9	36	7.84	2.23	4	3.53
Kanred x Hard Federation	10091	4-19	38	4	33	8.35	2.47	0	3.51
Nebraska 28	5147	4-15	85	0	29	8.37	2.31	0	3.50
Turkey Selection	10095	4-30	94	10	34	7.20	2.23	6	3.49
Turkey Selection	10083	4-29	75	8	38	8.32	2.27	39	3.48
Minturki x Bel. Buffum	10088	5-2	81	9	40	8.43	2.26	24	3.48
Kanred x Minturki	10012	5-2	75	9	39	7.61	2.23	29	3.45
Canadian Hybrid, Col. Row 359	-	4-20	88	10	36	8.17	2.27	13	3.42
Kanred	5146	5-1	76	8	36	9.59	2.35	35	3.40

Table 1 (continued)

Variety or strain	C.I. No.**	Date of first head	Per cent Leaf rust	Per cent Stem rust	Plant height in inches	Length of lower inter-node cm.***	Diameter of culm mm.***	Estimated field lodging Per cent	Pounds required to break 5 culms Avg. 20 tests
Turkey Selection	10097	4-29	94	8	35	6.41	2.09	10	3.39
Turkey Selection	10016	4-28	96	9	36	7.97	2.19	4	3.39
Turkey Selection	11375	4-29	91	16	37	7.83	2.17	15	3.36
Turkey Selection	10096	4-29	96	9	35	6.85	2.17	4	3.30
Turkey Selection	10015	4-30	94	6	36	6.50	2.15	6	3.26

* Accession number of Texas Experiment Station
** Accession number of Division of Cereal Crops and Diseases, U.S.D.A.
*** Average of measurements taken on 100 culms

The variability of the data on strength of straw as well as the experimental error was determined by the analysis of variance method as described by Snedecor(46). Results of the statistical analysis are given in table 2.

Table 2. Analysis of variance of strength of straw determinations of 65 winter wheat varieties. 1932.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total variance	1299	892.6116	.687
Variance between varieties	64	571.0846	8.923
Variance within varieties	1235	321.5270	.260

Standard deviation of a single plot .... .510
Standard error of the mean of any variety .... .114
Standard error of a difference between any two varieties .161
Least significant difference between two varieties....... .338

From the above results it will be observed that the data obtained in the 1932 season was reasonably uniform within varieties. This resulted in a rather low standard error of the mean of a variety. A difference of only .338 pounds between means of any two varieties would be considered significant and would indicate an actual varietal difference in strength of straw.

The relationship of characters studied among each other in all combinations has been determined by means of correlation coefficients. These are given in table 3.

Table 3. Correlation coefficients for each pair of characters studied in 65 winter wheat varieties, Denton, Texas. 1932.

		B	C	D	E	F
Breaking strength	A	.613	-.046	.253	.861	-.112
Plant height	B		.286	.479	.682	.322
Lodging in the field	C			.159	-.063	.259
Length of lower internode	D				.501	.216
Diameter of culm at base	E					-.056
Date of maturity	F					

Breaking strength of straw and leaf rust r = -.360.
Breaking strength of straw and stem rust r = .589.

Least significant value of r = .250.
Least highly significant value of r = .325.

From the data secured in 1932 a close correlation was found between breaking strength and diameter of culm, also between breaking strength and height. This shows that the stronger strawed varieties were more vigorous growers and produced taller, larger stems than the weaker varieties. Field lodging was associated with date of maturity in 1932. Plant height was closely correlated with length of lower internode, diameter of culm, as well as strength of straw. Length of lower internode was correlated with diamter of culm, height of plant, and breaking strength of straw. Date of maturity was correlated with plant height, lodging, and to some extent with internode length.

No correlation was obtained in 1932 between breaking strength and lodging in the field. The lodging took place during a storm which occurred when the majority of the varieties were just starting to ripen. No doubt differences in maturity as well as differences in height, productiveness, and vegetative growth all influenced the amount of lodging. In order to determine the amount of influence of certain factors on the correlation of breaking strength and lodging, partial correlations were calculated for breaking strength and lodging with variability due to height of plant, length of lower internode, and date of maturity removed. Thus if 1 = breaking strength, 2 = lodging, 3 = date of maturity, 4 = plant height, and 5 = length of lower internode.

$$r_{12.3} = -.078$$

$$r_{12.4} = .023$$

$$r_{12.5} = .006$$

From the results of these calculations, it would seem that variability of these factors was not directly responsible for the lack of correlation of breaking strength and lodging in the field.

Results in 1933

Data obtained in the 1933 season on 44 varieties of hard and soft winter wheat are given in table 4.

Table 4. Data recorded on 44 varieties of hard and soft winter wheat, 1933.

Variety or Strain	C.I. No.**	Date of first head	Per cent Leaf rust	Per cent Stem rust	Plant height in cm.	Length of lower inter-node cm.***	Dia-meter of culm mm.***	Weight of grain from 100 heads	Weight of 100 culms gm.	Weight of 100 8 cm. culm sec-tions	Esti-mated field lodg-ing Per cent	Pounds required to break 5 culms average 20 tests
P.1066-1 x Burbank	10087	5-6	48	5	80	10.1	3.4	101	124	15.1	3	7.66
Clarkan	8858	5-8	45	18	84	11.2	3.3	77	114	12.6	1	6.80
Harvest Queen	6199	5-8	78	15	84	11.9	3.2	62	109	11.8	0	6.74
Mediterranean, T.S.* 3015-105-1	-	5-8	8	49	79	9.5	3.1	71	104	12.3	1	6.30
Mediterranean, T.S.* 5933-23	11525	5-7	1	24	80	9.3	3.0	73	96	11.3	3	5.96
Fulhard	8257	5-6	51	24	83	10.1	2.8	64	97	11.2	2	5.88
Sibley 81	10084	5-9	48	8	71	9.7	2.7	59	82	10.5	1	5.82
Kanred x Kawvale, T.S.* 20409	-	5-10	5	4	78	10.5	3.0	66	93	11.6	3	5.76
Nebraska 28	5147	4-18	83	0	63	8.3	2.7	45	69	10.3	0	5.71
T.S.* 20405****	-	5-2	11	4	82	11.4	2.9	84	91	10.6	19	5.69
Fulcaster	6471	5-8	60	25	78	9.7	2.8	62	89	10.5	3	5.66
Mediterranean, T.S.* 3015-63	-	5-8	3	30	79	10.9	2.8	67	85	10.0	3	5.63
Denton x Kanred, 4-31-28	-	5-8	15	16	87	12.0	2.9	64	93	9.3	18	5.50
Mediterranean, T.S.* 3015-72	11567	5-7	19	34	83	9.4	2.6	53	91	10.9	3	5.46
Kawvale	8180	5-8	7	11	81	11.1	2.9	66	88	10.2	4	5.43
Sutton	10053	5-8	44	18	76	10.0	2.8	55	89	9.9	3	5.38
White Mediterranean	10023	5-1	85	11	78	11.2	2.7	67	81	10.0	3	5.28
Kanred x Hard Federation	11373	5-2	45	23	83	10.7	2.8	74	83	10.3	18	5.26
Denton	8265	5-9	12	23	85	10.2	2.7	60	86	10.0	4	5.24
Kanred x Fulcaster, Ks. Row 93	-	5-8	14	3	79	10.8	2.8	56	81	9.8	0	5.16
Mediterranean, T.S.* 5933-20	10085	5-5	13	13	74	9.1	2.4	55	76	9.7	13	5.09
Mediterranean, T.S.* 3015-81	10086	5-9	13	26	73	8.6	2.6	50	71	9.3	4	4.91
Mediterranean, T.S.* 5933-34	11526	5-5	14	1	83	10.3	2.5	50	74	9.2	5	4.86
Quiriva	8886	5-1	24	1	87	11.9	2.9	67	90	9.2	4	4.86
Tenmarq x Kawvale, T.S.* 20406	-	5-6	14	19	79	10.3	2.7	58	78	9.2	3	4.81
Early Blackhull	8856	4-27	75	1	85	10.0	2.7	59	80	9.5	4	4.71
Kanred x Kawvale, T.S.* 20408	-	5-9	4	0	87	12.2	2.7	47	81	7.8	0	4.62
Blackhull	6251	5-8	85	1	83	10.3	2.6	46	75	8.3	6	4.58
Leidigh, L-5-6	-	5-9	4	3	83	11.8	2.9	67	85	9.0	8	4.57

Table 4 (continued)

Variety or Strain	C.I. No.**	Date of first head	Per cent Leaf rust	Per cent Stem rust	Plant height in cm.	Length of lower inter-node cm.***	Dia-meter of culm mm.***	Weight of grain from 100 heads	Weight of 100 culms gm.	Weight of 100 8 cm. culm sec-tions	Esti-mated field lodg-ing Per cent	Pounds required to break 5 culms average 20 tests
Beloglina Selection	8885	5-13	74	5	73	11.1	2.7	52	73	8.7	6	4.52
Turkey Selection	10094	5-10	95	0	65	9.4	2.6	36	58	8.3	0	4.51
Minturki	6155	5-12	60	65	75	11.2	2.6	39	71	8.3	0	4.47
Denton Selection S-31-71	-	5-10	39	9	75	11.4	2.8	54	74	9.8	4	4.38
Red May Selection 7250-1	-	5-3	35	19	72	9.2	2.5	50	68	8.2	4	4.38
Kanred	5146	5-10	80	1	80	11.5	2.7	50	72	7.6	4	4.28
Tenmarq	6936	5-7	40	1	81	11.9	2.7	61	74	7.9	3	4.26
Oro	8220	5-10	76	3	81	12.0	2.5	43	67	7.0	0	4.19
Iobred	6934	5-10	58	10	68	9.6	2.6	39	63	8.4	0	4.13
Kanred Selection	10099	5-10	78	0	63	9.4	2.5	38	52	8.1	0	4.13
Nebraska 60	6250	5-13	88	8	74	10.6	2.6	34	64	7.8	0	4.12
Cheyenne	8885	5-10	83	1	78	10.3	2.6	40	61	7.5	0	4.10
Webster x Malakof, T.S.* 20410	-	5-10	25	6	78	10.6	2.6	47	64	6.7	14	4.04
Kharkof	1442	5-12	83	9	76	10.9	2.6	34	64	7.4	6	4.03
Turkey Selection	11375	5-11	95	0	58	8.3	2.4	27	33	7.0	0	3.84

** Accession number of Division of Cereal Crops and Diseases, United States Department of Agriculture
* Accession number of Texas Experiment Station
*** Average of measurements taken on 100 culms
**** (Kanred x Fulcaster) x (Kanred x Hard Federation)

The measurements and notes taken in 1933 include the same ones taken in 1932. In addition data were obtained on weight of culm, weight per unit of culm at the base of the plant, weight of 100 heads, and weight of grain from 100 heads.

An analysis of the variability of the data on breaking strength was made as in 1932. The results of this analysis are given in table 5.

Table 5. Analysis of variance of strength of straw determinations of 44 varieties of winter wheat. 1933.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total variance	879	1,068.087	1.215
Variance between varieties	43	617.146	14.352
Variance within varieties	836	450.941	.539

Standard deviation of a single determination..........	.734
Standard error of the mean of any variety.............	.164
Standard error of a difference between two varieties..	.232
Least significant difference between two varieties....	.486

The varieties were in general stronger strawed in 1933 than in 1932 but the ranking was much the same. A close correlation was found between results in 1932 and 1933 when the same varieties were considered. The experimental error was higher in 1933 than in 1932 as is shown by a comparison of the standard error of the mean of a variety or by the difference necessary to indicate an actual difference in strength of straw between two varieties.

The relationship of morphological characters studied to breaking strength and lodging, has been determined by means of correlation coefficients. The results of these calculations are given in table 6.

From the results of the correlation studies, it is readily seen that a number of morphological characters are closely correlated with strength of straw. Diameter of culm at base of the plant and weight per unit of culm at the base of the plant are very closely related to strength of straw. Weight of grain and height of plant were also significantly correlated with strength of straw. This is no doubt an association of characters since the more productive varieties in any locality are naturally better developed and in this instance taller.

Date of maturity was positively correlated with strength of straw and negatively correlated with field lodging in 1933. Only a small amount of field lodging occurred in 1933 and notes on this lodging showed no relationship to breaking strength. Field lodging was correlated with weight of grain indicating that the more productive varieties were less able to straighten up after storms.

Because of the influence which date of maturity, plant

Table 6. Correlation coefficients for each pair of characters studied in 44 varieties of hard and soft winter wheat. 1933.

		B	C	D	E	F	G	H	I
Breaking strength of straw	A	.348	.025	.004	.903	-.355	.788	.895	.956
Plant height	B		.327	.664	.382	.086	.563	.662	.294
Field lodging	C			.208	.023	-.209	.347	.126	.003
Length of lower internode	D				.266	.267	.250	.292	.078
Diameter of culm at base	E					.023	.896	.964	.887
Date of maturity	F						-.256	-.229	-.353
Weight of grain from 100 heads	G							.871	.814
Weight of 100 culms	H								.869
Weight per unit of culm at base of plant	I								

Breaking strength of straw and leaf rust infection r = -.302
Breaking strength of straw and stem rust infection r = .293

Least significant value of r = .288.
Least highly significant value of r = .372.

height, and length of internode exert on field lodging it was considered desirable to study the influence of the variability of these factors on the correlation of strength of straw and lodging. Partial correlation coefficients were calculated to determine the influence of the variability of the above factors on the correlation of breaking strength of straw and lodging. Thus if 1 = breaking strength, 2 = lodging, 3 = date of maturity, 4 = plant height, 5 = length of lower internode.

$$r_{12.3} = -.005$$

$$r_{12.4} = -.010$$

$$r_{12.5} = .026$$

From the results of these calculations, it would seem that as in 1932, the variability due to these other factors was not important in the correlation of breaking strength and lodging.

Scatter diagrams with regression lines fitted, figures 2 and 3, have been made to show the relationship and high correlation between strength of straw and diameter of culm, strength of straw and weight per unit of culm at the base of the plant.

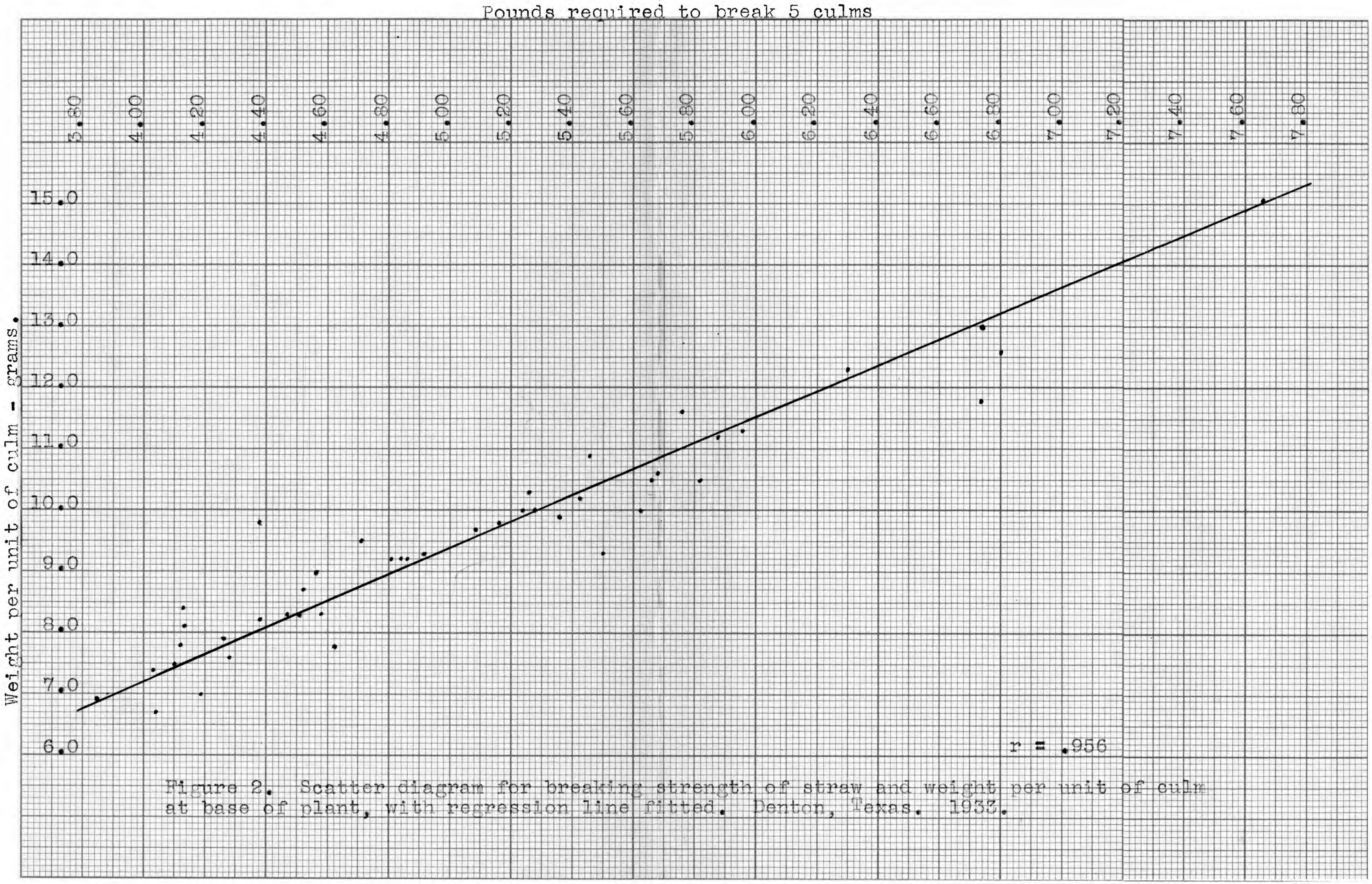

Figure 2. Scatter diagram for breaking strength of straw and weight per unit of culm at base of plant, with regression line fitted. Denton, Texas. 1933.

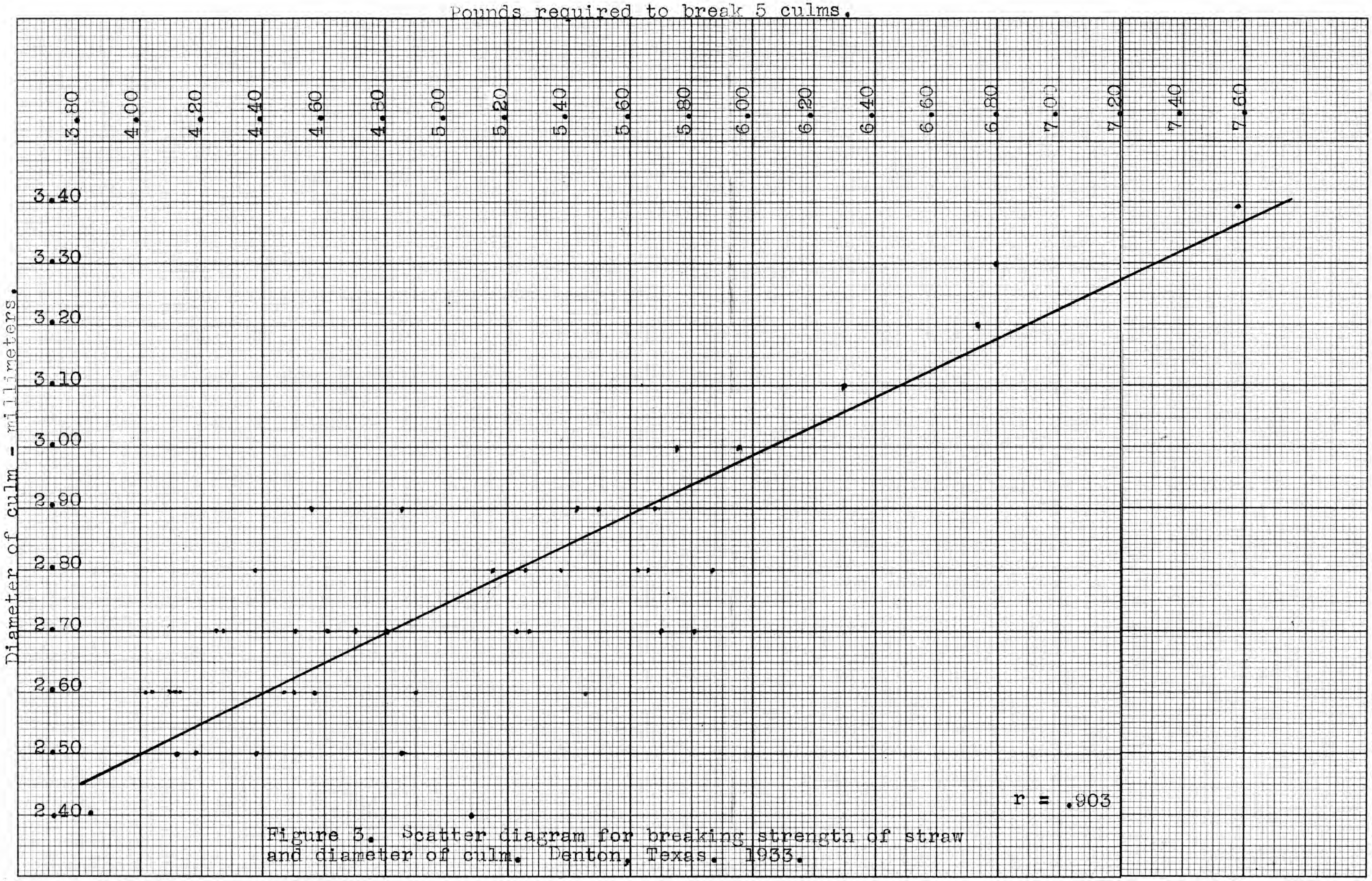

Figure 3. Scatter diagram for breaking strength of straw and diameter of culm. Denton, Texas. 1933.

Results in 1934

In 1934 the study of plant characters in relation to lodging was enlarged to include 129 varieties of hard and soft winter wheats. A few spring wheat varieties were planted but due to winter-killing, followed by replanting they could not be used in the study. The varieties included in the study consisted of nearly all the commercially grown varieties of hard and soft winter wheat. Many of them were poorly adapted to growing at Denton because of susceptibility to leaf and stem rust. This difficulty was a measure overcome by dusting the entire planting with sulfur from the time leaf rust appeared in the spring until near maturity. In this way the rust infection was held so low that it did not materially influence their growth. Considerable rust developed late in the season but it is believed that for the purpose of this experiment the varieties were not appreciable injured. Leaf and stem rust notes were taken and correlation coefficients calculated to determine the influence of these diseases on breaking strength.

No lodging occurred in this experiment as the test was located on rather high ground. Forty four varieties which were studied in 1933 were included in the study in 1934. These varieties were included in the regular replicated yield nursery and data on lodging obtained on them in that planting. The lodging of these 44 varieties was correlated with the plant characters studied.

Notes and plant characters studied and measured were the same as in 1933. In addition, a count of the number of culms at harvest time was made to determine its relationship to breaking strength and plant development. Results for 1934 are given in table 7.

Table 7. Data recorded on 129 varieties of hard and soft winter wheat, 1934.

Variety or Strain	C.I. No.**	Date of first head	Per cent Leaf rust	Per cent Stem rust	Plant ht. in cm.	Stand: culms per 8 foot row	Length of lower inter-node cm.#	Dia-meter of culm mm.#	Weight of grain from 100 heads	Weight of 100 culms gm.	Weight of 100 8 cm. culm sec-tions	Esti-mated field lodg-ing Per cent	Pounds required to break 5 culms Average 20 tests
Nittany	6362	5-2	40	5	88	194	10.1	3.36	69	119	12.9	-	7.52
Red Chief	3392	5-5	75	5	99	198	11.1	3.42	59	112	11.8	-	7.06
Powers Club	8276	5-5	65	10	100	284	12.6	3.36	72	118	10.8	-	6.71
Clarkan	8858	4-30	75	5	101	299	11.0	3.12	60	105	11.4	0	6.62
Longberry No. 1	5823	5-7	45	20	97	183	11.0	3.36	59	103	11.4	-	6.60
Coppei	4238	5-5	75	5	82	263	11.3	3.38	69	97	10.9	-	6.49
Rupert	5920	5-7	60	15	85	168	8.4	3.20	59	101	12.4	-	6.43
Prosperity	5380	5-12	98	45	74	116	9.3	3.24	45	87	11.6	-	6.35
Red Wave	3500	5-5	75	25	98	220	9.7	3.20	60	103	11.3	-	6.35
Arco	8246	4-26	98	10	93	289	13.6	3.96	65	114	11.8	-	6.29
Fultz-Mediterranean	4811	4-30	95	10	81	201	10.0	3.10	54	85	10.3	-	6.20
Rochester	5693	5-5	95	5	89	220	10.8	3.16	45	98	10.3	-	6.20
Walker	6445	4-27	85	0	100	235	10.6	2.96	48	97	10.4	-	6.17
China	180	5-7	95	20	89	276	10.8	3.20	44	94	11.4	-	6.16
Russian	5737	5-2	75	10	106	314	12.3	3.00	58	103	10.4	15	6.16
Dreadnaught	-	4-27	15	0	90	313	10.5	3.32	65	94	11.1	-	6.15
Purkof	8381	5-5	85	5	97	338	10.8	3.12	60	98	10.9	-	6.07
Democrat	3384	5-5	65	15	92	232	11.5	3.12	50	87	9.6	-	6.05
Rural New Yorker No. 6	5921	5-7	50	10	83	150	11.2	3.38	53	86	10.3	-	5.99
Goldcoin	4156	5-4	45	10	97	278	10.3	3.22	46	94	9.9	-	5.97
Genro	11535	5-7	85	30	72	222	8.4	3.30	56	85	10.5	-	5.96
Imperial Amber	5338	5-5	60	10	93	190	10.1	3.20	50	94	11.3	-	5.96
Nabob	8869	5-3	85	5	95	222	12.0	3.06	48	94	10.6	-	5.91
Jones Fife	4466	5-3	98	10	88	246	12.3	3.42	44	90	10.8	-	5.80
Diehl-Mediterranean	1395	5-5	50	5	100	200	10.9	2.92	54	89	9.9	-	5.80
Greeson	6320	4-30	85	T	86	250	10.2	3.00	59	87	9.9	-	5.73
Eaton	4682	5-17	100	20	69	184	9.7	3.32	28	88	11.5	-	5.69
P.1066 x Burbank	10087	4-30	50	5	86	260	9.7	3.10	61	84	10.3	11	5.67
Denton x Kanred, 4-31-28	-	5-3	50	5	104	350	11.5	3.12	61	100	10.0	56	5.66
V.P.I. 131	10047	4-30	85	5	89	216	10.8	2.96	51	82	10.3	-	5.65

Table 7 (continued)

Variety or Strain	C.I. No.**	Date of first head	Per cent Leaf rust	Per cent Stem rust	Plant ht. in cm.	Stand: culms per 8 foot row	Length of lower inter-node cm.#	Dia-meter of culm mm.#	Weight of grain from 100 heads	Weight of 100 culms gm.	Weight of 100 8 cm. culm sec-tions	Esti-mated field lodg-ing Per cent	Pounds required to break 5 culms Average 20 tests
Goens	4857	4-30	75	T	91	282	9.0	2.90	49	71	10.3	-	5.58
Leap	4823	4-23	75	0	85	220	10.6	3.20	57	89	10.3	-	5.55
Honor	6161	4-30	95	10	99	327	9.8	3.10	49	95	10.5	-	5.52
Triplet	5408	5-5	98	5	99	252	11.1	3.42	59	112	11.8	-	5.52
Dawson	3342	4-30	98	5	95	330	8.3	3.14	49	78	10.3	-	5.50
Silvercoin	6013	5-5	45	10	90	268	12.3	3.28	45	91	9.3	-	5.49
Red May	5336	5-2	95	5	79	170	7.6	3.06	38	73	10.2	-	5.43
Gypsy	3436	5-7	85	5	80	174	9.2	2.98	49	72	10.1	-	5.42
Gennessee Giant	1744	4-26	85	10	74	163	9.9	3.14	48	69	9.5	-	5.36
Quivira	8886	4-26	65	T	88	363	10.1	2.90	59	75	9.3	5	5.30
Denton	8265	5-1	34	5	95	335	10.9	2.78	48	83	9.1	8	5.29
Harvest Queen	6199	5-3	85	10	96	290	12.9	3.08	40	81	8.5	1	5.27
Russian Red	5928	5-5	95	25	90	232	10.7	3.18	55	90	10.1	-	5.26
Sol	6009	5-16	65	25	70	178	9.7	3.46	40	89	11.4	-	5.24
Red Clawson	3393	5-2	95	5	86	222	10.7	3.22	50	79	10.1	-	5.24
Mediterranean, T.S.* 5933-23	11525	4-30	5	10	97	290	12.1	2.76	45	80	8.9	4	5.17
Oakley	6301	4-23	75	5	72	192	8.1	2.70	41	69	8.5	-	5.16
Leidigh, L-5-6	-	5-6	5	10	81	242	11.3	2.88	54	68	8.7	50	5.14
Illini Chief	5406	4-30	95	T	85	246	11.0	2.96	46	77	8.9	-	5.12
White Winter	5219	5-17	99	20	77	216	10.1	3.00	37	87	9.2	-	5.11
Mediterranean, T.S.* 3015-63	-	4-30	50	5	100	306	12.6	2.78	47	84	8.3	5	5.08
Portage	5654	5-5	50	10	93	227	11.4	3.20	50	89	9.1	-	5.06
Forward	6691	5-2	55	5	91	276	13.3	2.98	54	82	9.1	-	5.04
Fishhead x Velvet Chaff 51	-	4-17	65	0	70	154	9.6	3.16	73	73	9.6	-	5.04
Odessa	4475	5-5	75	20	86	206	9.9	3.00	48	88	10.5	-	5.02
Mealy	3358	4-30	99	10	91	293	10.5	2.94	51	84	9.6	-	5.02
Berkeley Rock	8272	5-7	75	5	86	242	8.8	2.88	40	75	9.3	-	5.02
Golden	10063	5-6	45	20	81	252	10.8	3.30	45	80	10.1	-	5.02
Currell	3326	4-30	70	5	88	233	10.5	2.98	49	81	9.5	-	5.00
Hybrid 128	4512	5-9	99	20	80	232	7.5	2.96	38	76	9.1	-	4.98

Table 7 (continued)

Variety or Strain	C.I. No.**	Date of first head	Per cent Leaf rust	Per cent Stem rust	Plant ht. in cm.	Stand: culms per 8-foot row	Length of lower inter-node cm.#	Diameter of culm mm.#	Weight of grain from 100 heads	Weight of 100 culms gm.	Weight of 100 8 cm. culm sections	Estimated field lodging Per cent	Pounds required to break 5 culms Average 20 tests
Valley	5923	5-7	85	15	83	209	11.2	2.80	39	74	9.6	-	4.97
Rice	5734	4-18	85	0	79	254	10.6	2.84	50	74	9.4	-	4.95
Tenmarq x Kawvale, T.S.* 20406	-	5-1	20	0	90	354	11.2	2.90	52	74	9.1	8	4.94
Mosida	6688	5-2	99	5	79	240	9.3	2.76	45	71	8.9	-	4.94
Mediterranean, T.S.* 3015-81	10086	4-27	65	5	90	348	9.6	2.66	40	71	8.6	5	4.93
Sutton	10053	5-3	30	10	90	314	11.0	2.80	44	79	8.5	5	4.93
Fishhead x Velvet Chaff 13	-	4-19	65	0	78	182	9.0	3.18	77	90	10.8	-	4.92
Kanred x Fulcaster, T.S.* 20401	-	5-5	10	0	88	356	11.1	2.94	53	71	8.4	3	4.86
Shepherd	6163	4-30	95	T	81	211	9.2	2.88	46	76	9.3	-	4.84
Minturki	6155	5-6	75	0	81	238	9.3	2.64	36	62	8.4	-	4.82
Kinney	5189	5-3	65	10	81	356	9.6	2.76	42	69	8.3	-	4.82
Michikof	6990	5-5	99	15	89	256	10.8	2.70	41	75	8.3	-	4.81
Mediterranean, T.S.* 5933-20	10085	4-26	40	10	83	330	9.8	2.46	38	62	7.5	18	4.81
Red Hart	8898	4-23	85	0	84	270	9.2	2.86	51	76	8.9	-	4.80
Red Indian	8382	5-6	55	5	81	228	10.4	2.86	47	67	8.8	-	4.80
Mammouth Red	2008	5-7	85	15	83	166	9.5	2.84	42	74	9.1	-	4.79
Kofod	4337	5-2	75	10	91	256	11.3	2.80	45	78	8.3	-	4.78
Wheedling	4316	5-5	95	5	80	202	9.2	2.98	42	79	10.1	-	4.75
Fulhio	6999	5-2	85	T	90	206	10.8	2.84	46	79	8.9	-	4.74
Gladden	5644	5-2	65	25	74	206	10.1	2.82	43	65	8.4	-	4.74
White Mediterranean	10023	4-25	99	10	81	284	10.9	2.68	49	69	8.1	44	4.74
Ruby	4873	5-4	85	5	103	271	11.3	3.00	52	88	9.1	-	4.73
Golddrop	6316	4-18	85	5	76	236	10.2	2.64	47	69	8.1	-	4.73
Gasta	11398	4-20	65	0	78	288	9.4	2.54	45	67	8.4	-	4.71
Kanred x Hard Federation	11373	4-27	75	5	80	346	10.2	2.84	49	65	8.3	3	4.71
Sibley 81	10084	5-5	65	5	94	292	10.9	2.80	47	73	8.5	26	4.71
Nigger	5366	5-5	85	5	78	206	9.7	2.94	40	68	8.7	-	4.68
Red Rock	5597	5-3	75	T	87	292	9.3	2.80	42	65	8.5	-	4.65
Mediterranean, T.S.* 5933-34	11526	4-27	40	5	82	362	10.8	2.36	37	58	7.1	16	4.60
Poole	3488	5-5	95	10	90	214	11.7	3.02	39	74	8.2	-	4.56

Table 7 (continued)

Variety or Strain	C.I. No.**	Date of first head	Per cent Leaf rust	Per cent Stem rust	Plant ht. in cm.	Stand: culms per 8 foot row	Length of lower inter-node cm.#	Diameter of culm mm.#	Weight of grain from 100 heads	Weight of 100 culms gm.	Weight of 100 8 cm. culm sections	Estimated field lodging Per cent	Pounds required to break 5 culms Average 20 tests
Kanred Selection	10099	5-5	50	5	81	288	11.4	2.72	50	60	7.5	33	4.54
Cooperatorka	8861	5-2	99	0	81	321	9.8	2.62	35	62	8.1	-	4.49
Minhardi	5149	4-18	75	0	82	230	9.9	2.96	48	75	9.3	-	4.48
Fishhead x Velvet Chaff 47	-	4-17	65	0	73	204	10.3	2.92	68	65	8.9	-	4.47
Kawvale	8180	5-3	15	0	94	370	11.6	2.88	48	76	8.4	1	4.41
T.S.* 20405***	-	4-25	25	5	87	359	12.7	2.78	60	69	7.3	28	4.38
Early Blackhull	8856	4-23	85	2	77	239	9.2	2.50	43	54	7.5	15	4.37
Fultz	1923	4-20	75	0	78	274	11.3	2.80	43	68	8.1	61	4.33
Tenmarq	6936	5-3	70	T	88	333	10.7	2.80	49	69	8.1	21	4.33
Trumbull	5657	5-5	95	5	74	197	10.7	2.72	40	65	7.6	-	4.32
Fulcaster	6471	5-3	60	10	89	284	11.2	2.52	42	64	6.9	6	4.32
Flint	6307	4-20	75	0	85	315	11.4	2.84	48	74	7.8	0	4.31
Purplestraw	1915	4-19	95	0	72	322	9.4	2.38	42	56	7.7	-	4.28
Ridit	6703	5-3	99	5	90	292	11.4	2.60	39	68	7.0	-	4.27
Mediterranean, T.S.*3015-105-1	-	4-29	20	5	95	344	10.6	2.80	48	73	7.9	18	4.26
Zimmerman	2907	4-18	65	0	79	244	9.7	2.78	44	69	8.3	-	4.23
Fulhard	8257	5-5	99	0	79	282	9.4	2.68	37	57	7.8	4	4.22
Webster x Malakof, T.S.*20410	-	5-5	40	0	102	295	13.5	2.88	53	74	7.8	78	4.20
Ashkof	6680	5-8	65	5	77	232	11.0	2.72	33	57	7.5	-	4.12
Beloglina Selection	8884	5-9	60	0	77	312	11.1	2.52	45	56	6.4	31	4.11
White Odessa	4655	5-7	95	10	78	272	10.4	2.62	30	60	7.3	-	3.99
Mediterranean, T.S.* 3015-72	11567	4-29	45	5	91	334	11.3	2.22	40	63	7.3	10	3.97
Windsor	5915	5-2	85	30	61	228	7.0	2.74	31	51	7.6	-	3.95
Iobred	6934	5-7	99	10	80	243	11.7	2.66	30	57	7.1	-	3.94
Blackhull	6251	5-2	85	5	84	352	9.8	2.52	34	59	6.9	26	3.88
Cheyenne	8885	5-6	85	T	71	310	10.3	2.68	36	49	7.1	8	3.86
Kanred	5146	5-6	60	0	89	354	12.1	2.62	43	62	6.3	73	3.82
Alton	1438	5-7	99	10	85	308	11.8	2.60	39	61	6.6	13	3.79
Ashland	6692	5-5	95	T	78	266	10.9	2.60	32	55	7.1	-	3.78
Prohibition	4068	5-8	85	T	65	283	14.8	3.22	36	66	9.3	-	3.77

Table 7 (continued)

Variety or Strain	C.I. No.**	Date of first head	Per cent Leaf rust	Per cent Stem rust	Plant ht. in cm.	Stand: culms per 8 foot row	Length of lower inter-node cm.#	Diameter of culm mm.#	Weight of grain from 100 heads	Weight of 100 culms gm.	Weight of 100 8 cm. culm sections	Estimated field lodging Per cent	Pounds required to break 5 culms Average 20 tests
Oro	8220	5-6	85	T	71	276	10.3	2.48	37	47	6.4	-	3.76
Nebraska 60	6250	5-7	98	T	73	244	10.0	2.52	36	49	6.2	16	3.69
Sherman	4430	5-8	98	5	70	276	11.2	2.48	32	46	6.0	-	3.57
Wisconsin Pedigree No.2	6683	5-7	98	T	78	272	9.2	2.54	27	51	6.5	-	3.51
Turkey	1558	5-8	85	T	67	332	8.5	2.38	34	40	6.1	-	3.48
Nebraska 28	5147	4-15	85	0	66	297	9.8	2.44	39	48	6.8	0	3.48
Huston	5208	4-23	99	5	66	259	8.9	2.36	27	40	6.3	-	3.36
Early Kanred	-	4-14	85	0	67	298	9.3	2.20	38	42	6.6	-	3.30
Kharkof	1442	5-6	85	0	70	292	11.4	2.36	32	42	5.1	26	3.21

* Accession number of the Texas Experiment Station

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*** (Kanred x Fulcaster) x (Kanred x Hard Federation)

\# Average of measurements taken on 100 culms.

An analysis of the variability of the data secured on strength of straw was made by the analysis of variance method as in 1932 and 1933. The analysis is given in table 8.

Table 8. Analysis of variance of strength of straw determinations of 129 varieties of winter wheat. 1934.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total variance	2579	3,106.018	1.204
Variance between varieties	128	1,886.830	14.741
Variance within varieties	2451	1,219.188	.497

Standard deviation of a single determination......... .705
Standard error of the mean of any variety............ .158
Standard error of a difference between two varieties. .223
Least significant difference between two varieties... .467

The range in strength of straw was greater in 1934 than in any other season due to the large number of varieties included. Nittany, C.I. 6362 ranked first in strength of straw requiring 7.52 pounds to break 5 culms. Kharkof was the weakest variety requiring only 3.21 pounds to break 5 culms. The variability of the data was somewhat similar to that in 1933. The experimental error or the standard error of the mean of any variety was .158 pounds while the least difference that could be considered an actual varietal difference was .467 pounds.

The variability of the measurements of morphological characters was not determined as in many instances only one determination was made for each variety. For example 100 culms were weighed at once, while for diamter of culm 5 culms were measured at once and from the average of 20 such measurements, the average diameter for the variety was calculated.

Correlation coefficients were calculated for each pair of characters studied and are given in table 9. The relationships found were in close agreement with those obtained in 1933. In a number of instances the results did not agree possibly due to the fact that a much larger number of varieties were studied. Very high correlation was found as in 1933 between breaking strength and diameter of culm at the base, and between breaking strength and weight per unit of culm at the base of the plant. The correlation of breaking strength and lodging is the highest found in any one season and although it is not quite high enough to be considered statistically significant, it does indicate relationship. It will be noted that the lodging in the 1934 season was quite severe for the group of varieties noted. Breaking strength of straw as well as weight of culm, diameter of culm and weight per unit of culm were all negatively corre-

Table 9. Correlation coefficients for each pair of characters studied in 129 varieties of hard and soft winter wheat, Denton, Texas. 1934.

		B	C	D	E	F	G	H	I	J
Breaking strength of straw	A	.542	-.196	-.411	.789	.152	.544	.901	.911	-.330
Height of plant	B		.056	.435	.423	.129	.142	.672	.431	.296
Lodging in the field*	C			.351	-.001	.178	.158	-.575	-.210	-.039
Length of lower internode	D				.249	.114	-.183	.229	-.010	.342
Diameter of culm at base	E					.238	.324	.811	.868	-.396
Date of maturity	F						-.478	.153	.143	-.213
Weight of grain from 100 heads	G							.648	.524	-.433
Weight of 100 culms	H								.893	-.317
Weight per unit of culm at base	I									-.518
Stand- culms per 8 foot row	J									

Correlation of breaking strength and leaf rust r = .355
Correlation of breaking strength and stem rust r =-.330

Least significant value of r = .195
Least highly significant value of r = .254

* Correlation coefficients for lodging calculated from 40 varieties. Least significant value of r = .304

lated with stand as no doubt would be expected. The stand in this instance is a reflection of the natural stooling ability of the varieties and not due to a difference in number of plants planted per row.

The relationship of plant characters other than breaking strength of straw were about the same as in 1933. Height was most closely related to weight of culm, length of internode, and strength of straw. Diameter of culm at the base was closely correlated with weight of culm, and weight per unit of culm at the base of the plant. For the current season date of maturity was closely related to productiveness as indicated by yield of grain from 100 heads. The relationship or correlation was negative indicating that the highest yields were produced by the earlier varieties. Lodging was not correlated with date of maturity as it was in 1933.

Because of the extremely high correlation, .789 , between strength of straw and diameter of culm at the base; and between breaking strength and weight per unit of culm at the base of the plant, .911 , it was considered desirable to show this relationship graphically. Scatter diagrams with regression lines fitted to show relationship of the above characters are given in figures 4 and 5.

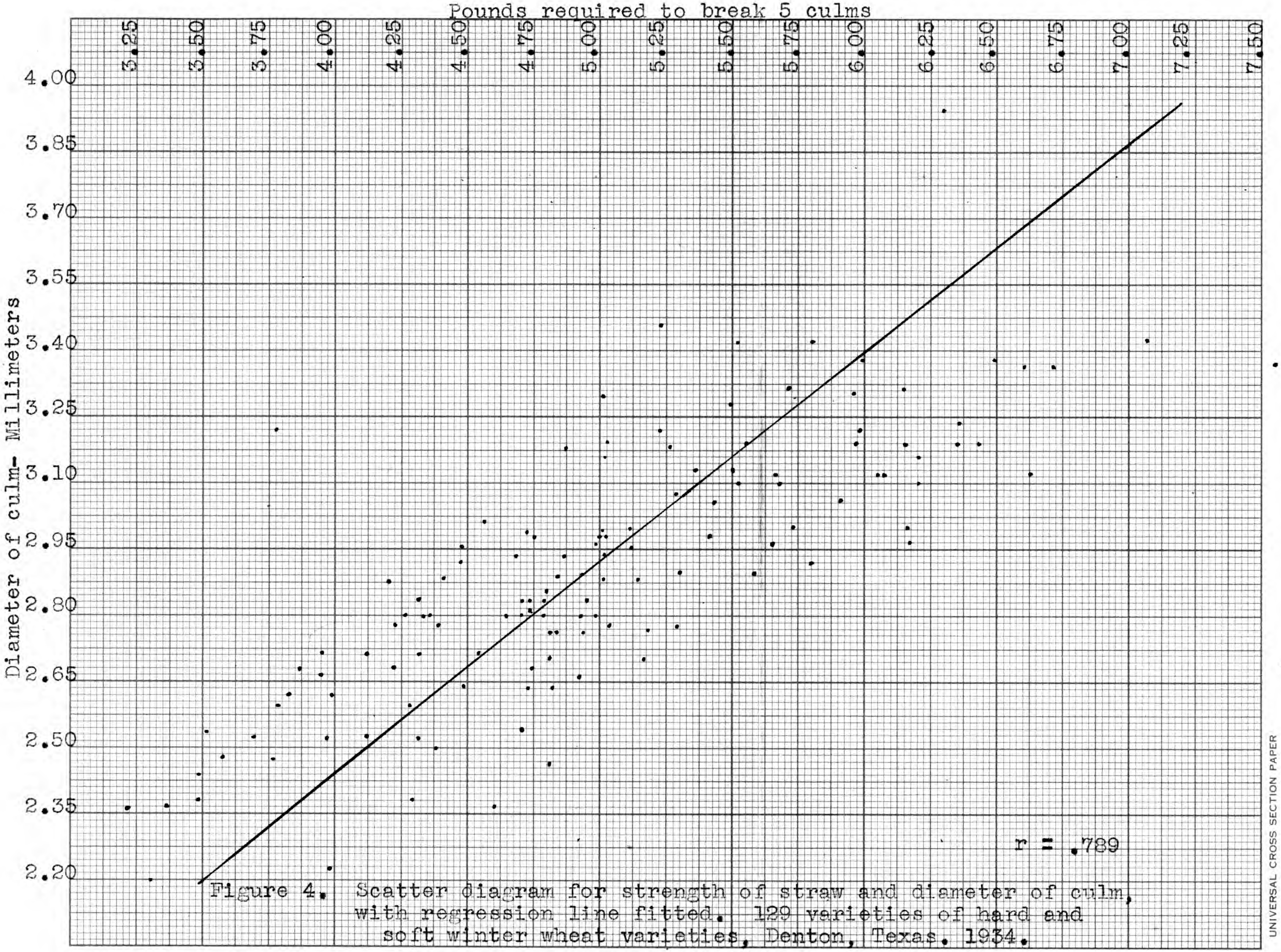

Figure 4. Scatter diagram for strength of straw and diameter of culm, with regression line fitted. 129 varieties of hard and soft winter wheat varieties, Denton, Texas. 1934.

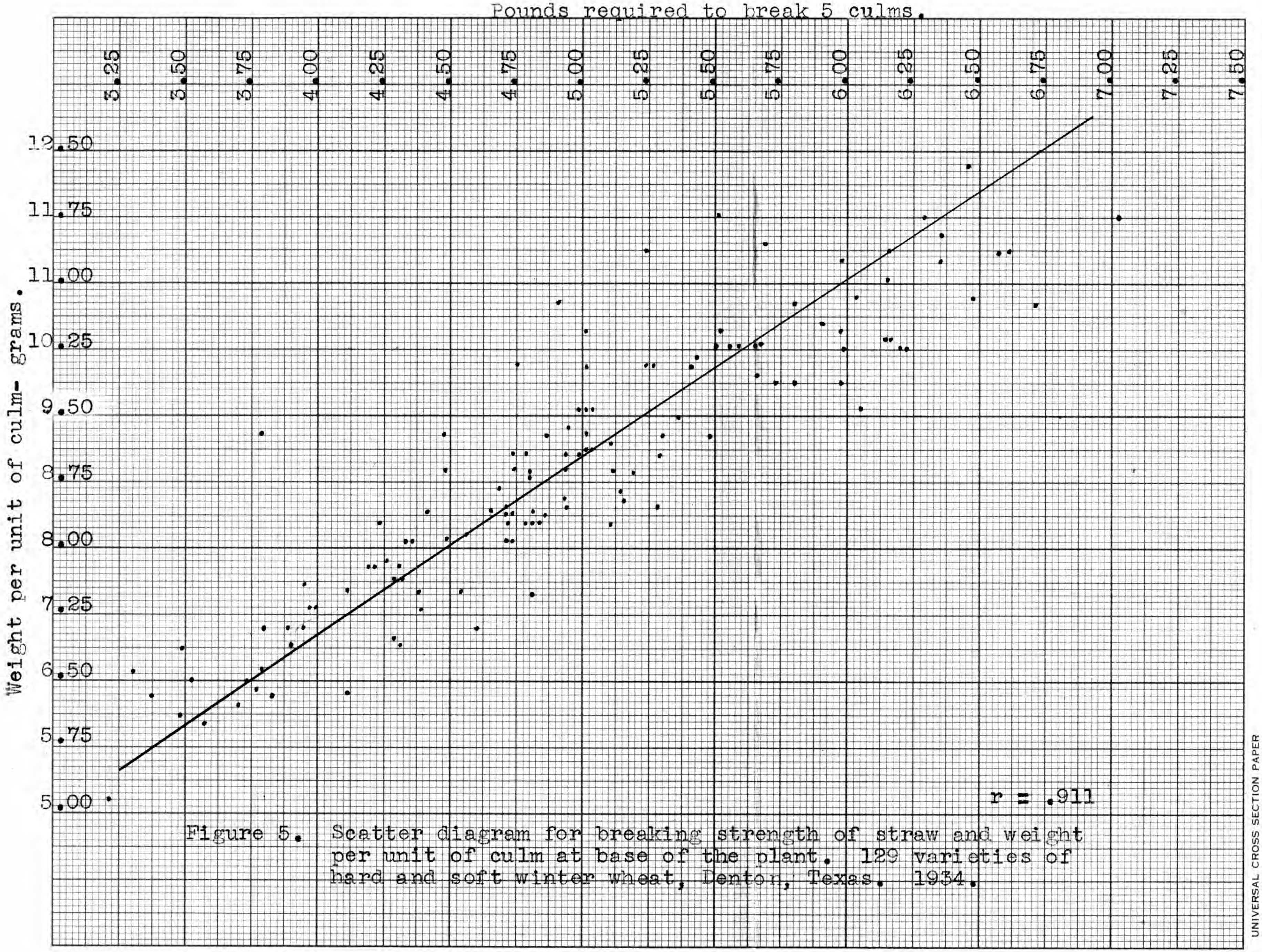

Figure 5. Scatter diagram for breaking strength of straw and weight per unit of culm at base of the plant. 129 varieties of hard and soft winter wheat, Denton, Texas. 1934.

To determine the importance of the variability of certain characters on the correlation of breaking strength and lodging, the variability due to these factors was removed by means of partial correlation coefficients. Thus if 1 = breaking strength, 2 = field lodging, 3 = height of plant, 4 = length of lower internode, and 5 = date of maturity then the correlations were as follows.

$r_{12.3} = -.270$

$r_{12.4} = -.061$

$r_{12.5} = -.229$

$r_{12.34} = -.011$

$r_{12.35} = -.291$

$r_{12.45} = -.110$

From the results obtained it was found that by removing the variability due to height of plant the correlation of breaking strength and lodging was increased from -.196 to -.270. By removing the variability due to date of maturity the correlation of breaking strength and lodging was increased from -.196 to -.229. By removing the variability of the two factors, date of maturity and height, the correlation of breaking strength and field lodging was increased from -.196 to -.291. This correlation is very close to the value of correlation which is considered significant, .304.

Interannual Correlations, 1931 to 1934 Inclusive

Interannual correlation coefficients of breaking strength have been calculated for the years 1931 to 1934 inclusive. The results of these calculations are given in table 10. In 1931 only 18 varieties were grown and tested. These are correlated with the same varieties in other years. In 1932 thirty three varieties were grown and tested while in 1933 and 1934 thirty nine varieties were common to both years. In general the results correlate very well, the correlation coefficients being well above the minimum significant value in each comparison. For 18 varieties as in 1931 comparisons, a value of .561 is necessary in order to obtain odds of 99 to 1. In 1932 when 33 varieties were compared a value of .418 is the minimum, while in 1933 and 1934 with 39 varieties a minimum value of .392 is necessary.

Table 10. Interannual correlation coefficients of breaking strength of straw for the years 1931 to 1934 inclusive.

	1932	1933	1934
1931	.854±.043	.733±.074	.632±.095
1932		.756±.050	.816±.039
1933			.533±.077

RELATIONSHIP OF STRENGTH OF STRAW AND WEIGHT PER UNIT LENGTH OF CULM AT BASE OF PLANT TO LODGING.

From the analysis of the data for individual years, it was found that under the conditions of this experiment, no close correlation was secured for a single season between strength of straw or weight per unit length of culm and lodging notes taken in the field. The lack of correlation might be expected because of the many factors which influence lodging in the field.

Lodging of small grains may be caused by any one or a combination of several factors, among the more important of which are high natural fertility of the land, application of commercial fertilizers, abundant or excessive precipitation during the growing season, wind storms at various stages of maturity, diseases, and inherent varietal susceptibility to lodging. Because of these many factors which might influence lodging in any one season, it was considered desirable to obtain as many observations as possible on the resistance or susceptibility to lodging of each variety studied. Only in this way could an accurate evaluation of the resistance to lodging of a variety be obtained.

The cooperation of a number of Experiment Stations was secured in compiling as much data as possible for each variety. Data was secured from several stations but only a small amount of the data could be used because only a few varieties were grown in common by a number of stations (a). In combining data on lodging from several stations it is necessary to assume that in general a variety will react the same wherever it is grown. That varieties do react in this manner is indicated by the fact that a correlation of .787 was found between breaking strength results obtained at Denton, Texas and results obtained with similar varieties at Manhattan, Kansas.

At the Kansas Experiment Station, strength of straw determinations have been made on varieties of winter wheat included in the field plot tests each year since 1926. Lodging of a differential character has occurred in six years during that period. In the other years no lodging occurred in any variety. Nine varieties have been tested throughout this period. For these nine varieties a correlation of -.644 was obtained between breaking strength and

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a. Thanks are due the following persons and stations for permission to use unpublished data on lodging.
Mr. H.H. Laude and Dr. J.H. Parker of the Kansas Agricultural Experiment Station.
Mr. Howard B. Sprague of the New Jersey Agricultural Experiment Station.
Mr. O.H. Vogel, Division of Cereal Crops and Diseases, United States Department of Agriculture and the Washington Agricultural Experiment Station.
Mr. R.W. Woodward, Division of Cereal Crops and Diseases, United States Department of Agriculture and the Utah Agricultural Experiment Station.

lodging in the field. For the five year period 1930 to 1934 inclusive, 14 varieties have been grown each year and differential lodging occurred in three years of the five. For this period a correlation of -.276 was found between breaking strength of straw and lodging in the field. This indicates as suggested previously, that lodging observations for one season or for short periods are subject to considerable inaccuracies. Numerous varieties were tested for short periods at the Kansas Station. The data on lodging and breaking strength for all years and including all varieties was recalculated using all the data in years when there was differential lodging. Each determination was used as a separate item disregarding the varietal factor. By this method a correlation of -.323 was found between strength of straw and lodging in the field.

In table 11 data on lodging behavior of 39 varieties of hard and soft winter wheat is presented. This table combines observations made at New Brunswick, New Jersey; Manhattan, Kansas; and Denton, Texas. The data from Manhattan, Kansas and Denton, Texas include both field plot and nursery tests. Since the varieties were not all tested every season at each place, the data were summarized and expressed in per cent of Kanred, a variety common to all tests. This expression of the lodging behavior of a variety

Table 11. Field lodging of selected wheat varieties at three Experiment Stations, compared with breaking strength of straw and weight per unit length of culm at Denton, Texas.

Variety or strain	C.I. No.**	New Jersey Expt. Sta. 1928	Estimated field lodging, Denton, Texas, Per cent: Nursery test 1931	1932	1933	1934	Field plat test 1931	1932	1933	1934	Estimated field lodging, Manhattan, Kansas, Per cent: Nursery test 1927	1928	1929	1930	1931	1932	Field plat test 1927	1928	1929	1930	1931	1932	Average	Average Kanred for same years	Per cent of Kanred	Breaking strength Average 1933-34	Weight per unit of culm Average 1933-34
Clarkan	8858	-	1	0	1	0	-	-	0	3	-	-	35	45	55	18	-	-	-	-	32	50	20.0	46.8	42.7	6.71	12.0
P. 1066-1 x Burbank	10087	-	-	9	3	11	-	-	-	-	-	-	-	-	50	15	-	-	-	-	-	-	17.6	46.2	38.1	6.67	12.7
Harvest Queen	6199	10	1	1	0	1	4	3	0	6	77	18	54	58	50	23	1	0	9	3	10	53	18.2	40.4	45.0	6.01	10.2
Denton x Kanred Sel. 4-31-28	-	-	-	-	18	56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	37.0	38.5	96.1	5.58	9.7
Mediterranean T.S.* 5933-23	11525	-	1	10	3	4	-	9	0	4	-	-	-	-	-	-	-	-	-	-	-	-	4.4	24.0	18.3	5.57	10.1
Mediterranean T.S.* 3015-63	-	-	4	9	3	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.3	29.3	18.1	5.36	9.2
Mediterranean T.S.* 3015-105-1	11587	-	1	21	1	18	-	-	0	6	-	-	-	-	-	-	-	-	-	-	-	-	7.8	23.8	32.7	5.28	10.1
Denton	8265	-	4	9	4	8	8	2	0	3	-	-	-	-	-	-	-	-	-	-	-	-	4.8	22.4	21.4	5.27	9.6
Sibley No. 81	10084	-	-	18	1	26	-	-	-	-	-	-	-	-	-	23	-	-	-	-	-	-	15.0	39.3	38.2	5.27	9.5
Sutton	10023	-	4	13	3	5	4	19	0	6	-	-	-	-	-	-	-	-	-	-	-	-	6.8	22.4	30.4	5.16	9.2
Quivira	8886	-	2	9	4	5	8	11	0	5	46	37	67	83	85	22	-	1	18	0	10	2	21.8	41.4	52.7	5.08	9.3
Fulhard	8257	-	-	-	2	4	-	-	-	-	-	34	88	84	43	6	-	-	-	-	-	-	37.3	61.6	60.6	5.05	9.5
T.S.* 20405 ****	-	-	-	-	19	28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23.5	38.5	61.0	5.04	9.0
Kanred x Fulcaster, Ks. R.N. 93	-	-	2	3	0	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	29.3	6.8	5.01	9.1
White Mediterranean	10053	-	-	10	3	44	-	21	0	11	-	-	-	-	-	-	-	-	-	-	-	-	14.8	27.2	54.4	5.01	9.1
Fulcaster	6471	40	2	8	3	6	4	24	0	9	72	35	82	68	67	-	8	0	19	7	17	35	25.3	40.2	62.9	4.99	8.7
Kanred x Hard Federation	11373	-	-	4	18	3	-	-	-	-	-	5	72	81	68	12	-	-	-	-	-	19	31.3	58.0	54.0	4.99	9.3
Mediterranean T.S.* 5933-20	10085	-	6	13	13	18	-	10	0	11	-	-	-	-	-	-	-	-	-	-	-	-	10.1	24.0	42.1	4.95	8.6
Mediterranean T.S.* 3015-81	10086	-	7	33	4	5	2	9	0	13	-	-	-	-	-	-	-	-	-	-	-	-	9.1	22.4	40.6	4.92	9.0
Kawvale	8180	-	1	1	0	0	1	0	0	1	-	25	75	83	70	12	10	0	10	10	0	17	16.6	41.5	40.0	4.92	9.3
Red May Sel. T.S.* 7250-1	-	-	2	9	4	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.0	29.3	17.1	4.91	9.2
Tenmarq x Kawvale, T.S.* 20406	-	-	-	-	3	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.5	38.5	14.3	4.88	9.2
Leidigh L-5-6	-	-	-	-	8	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29.5	38.5	76.6	4.86	8.9
Mediterranean T.S.* 5933-34	11526	-	5	9	5	16	-	19	0	8	-	-	-	-	-	-	-	-	-	-	-	-	8.9	24.0	37.1	4.73	8.2
Mediterranean T.S.* 3015-72	11567	-	5	39	9	10	26	21	0	-	-	-	-	-	-	-	-	-	-	-	-	-	15.7	21.9	71.7	4.72	9.1
Minturki	6155	-	-	-	-	-	-	-	-	-	72	0	0	27	-	6	-	-	-	-	18	12	19.3	67.6	28.6	4.65	8.4
Nebraska No. 28	5147	-	4	0	0	0	3	0	0	-	61	31	63	-	-	-	-	-	-	-	-	-	16.2	37.1	43.7	4.60	8.6

Table 11 (continued)

Variety or strain	C.I. No.**	New Jersey Expt. Sta. 1928	Estimated field lodging, Denton, Texas, Per cent: Nursery test 1931	1932	1933	1934	Field plat test 1931	1932	1933	1934	Estimated field lodging, Manhattan, Kansas, Per cent: Nursery test 1927	1928	1929	1930	1931	1932	Field plat test 1927	1928	1929	1930	1931	1932	Average	Average Kanred for same years	Per cent of Kanred	Breaking strength Average 1933-34	Weight per unit of culm Average 1933-34
Early Blackhull	8856	-	4	2	4	15	15	-	0	8	-	35	93	75	-	30	-	7	21	7	23	48	24.2	37.3	64.9	4.54	8.5
Kanred Selection	-	-	-	28	T	33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.3	37.3	54.4	4.34	7.8
Beloglina Selection	8884	-	-	35	6	-	-	-	-	-	-	-	-	50	80	28	-	-	-	-	-	-	39.8	50.2	79.3	4.32	7.6
Tenmarq	6936	-	2	13	3	21	4	10	0	6	69	28	81	86	58	11	9	1	15	0	3	38	22.9	40.0	57.3	4.30	8.0
Blackhull	6251	40	6	20	6	26	3	19	0	13	76	27	84	89	75	45	15	7	26	11	8	87	32.5	40.4	80.4	4.23	7.6
Webster x Malakof, T.S.* 20410	-	-	-	-	14	78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	46.0	38.5	119.5	4.12	7.3
Kanred	5146	50	5	35	4	73	11	25	0	26	76	53	89	93	74	45	13	17	36	7	36	81	40.4	-	-	4.05	7.0
Iobred	6934	-	-	-	0	-	-	-	-	-	-	70	0	40	-	-	-	-	-	-	-	-	27.5	59.8	45.9	4.04	7.8
Cheyenne	8885	-	-	6	0	8	-	-	-	-	-	-	-	78	48	10	-	-	-	0	12	17	19.9	49.8	40.0	3.98	7.3
Oro	8220	-	-	6	0	-	-	-	-	-	-	22	79	79	83	6	0	3	6	7	38	55	29.5	44.8	65.8	3.98	6.7
Nebraska No. 60	6250	-	1	19	0	16	5	20	0	9	70	0	60	-	48	22	-	-	-	-	8	58	22.4	42.2	53.1	3.91	6.3
Kharkof	1442	-	4	10	6	26	5	25	0	29	72	22	78	77	82	23	1	4	34	10	23	42	28.7	40.0	71.8	3.62	7.0

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**** (Kanred x Fulcaster) x (Kanred x Hard Federation).

was then compared with the 2 year average of strength of straw determinations made at Denton, Texas. A correlation of -.371 was obtained between field lodging, taken as above reported, and breaking strength at Denton, Texas. By using only 33 varieties given in this table the comparison can then be made with a 3 year average of breaking strength. In this case the correlation is -.419. These correlations are both highly significant according to Fisher's (15) table of "Values of the correlation coefficient for different levels of significance".

In table 12 data on lodging behavior of 16 varieties of wheat grown at Pullman, Washington; Logan, Utah; Newton, Utah; and New Brunswick, New Jersey are presented in comparison with breaking strength and weight per unit of culm obtained on the same varieties at Denton, Texas. The data are summarized in terms of a common variety, Hybrid 128, C.I. 4512. A correlation of -.636 was obtained between lodging behavior of these varieties at these stations and breaking strength of straw at Denton, Texas. Although the number of varieties for which data is presented in table 12 is low the correlation is statistically significant. As in table 11 the data indicate that there is a relationship of between strength of straw and lodging behavior.

Table 12. Lodging of wheat varieties at selected stations in western United States compared with strength of straw at Denton in 1934.

Variety	C.I. No.	Agri. Expt. Sta., Pullman, Washington									Utah Agri. Expt. Sta.								New Brunswick: New Jersey		Average of: Hybrid 128:	Per cent of	Number years	Denton, Texas, 1934	
		variety test				nursery test					Logan, Utah				Newton, Utah									Breaking strength	Weight per unit
		1931	1932	1933	1934	1930	1931	1932	1933	1934	1931	1932	1933	1934	1931	1932	1933	1934	1928	Average	same years	Hybrid 128	compared	of straw	of culm - gms.
Coppei	4238	0	0	0	-	0	1	7	0	-	-	-	-	-	-	-	-	-	5	1.6	1.8	88.9	8	6.49	10.9
Goldcoin	4156	-	-	-	-	-	-	-	-	-	16	12	20	8	-	-	-	-	5	12.2	12.2	100	5	5.97	9.9
Jones Fife	4466	0	14	2	49	3	3	4	2	100	-	-	-	-	-	-	-	-	-	19.7	23.3	84.5	9	5.80	10.8
Triplet	5408	0	2	2	55	3	3	4	2	100	15	23	17	13	15	23	17	13	20	18.2	17.4	104.6	18	5.52	11.8
Silvercoin	6013	-	-	-	-	-	-	-	-	-	16	10	17	8	-	-	-	-	10	12.2	12.2	100.0	5	5.49	9.3
White Winter	5219	-	-	-	-	-	0	0	1	-	-	-	-	-	15	15	17	-	-	8.0	7.2	111.1	6	5.11	9.2
Odessa	4475	-	-	-	-	-	-	-	-	-	21	25	22	-	-	-	-	-	30	24.5	13.3	184.2	4	5.02	10.5
Golden	1003	-	2	0	100	0	6	8	0	100	17	20	8	-	-	17	20	8	-	21.9	20.3	107.9	14	5.02	10.1
Hybrid 128	4512	1	2	0	97	0	0	0	1	100	17	7	19	8	10	13	19	9	10	17.4	-	100	18	4.98	9.1
Mosida	6688	-	-	-	-	1	0	13	2	98	-	-	-	-	-	-	-	-	20	22.3	18.5	120.5	6	4.94	8.9
Ridit	6703	4	3	2	100	0	1	17	2	100	16	18	20	15	17	18	20	15	20	21.6	17.4	124.1	18	4.27	7.0
White Odessa	4655	-	-	-	-	3	0	9	2	100	22	16	17	-	-	-	-	-	5	24.1	22.0	109.5	7	3.99	7.3
Oro	8220	-	-	-	-	4	19	12	0	100	24	13	30	15	25	-	30	15	-	23.9	15.8	151.2	12	3.76	6.4
Nebraska No. 60	6250	1	3	0	-	-	-	6	0	-	-	-	-	-	-	-	-	-	-	2.0	.8	250.0	5	3.69	6.2
Sherman	4430	-	-	-	-	-	-	-	-	-	30	23	30	-	28	23	30	-	20	26.2	13.6	192.6	7	3.57	6.0
Kharkof	1442	1	9	1	100	6	0	11	1	100	25	23	30	20	25	23	30	20	-	25.0	17.8	140.4	17	3.21	5.1

In table 13 data on lodging, strength of straw, and weight per unit of culm at the base of the plant for the period 1931 to 1934 inclusive at Denton, Texas are given. Averages for 18 varieties are given for the four year period and for the two year period 1933-1934, averages for 36 varieties are given. The greatest amount of lodging occurred in 1932 and in 1934 although small differences are noted for the other years. Comparing 18 varieties for the four year period, a correlation of -.626 was found between breaking strength and lodging. This correlation is sufficiently high to be significant although the number of varieties is small. For the two year period 1933-1934, a correlation of -.387 was found between strength and lodging with 36 varieties. This is highly significant.

From the results presented above it is apparent that there is a definite correlation between breaking strength of straw and lodging behavior of wheat varieties in the field. Although the correlation for a single year was not significant, with the possible exception of 1934, data for a period of years or data combined from a number of stations showed a significant correlation of breaking strength and lodging behavior. The correlation coefficients obtained in the above studies ranged from -.371 to as high as -.644 and in all cases were highly significant. From these

Table 13. Summary of data on lodging, breaking strength, and weight per unit length of culm for 36 winter wheat varieties grown at Denton, Texas. 1931-1934.

Variety or strain	C.I. No.**	Estimated field lodging 1931	1932	1933	1934	Avg. 1931-1934	Avg. 1933-1934	Breaking strength- Pounds*** 1931	1932	1933	1934	Avg. 1931-1934	Avg. 1933-1934	Weight per unit length of culm grams 1933	1934	Average
Clarkan	8858	1	0	1	0	.5	.5	6.73	6.06	6.80	6.62	6.55	6.71	12.6	11.4	12.0
P. 1066-1 x Burbank	10087	-	9	3	11	-	7.0	-	5.23	7.66	5.67	-	6.67	15.1	10.3	12.7
Harvest Queen	6199	1	1	0	1	.8	.5	6.92	5.89	6.74	5.27	6.21	6.01	11.8	8.5	10.2
Denton x Kanred, Sel. 4-31-28	-	-	-	3	56	-	29.5	-	-	5.50	5.66	-	5.58	9.3	10.0	9.7
Mediterranean T.S.* 5933-23	11525	1	10	3	4	4.5	3.5	5.13	4.44	5.96	5.17	5.18	5.57	11.3	8.9	10.1
Mediterranean T.S.* 3015-63	-	-	9	3	5	-	4.0	-	4.20	5.63	5.08	-	5.36	10.0	8.3	9.2
Mediterranean T.S.* 3015-105-1	11587	1	21	1	18	10.3	10.0	5.07	4.36	6.30	4.26	5.00	5.28	12.3	7.9	10.1
Denton	8265	4	9	4	8	6.3	6.0	5.54	4.70	5.24	5.29	5.19	5.27	10.0	9.1	9.6
Sibley No. 81	10084	-	18	1	26	-	13.5	-	4.76	5.82	4.71	-	5.27	10.5	8.5	9.5
Sutton	10053	4	13	3	5	6.3	4.0	5.93	4.80	5.38	4.93	5.26	5.16	9.9	8.5	9.2
Quivira	8886	2	9	4	5	5.0	4.5	4.97	4.45	4.86	5.30	4.90	5.08	9.2	9.3	9.3
Fulhard	8257	-	5	2	4	-	3.0	-	3.54	5.88	4.22	-	5.05	11.2	7.8	9.5
T.S. 20405 ****	-	-	-	19	28	-	23.5	-	-	5.69	4.38	-	5.04	10.6	7.3	9.0
Kanred x Fulcaster, Ks. R.N.93	-	-	3	0	3	-	1.5	-	4.69	5.16	4.86	-	5.01	9.8	8.4	9.1
White Mediterranean	10023	-	10	3	44	-	23.5	-	4.36	5.28	4.74	-	5.01	10.0	8.1	9.1
Fulcaster	6471	2	8	3	6	4.8	4.5	6.48	4.81	5.66	4.32	5.32	4.99	10.5	6.9	8.7
Kanred x Federation	11373	-	4	18	3	-	10.5	-	3.79	5.26	4.71	-	4.99	10.3	8.3	9.3
Mediterranean T.S.*5933-20	10085	6	13	13	18	12.5	15.5	5.16	3.92	5.09	4.81	4.75	4.95	9.7	7.5	8.6
Kawvale	8180	0	1	0	1	.5	.5	5.57	5.25	5.43	4.41	5.17	4.92	10.2	8.4	9.3
Mediterranean T.S.* 3015-81	10086	7	33	4	5	12.3	4.5	5.16	3.90	4.91	4.93	4.73	4.92	9.3	8.6	9.0
Red May Selection, T.S.* 7250-1	-	-	9	4	-	-	6.5	-	3.90	4.38	5.43	-	4.91	8.2	10.2	9.2
Tenmarq x Kawvale, T.S.* 20406	-	-	-	3	8	-	5.5	-	-	4.81	4.94	-	4.88	9.2	9.1	9.2
Leidigh L-5-6	-	-	-	8	50	-	29.0	-	-	4.57	5.14	-	4.86	9.0	8.7	8.9
Mediterranean T.S.* 5933-34	11526	5	9	5	16	8.8	10.5	4.71	3.90	4.86	4.60	4.52	4.73	9.2	7.1	8.2
Mediterranean T.S.* 3015-72	11567	-	39	3	10	-	6.5	-	3.59	5.46	3.97	-	4.72	10.9	7.3	9.1
Nebraska No. 28	5147	4	0	0	0	1.0	0.0	4.56	3.50	5.71	3.48	4.31	4.60	10.3	6.8	8.6
Early Blackhull	8856	4	2	4	15	6.3	9.5	4.55	4.71	4.71	4.37	4.59	4.54	9.5	7.5	8.5
Kanred Selection	10099	-	28	0	33	-	16.5	-	3.90	4.13	4.54	-	4.34	8.1	7.5	7.8

Table 13 (continued)

Variety or strain	C.I. No.**	Estimated field lodging						Breaking strength- Pounds***						Weight per unit length of culm grams		
		1931	1932	1933	1934	Avg. 1931-1934	Avg. 1933-1934	1931	1932	1933	1934	Avg. 1931-1934	Avg. 1933-1934	1933	1934	Average
Beloglina Selection	8884	-	35	6	31	-	18.5	-	4.03	4.52	4.11	-	4.32	8.7	6.4	7.6
Tenmarq	6936	2	11	3	21	9.8	12.0	4.54	3.93	4.26	4.33	4.52	4.30	7.9	8.1	8.0
Blackhull	6251	6	20	6	26	14.5	16.0	4.86	4.06	4.58	3.88	4.35	4.23	8.3	6.9	7.6
Webster x Malakof, T.S.* 20410	-	-	-	14	78	-	46.0	-	-	4.04	4.20	-	4.12	6.7	7.8	7.3
Kanred	5146	5	35	4	73	29.3	38.5	4.31	3.40	4.28	3.82	3.95	4.05	7.6	6.3	7.0
Cheyenne	8885	-	6	0	8	-	4.0	-	3.87	4.10	3.86	-	3.98	7.5	7.1	7.3
Kharkof	1442	4	10	6	26	11.5	16.0	4.88	3.64	4.03	3.21	3.94	3.62	7.4	5.1	6.3
Nebraska No. 60	6250	-	19	0	16	-	8.0	-	3.66	4.12	3.69	-	3.91	7.8	6.2	7.0

* Accession number of the Texas Experiment Station

** Accession number of the Division of Cereal Crops and Diseases, United States Department of Agriculture

**** (Kanred x Fulcaster) x (Kanred x Hard Federation).

results it appears that breaking strength determinations can be used to predict lodging behavior in the field and for the isolation of lodging resistant strains in a breeding program.

In calculating correlation coefficients of morphological characters in 1933 and 1934 it was observed that weight per unit length of culm near the base of the plant was closely correlated with breaking strength of straw. Considerable time is required to make strength of straw measurements when large numbers of varieties are to be tested. Furthermore there is some personal element involved in the determinations such as the speed at which the weight is released upon the straws. For the above reasons it was considered pertinent to determine whether weight per unit of culm might be substituted for determination of breaking strength as a measure of the lodging resistance of a variety. To determine the applicability of this method, correlation coefficients between weight per unit of culm and lodging behavior as given in tables 11,12, and 13 were calculated.

In table 11 it is possible to correlate lodging behavior with weight per unit of culm for a two year period using 39 varieties of wheat. A correlation of -.416 was obtained when this was calculated which is slightly higher than the correlation of -.371 obtained between breaking strength and lodging for the same data. For the 16 varieties for which data are given in table 12, a correlation of -.570 was found between weight per unit of culm and lodging. The correlation between strength of straw and lodging for the same data was -.636. For the 36 varieties studied at Denton, Texas as reported in table 13, the correlation of weight per unit of culm and lodging was -.411 whereas the correlation of breaking strength and lodging was -.387.

From the above results it seems that weight per unit of culm at the base of the plant is equally as good a measure of lodging resistance as breaking strength. From a practical standpoint it is a better method because it requires much less time in securing data and reduces the personal element to a considerable extent.

INFLUENCE OF RATE OF PLANTING ON STRENGTH OF STRAW AND MORPHOLOGICAL CHARACTERS OF THE PLANT.

The influence of stand upon strength of straw as well as development of the plant was studied in four varieties of wheat. Plantings were made in regular three row nursery plots at the following rates per rod row: 32 grams, 24 grams, 16 grams, 12 grams, 8 grams, and 4 grams. In 1933 plants were spaced 3,6,12,24, and 36 inches apart each way in order to permit in some cases maximum development of the plant. No data was secured from these plantings as a severe freeze reduced the stands to such an extent that the material could not be used. Some reduction in stand took place in the other plantings.

Data on stands in the fall and spring, culms per unit of area at harvest, and certain measurements of the plants are given in tables 14,15, and 16. In 1933 data were recorded at both the soft dough stage of growth and at harvest. In 1934 the data were recorded only at maturity. Stands were reduced somewhat in 1933 but the varieties showed the same trend in both years. Thick planted plots stooled very little so that the average number of culms was low, while the number of culms per plant increased as the rate of planting decreased. All plant characters measured were influenced by the rate of planting. Although date of heading and ripening are not given in the table, thick planting hastened the maturity of the plant while thin seeding delayed the maturity.

Strength of straw was greatly increased by thin seeding. Kanred, which is a weak strawed variety showed a maximum strength of 4.65 pounds for the 4 gram rate while at the 32 gram rate the strength of Kanred was only 2.81 pounds.

From this study it is readily seen that the strength of straw of a variety is greatly influenced by the number of culms per area. The number of culms per unit area may be determined by the amount of stooling or the rate of planting. The factor of stands and culms per unit of area is important in the study of varieties. Varieties which stool heavily may be at a considerable disadvantage when grown and compared with varieties which stool less.

The influence of stand upon breaking strength, diameter of culm, and weight per unit of culm is shown in figure 6. In this figure the four varieties have been combined to show only the effect of stand.

Table 14. The influence of rate of planting upon strength of straw and other characters in four wheat varieties at the soft dough stage. 1933.

Variety	Rate of plant-ing gm.**	Number plants in 3 sq.ft. fall	Number plants in 3 sq.ft. spring	Number culms in 3 sq.ft. harvest	Number culms per plant	Average height head removed cm.***	Weight of 100 culms gm.	Weight of 100 sections of lower internode gm.	Average diameter of culm at base mm.***	Average length lower inter-node cm.***	Pounds required to break 5 culms*
Nebraska No. 28	32	192	118	162	1.4	50	133	6.8	2.18	7.38	3.52
Nebraska No. 28	24	130	102	141	1.4	50	149	8.9	2.16	7.01	4.09
Nebraska No. 28	16	90	70	155	2.2	57	197	10.6	2.45	8.55	4.57
Nebraska No. 28	12	68	27	67	2.5	46	136	9.3	2.34	7.50	3.59
Nebraska No. 28	8	38	18	54	3.0	48	173	11.9	2.59	7.51	4.54
Nebraska No. 28	4	-	-	-	-	-	-	-	-	-	-
Kanred	32	194	140	226	1.6	57	117	6.8	2.00	8.15	2.81
Kanred	24	136	127	178	1.4	63	140	7.4	2.10	9.09	3.17
Kanred	16	88	87	171	2.0	72	236	11.5	2.69	11.26	4.65
Kanred	12	65	62	159	2.6	71	228	11.3	2.66	8.68	4.41
Kanred	8	35	33	103	3.1	64	213	11.1	2.74	7.80	4.45
Kanred	4	18	13	103	7.9	70	279	13.1	2.94	10.10	4.65
Tenmarq	32	134	95	131	1.4	63	174	9.8	2.44	7.81	4.06
Tenmarq	24	114	95	152	1.6	67	196	10.0	2.64	9.11	4.50
Tenmarq	16	66	55	139	2.5	69	225	11.9	2.81	8.77	4.79
Tenmarq	12	54	33	91	2.8	66	234	12.3	2.71	8.00	4.69
Tenmarq	8	35	20	92	4.6	68	258	12.5	3.00	8.53	5.20
Tenmarq	4	19	13	108	8.3	73	342	16.1	3.28	9.38	5.73
Harvest Queen	32	136	87	125	1.4	74	292	14.2	2.84	10.03	5.16
Harvest Queen	24	92	59	108	1.8	73	280	12.6	2.79	9.57	5.11
Harvest Queen	16	79	47	78	1.7	79	339	15.8	3.02	10.76	6.16
Harvest Queen	12	48	33	84	2.5	75	316	14.9	3.03	9.57	5.74
Harvest Queen	8	45	35	76	2.2	71	285	14.1	2.94	9.18	5.80
Harvest Queen	4	24	19	122	6.4	71	480	22.9	3.47	9.64	7.37

* Average of 20 determinations of 5 straws each.
** Rate of planting per 16 foot nursery row.
*** Average of 100 culms.

Table 15. Influence of rate of planting upon strength of straw and other plant characters in four wheat varieties at maturity. 1933.

Variety	Rate of planting gm. ***	Number culms in 3 sq.ft.	Average height culms with head removed cm. **	Weight of 100 culms gm.	Weight of 100 heads gm.	Weight of grain from 100 heads gm.	Weight of 100 sections of lower internode gm.	Average diameter of culm at base mm.**	Average length of lower internode cm.**	Pounds required to break 5 culms*
Nebraska No. 28	32	162	48	36	50.1	26.8	6.7	2.0	9.1	2.92
Nebraska No. 28	24	141	48	41	53.5	28.5	7.7	2.1	7.8	3.44
Nebraska No. 28	16	155	59	63	78.2	47.0	9.6	2.6	10.1	4.44
Nebraska No. 28	12	67	52	53	75.7	49.5	9.6	2.5	9.2	4.10
Nebraska No. 28	8	54	58	64	91.0	54.7	10.2	2.8	9.7	5.13
Nebraska No. 28	4	-	47	57	95.8	54.7	11.5	2.7	7.8	5.72
Kanred	32	226	57	34	49.3	26.3	5.4	2.0	9.8	2.70
Kanred	24	178	67	46	59.5	36.4	6.5	2.2	10.9	3.26
Kanred	16	171	66	63	76.7	45.8	7.6	2.5	12.5	3.92
Kanred	12	159	66	53	73.6	42.9	8.7	2.4	8.4	3.81
Kanred	8	103	78	71	89.3	57.5	8.8	2.8	10.8	5.16
Kanred	4	103	71	69	83.2	46.1	9.2	2.7	9.0	5.03
Tenmarq	32	131	58	43	66.8	39.1	7.1	2.3	10.3	3.32
Tenmarq	24	152	72	67	88.5	54.3	9.2	2.7	10.3	4.49
Tenmarq	16	139	72	66	85.6	56.0	10.6	2.7	8.7	4.47
Tenmarq	12	91	68	63	80.8	53.5	10.3	2.7	8.6	4.54
Tenmarq	8	92	77	81	95.3	54.0	11.1	3.0	9.4	5.83
Tenmarq	4	108	74	88	98.6	50.0	12.5	2.9	8.5	6.18
Harvest Queen	32	125	67	61	58.7	34.1	9.3	2.5	9.4	4.00
Harvest Queen	24	108	79	88	76.1	48.1	10.1	2.7	11.3	5.00
Harvest Queen	16	78	73	84	71.1	48.5	11.8	2.9	8.8	5.42
Harvest Queen	12	84	78	88	82.7	52.5	11.5	2.9	9.3	6.43
Harvest Queen	8	76	78	94	64.3	35.3	12.2	2.9	9.0	6.68
Harvest Queen	4	122	78	111	64.3	28.1	14.5	3.1	8.4	6.58

* Average of 20 determinations of 5 culms each.
** Average of 100 determinations
*** Rate of planting per 16 foot nursery row.

Table 16. Influence of rate of planting upon strength of straw and other plant characters in four wheat varieties at maturity. 1934.

Variety	Rate of planting per 16 ft. row gm.	Number plants per 16 ft. row fall	Number culms per 16 ft. row harvest	Average height culms head removed cm. **	Weight of 100 culms gm.	Weight of 100 sections of lower internode gm.	Weight of 100 heads	Weight of grain from 100 heads gm.	Length of lower inter-node cm.**	Average diameter of culm at base cm.**	Pounds required to break 5 culms*
Nebraska No. 28	32	1140	648	57	37	5.4	43	28	8.3	2.1	2.58
Nebraska No. 28	24	897	614	63	40	6.1	44	29	9.5	2.3	2.79
Nebraska No. 28	16	528	538	62	44	7.1	52	34	8.0	2.4	3.13
Nebraska No. 28	12	372	388	64	49	7.2	59	39	9.1	2.5	3.25
Nebraska No. 28	8	228	454	70	57	7.7	66	45	10.2	2.6	3.49
Nebraska No. 28	4	90	356	69	64	9.6	71	47	8.7	2.7	4.30
Kanred	32	1155	790	80	52	5.5	58	40	11.8	2.4	3.00
Kanred	24	816	772	71	48	5.8	50	35	11.9	2.4	3.03
Kanred	16	570	866	78	53	6.3	58	41	11.4	2.4	3.53
Kanred	12	285	745	80	64	6.9	74	52	12.1	2.6	3.63
Kanred	8	258	714	87	61	6.8	67	48	12.5	2.5	3.61
Kanred	4	93	710	82	74	7.1	76	52	12.2	2.7	3.78
Tenmarq	32	1404	768	74	47	6.5	51	36	9.5	2.2	3.19
Tenmarq	24	708	728	80	68	8.1	72	49	10.0	2.6	4.11
Tenmarq	16	501	855	70	50	7.3	58	40	10.6	2.5	3.57
Tenmarq	12	348	660	88	66	7.5	74	50	10.7	2.5	3.76
Tenmarq	8	291	684	87	76	8.9	88	61	9.9	2.7	4.48
Tenmarq	4	93	554	99	101	9.6	110	77	12.6	2.9	5.05
Harvest Queen	32	909	714	87	74	9.1	52	36	10.8	2.7	4.79
Harvest Queen	24	672	404	85	74	8.6	51	36	11.6	2.7	4.75
Harvest Queen	16	435	628	84	77	8.5	53	39	11.4	2.7	4.68
Harvest Queen	12	336	489	86	83	9.4	52	39	11.9	2.8	4.81
Harvest Queen	8	309	505	85	78	9.4	54	39	9.8	2.8	5.03
Harvest Queen	4	105	309	89	103	10.5	65	46	11.7	3.0	5.14

* Average of 20 determinations of 5 culms each.
** Average of 100 determinations

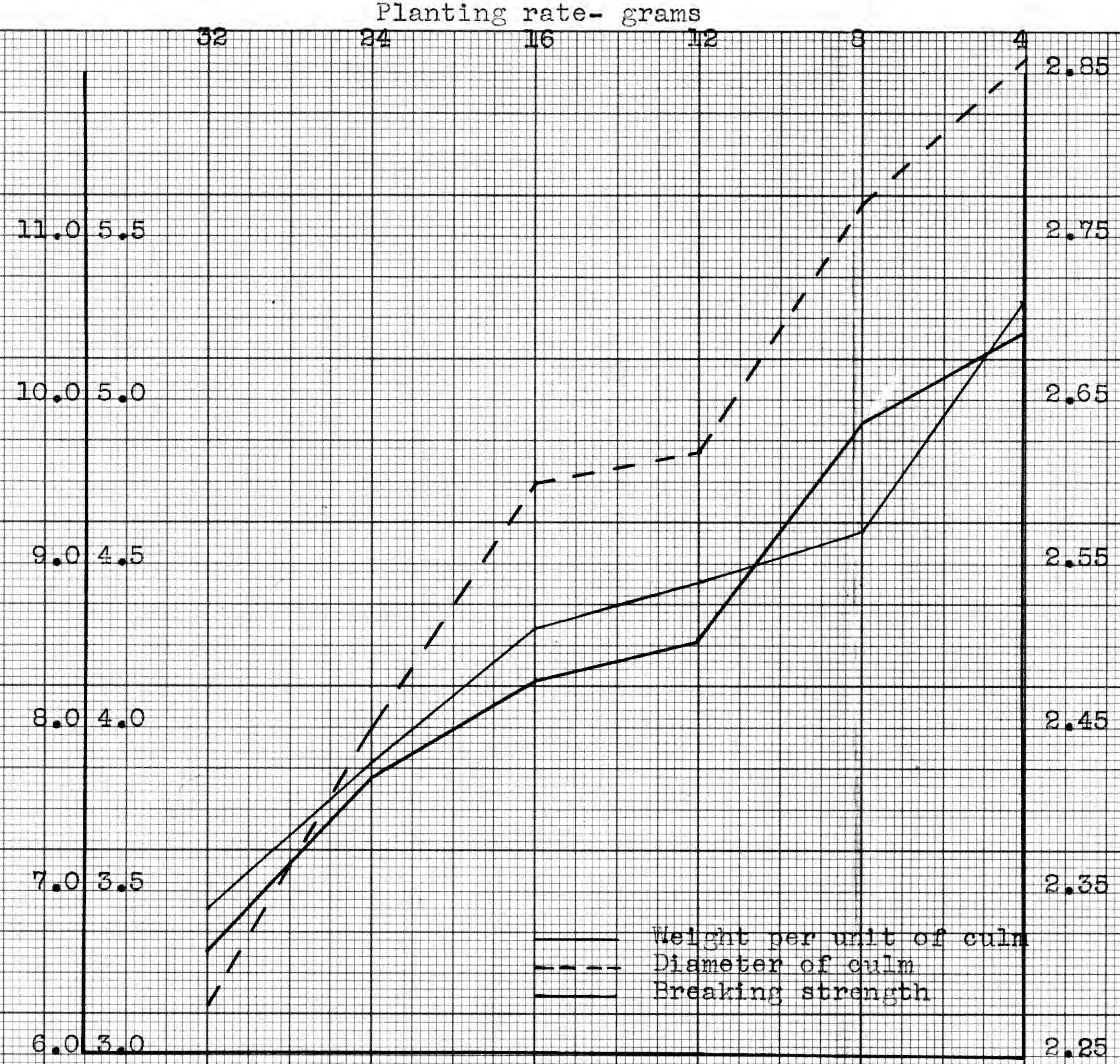

Figure 6. Influence of rate of planting upon breaking strength of straw and plant development. Average of four varieties for 1933 and 1934.

THE INFLUENCE OF FERTILIZERS UPON STRENGTH OF STRAW AND MORPHOLOGICAL CHARACTERS OF THE PLANT.

The economic value of commercial fertilizers and manure for wheat has been studied for several years at Texas Substation No.6, Denton, Texas. This test provided the opportunity of studying the influence of these fertilizers upon lodging of grain and strength of straw. Previous observations in this test showed that high applications of barnyard manure as well as high applications of nitrogen or a complete fertilizer produced increased vegetative growth, especially early in the season. This increased vegetative growth was usually accompanied by increased lodging as shown in figure 7.

The influence of fertilizers on the yield of grain has not been great under the prevailing conditions. Some increases in yield were obtained but in most instances they were barely sufficient to pay for the cost of the fertilizer. Barnyard manure and high applications of nitrogen caused severe lodging so that part of the crop was lost in harvesting in many years. The result was that average yields were lower from these fertilizers. Winter injury from freezes was also increased due to the rapid succulent fall growth.

In the study of strength of straw, only a part of the fertilizer treatments were used. These included the no

Figure 7. Lodging of wheat following application of 400 pounds of 4-12-4 fertilizer(Left) compared with unfertilized wheat (Right).

treatment plot, various rates of a 4-12-4 fertilizer, and applications of fertilizers in which one element was absent. Studies were also made on the plots receiving applications of barnyard manure.

In 1932 the studies of strength of straw and measurements of diameter of culm were made at three stages of growth. It was thought that since lodging usually occurs before maturity that some earlier stage of growth might indicate weakness of culm in certain applications. Data on strength of straw, measurements of length of internode, diameter of culm, plant height, and number of culms per unit area in the field are given in table 17. The influence of fertilizers on strength of straw at the various stages of growth is shown in figure 8. It will be noticed that at the first head stage there is little difference between plots in strength of straw. This is also true at the soft dough stage of growth. However at maturity there is a greater range in strength of straw with significant differences between treatments. Large applications of manure decreased the strength of straw materially. This was accompanied by an increase in length of lower internode which no doubt is a factor in the severe lodging of these plots. Lodging notes for the 1932 season show low lodging percentages for the manure plots. This was the result of heavy fall and winter growth followed by a severe spring freeze. The stands were materially thinned and subsequent growth was not normal.

Table 17. Determination of the influence of fertilizers on strength of straw and morphological characters in wheat. 1932.

Fertilizer formula	Rate of application	Number culms per sq. ft.	Diameter of lower internode - mm. average 125 culms			Length of lower internode - cm. average 125 culms			Pounds required to break 5 culms average 25 determinations			Estimated lodging per cent
			First head	Grain: soft dough	Maturity	First head	Grain: soft dough	Maturity	First head	Grain: soft dough	Maturity	
No treatment	-	23	2.24	2.39	2.65	6.45	5.90	8.10	3.30	4.11	5.20	5
4-12-0	400	23	2.32	2.32	2.50	6.84	7.16	7.78	3.93	4.25	4.82	10
0-12-4	400	20	2.28	2.23	2.51	6.66	5.71	7.17	3.45	4.20	4.47	20
4-0-4	400	20	2.34	2.34	2.29	6.93	6.50	6.04	3.76	4.13	5.58	5
4-12-4	200	24	2.28	2.17	2.65	6.35	5.96	7.19	3.43	3.92	5.34	25
4-12-4	400	21	2.24	2.31	2.52	6.50	6.21	7.35	3.32	4.42	4.59	25
4-12-4	600	27	2.41	2.24	2.47	8.12	6.29	7.99	3.53	4.32	4.78	20
4-12-4	800	23	2.42	2.23	2.69	8.63	6.41	7.46	3.47	4.21	5.07	50
8-12-8	800	26	2.48	2.36	2.38	8.20	9.70	7.15	3.36	4.47	4.69	50
Barnyard manure	16,000	21	2.33	2.32	2.45	7.49	6.97	7.28	3.45	4.17	4.62	10
Barnyard manure	24,000	24	2.34	2.37	2.61	7.61	7.26	9.64	3.07	4.39	4.18	10
Barnyard manure and phosphorous	24,000 400	26	2.35	2.29	2.42	6.34	7.56	8.06	3.30	4.13	3.80	5

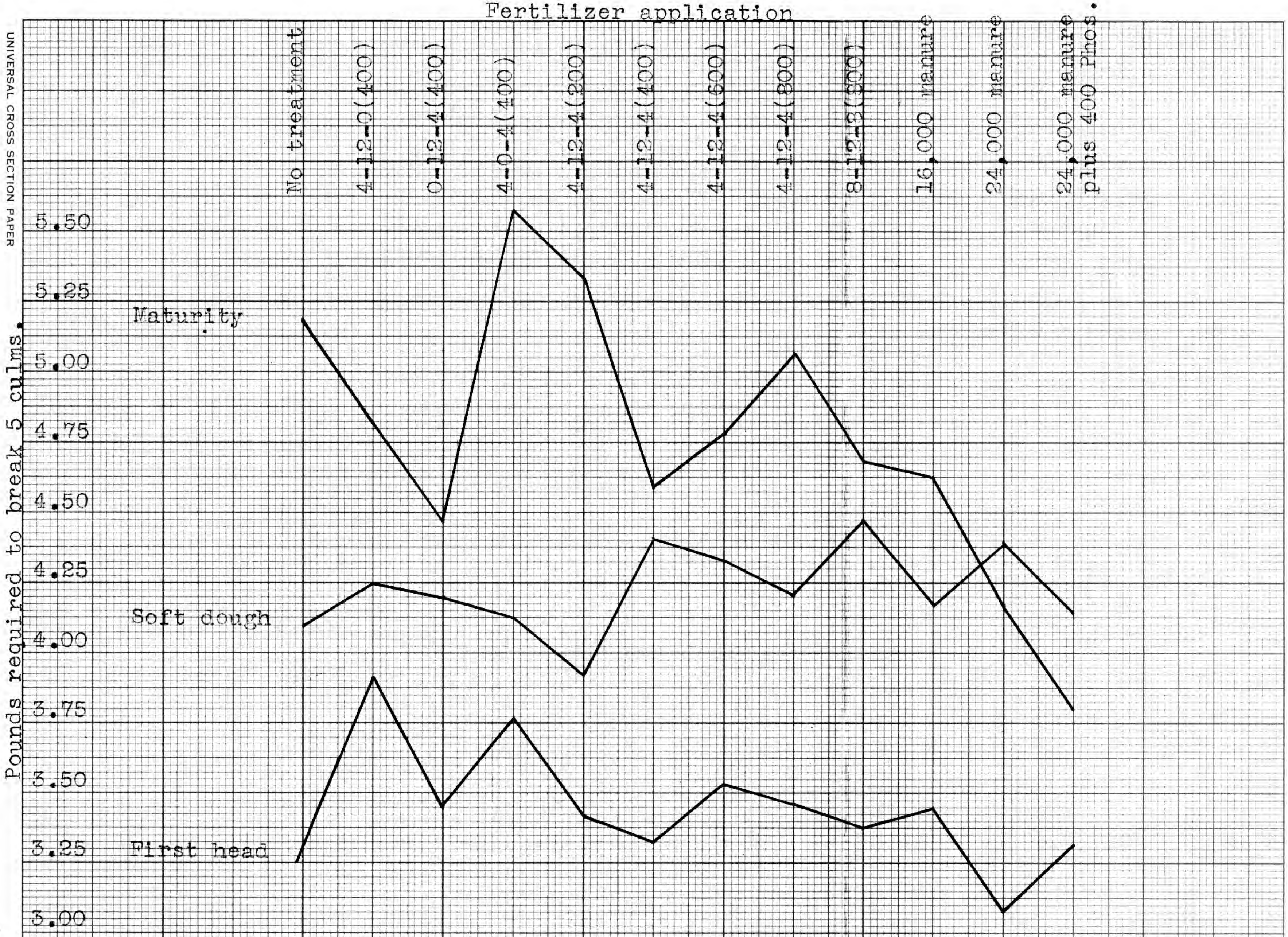

Figure 8. Influence of fertilizers on strength of straw at three stages of growth, Denton, Texas. 1932.

Measurements taken in 1933 and 1934 included those made in 1932 and in addition plant height, weight of culm, and weight per unit of culm at the base were obtained. The data obtained in 1933 and 1934 are given in tables 18 and 19 respectively. The influence of fertilizer treatment upon strength of straw is shown graphically in figure 9.

The results for 1932 and 1934 agree fairly well but the results in 1933 do not agree with the results obtained in the other two years. In 1934 the strongest straw was found on the plot receiving 600 pounds of a complete 4-12-4 fertilizer . The weakest straw was found on the plot receiving the high application of manure. In 1932 and 1933 a fertilizer in which nitrogen was lacking produced the weaker straw. Fertilizer lacking in phosphorus produced the strongest straw. In 1932 and 1934 weak straw was associated with the high applications of manure and complete fertilizer. This was not true in 1933.

No doubt the principal reason for the lack of definite results in this study is the fact that the soil on which the test was grown was a fertile soil to start with. A deficiency in the fertilizer applied would not mean that the plant suffered for lack of that element as there was already sufficient amounts of each element in the soil to meet the needs of the plant.

Table 18. Determinations of the influence of fertilizers on strength of straw and morphological characters in wheat. 1933.

Fertilizer and formula	Rate of appli-cation	Stand height (less head) cm.	Number culms per sq. ft. in field	Weight of 100 culms gm.	Weight of 100 8 cm. sec-tions gm.	Dia-meter of culm at base mm.*	Length of lower inter-nodes cm.*	Pounds required to break 5 culms *	Field lodging per cent
No treatment	-	78.1	34	212	8.6	2.7	8.9	4.22	0
4-12-0	400	80.2	29	223	9.1	2.6	9.0	4.15	0
0-12-4	400	68.4	28	155	7.8	2.4	7.9	3.65	0
4-0-4	400	75.7	24	208	8.2	2.5	10.4	4.17	0
4-12-4	200	74.9	26	171	7.6	2.5	8.7	3.95	0
4-12-4	400	73.8	27	203	9.8	2.6	7.1	4.06	0
4-12-4	600	81.9	27	218	8.2	2.6	9.6	3.98	0
4-12-4	800	86.7	37	247	8.3	2.7	9.8	4.25	0
8-12-8	800	86.5	32	273	9.2	2.7	10.3	4.74	25
Barnyard manure	16,000	83.8	35	272	8.6	2.8	11.6	4.12	65
Barnyard manure	24,000	84.4	35	278	8.6	2.8	11.0	4.20	65
Barnyard manure and phosphorous	24,000 400	82.5	33	318	10.6	2.9	11.5	4.41	65

* Average of 20 determinations using 5 straws at each determination.

Table 19. Determinations of the influence of fertilizers on strength of straw and morphological characters in wheat. 1934.

Fertilizer and formula	Rate of application	Stand: culms per 6 sq. ft. area	Plant height (less head) cm.	Weight of 100 culms gm.	Weight of 100 8 cm. sections gm.	Weight of 100 heads gm.	Weight of grain from 100 heads gm.	Length of lower internodes cm.*	Diameter of culm at base mm.*	Pounds required to break 5 culms	Field lodging per cent
No treatment	-	116	70	51	7.5	64	45	6.4	2.44	4.10	0
4-12-0	400	204	90	63	7.7	61	47	10.4	2.58	3.95	20
0-12-4	400	129	80	61	8.0	62	42	7.5	2.58	4.07	8
4-0-4	400	176	80	52	6.9	55	37	7.5	2.46	3.76	5
4-12-4	200	161	76	51	7.3	64	43	7.1	2.36	3.90	0
4-12-4	400	164	75	57	8.1	75	50	7.8	2.56	4.11	0
4-12-4	600	186	79	60	7.8	66	44	8.4	2.62	4.13	3
4-12-4	800	179	84	64	8.1	76	53	9.6	2.66	4.07	8
8-12-8	800	215	91	70	6.3	71	48	12.4	2.68	3.49	45
Barnyard manure	16,000	193	84	76	7.5	73	47	13.1	2.72	3.27	70
Barnyard manure	24,000	221	84	57	7.0	62	44	10.7	2.52	3.50	80
Barnyard manure and phosphorous	24,000 400	220	84	72	6.7	61	42	13.2	2.62	3.24	60

* Average 20 determinations of 5 straws each.

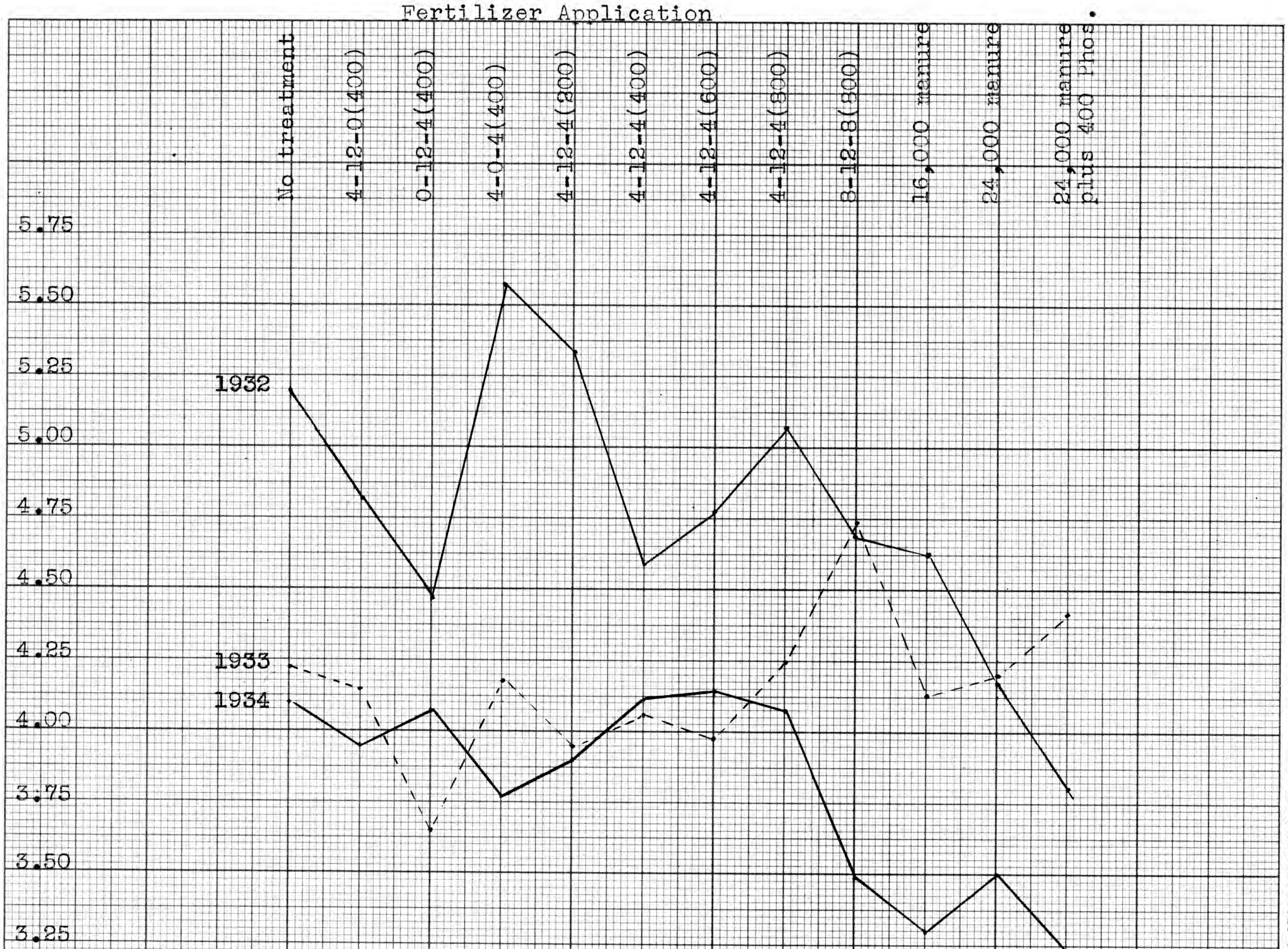

Figure 9. Influence of fertilizers on strength of straw at maturity. Denton, Texas. 1932, 1933 and 1934.

DISCUSSION

Lodging of small grains has been observed and studied for many years. Early investigators noted that lodging occurred more often and was most harmful on soils high in fertility. Attempts were made to determine the cause of lodging by analysis of the plant and soil. Later other investigators have studied many other factors in relation to lodging. Among the more important of these factors are fertilizers, temperature, precipitation, shading, stage of maturity of the plant at time of lodging, degree of lodging, morphological and anatomical differences, and inherent varietal differences.

Nearly all investigators reporting on lodging recognize the damage caused by lodging although few have attempted to measure the loss in crop yield. The economic loss due to lodging would of course depend upon such factors as the degree of lodging, the stage of maturity of the crop at time of lodging, and the climatic factors which might interfere with harvesting operations. The importance of lodging in reducing crop yields by making the grain difficult to harvest is shown to good advantage in figure 10 which may be compared to erect grain in figure 11.

Figure 10. Lodged grain.

Figure 11. Erect grain.

In the present study an attempt has been made to evaluate the lodging resistance of a considerable number of the hard and soft winter wheat varieties grown commercially in the United States. This has been done by determining their breaking strength and measuring morphological characters which it was thought might be associated with lodging. These characters have been correlated with lodging where data on lodging were available. Varietal differences in resistance to lodging are illustrated in figure 12.

Figure 12. Varietal differences in resistance to lodging. Mediterranean 3015-81 (Left).
Mediterranean 3015-72 (Right).

Morphological characters measured were found to vary considerably in their relation to each other from year to year. The relationship of date of maturity to lodging is of special interest because of its economic importance. In this study the date of first head was taken as a measure of date of maturity. In 1932 date of maturity was positively correlated with lodging but when partial correlations were calculated eliminating the variability due to date of maturity, the correlation between strength of straw and lodging was not greatly influenced.

In 1933 the correlation of lodging and breaking str strength of straw was not greatly influenced by eliminating the variability due to date of maturity. In 1934 the correlation of lodging and breaking strength of straw was increased almost to the point of significance by removing the variability due to date of maturity by means of partial correlation. Date of maturity was significantly correlated negatively with breaking strength in 1933 but in 1932 and 1934 a small positive correlation was obtained. A significant negative correlation between date of maturity and weight of grain from 100 heads was obtained in 1934.

From the above data it will be seen that date of maturity varies in its relationship to other plant characters.

Its importance from an economic standpoint is well illustrated by figure 13, which shows an early maturing strain of barley severely lodged while later maturing ones show no lodging. In this instance all strains were lodged in a storm but the later maturing strains were young and were able to straighten up after the storm.

Figure 13. Influence of date of maturity on lodging. Early strain in the center failed to straighten up after a storm in which all strains lodged.

The height of the plant is another important morphological character influencing the lodging resistance of a variety. The taller the plant the greater leverage the weight of heads and grain exert in bending. The soft winter wheats are as a group characterized by taller, heavier, and stronger stems than the hard winter wheats. There was a tendency each year of the present study for the taller varieties to lodge more than the short ones. This is shown in the positive correlation of height and lodging each year. In 1933 this correlation was highly significant. When the variability due to height was removed by means of partial correlation coefficients, the influence was not sufficient to increase the correlation of breaking strength and lodging significantly except in 1934. By removing the variability due to height in 1934 the correlation of breaking strength and lodging was increased from -.196 to -.229. By removing the combined variability due to height and to date of maturity in 1934 the correlation of breaking strength and lodging was increased to -.291. This figure is very close to value of .304 which is considered the minimum value of r.

The length of the lower internode is no doubt important in the resistance of a variety to lodging. From the studies of the influence of fertilizers it was found that as the height of the plant increased the length of the lower internode increased, thus giving less support to the plant. In the simple correlation coefficients determined, a positive was found each year between length of lower internode and lodging but this correlation was significant only in 1934. In the partial correlation coefficients, removing the variability due to length of internode materially decreased the correlation of lodging and breaking strength.

The diameter of the culm is a morphological character which was found to be closely correlated with strength of straw. As was the case with breaking strength and weight per unit of culm, the diameter of culm failed to correlate closely with lodging in any one season. The determination of weight per unit of culm was used in calculations because this factor included not only diameter but also thickness of cylinder wall and density of the culm.

Data have also been presented to show that breaking strength of straw is significantly correlated with lodging. Many factors influence lodging and therefore data on lodging notes must be taken over a period of several years or at a number of stations in order to properly evaluate the lodging resistance of a variety of small grain. For this reason it is believed that a measurement of some plant character such as diameter of culm, weight per unit of culm at the base of the plant or breaking strength will give a better index of the true lodging resistance of a variety than lodging notes taken over short periods. Data were also presented to show that weight per unit length of culm was correlated a little closer with lodging than was breaking strength and since this measure is more easily taken, it can be substituted for breaking strength determinations.

SUMMARY

Lodging of small grain is an important factor in the economic production of the crop in the more humid regions and especially on the more fertile soils. Investigations on the causes and effects of lodging have been conducted for a number of years. A brief summary of the investigations to date is herein reported.

The experiments herein reported were conducted at Texas Substation No.6, Denton, Texas as a part of the cooperative wheat improvement project of the Texas Experiment Station and the Division of Cereal Crops, Bureau of Plant Industry, United States Department of Agriculture.

A study was made during the 1932,1933 and 1934 seasons of a large number of hard and soft winter wheat varieties. Tests and measurements recorded included strength of straw,

diameter of culm, weight per unit of culm near the base of the plant, length of lower internode, height of plant, weight of culms, weight of grain, date of maturity, estimates of field lodging. The inter-relation of all characters measured was determined by means of correlation coefficients. The data on strength of straw was analyzed by means of the analysis of variance method.

Strength of straw determinations for two and four year periods were found to be correlated significantly with lodging during the same period. Significant correlations between breaking strength of varieties grown at Denton, Texas and lodging reaction of these varieties at other points was also found. For a single season or for short periods the correlation of lodging and breaking strength was not highly significant indicating that lodging in many seasons is not truly representative of the resistance of varieties to lodging. It is concluded that breaking strength determinations for a single season are probably a more accurate index of the lodging resistance or susceptibility than field observations for a single season. Comparisons of breaking strength should be made on varieties grown under the same conditions and with comparable stands.

Data on weight per unit length of culm near the base of the plant for the seasons of 1933 and 1934 indicate that this measurement is equally as good an index of standing power of a variety as breaking strength. Correlations between weight per unit length of culm near the base of the plant and lodging were higher in most instances than correlations between breaking strength and lodging. This measure to indicate lodging resistance is more easily and quickly obtained than determinations of strength of straw and may be substituted for it.

Diameter of culm at the base of the plant was found to be closely associated with breaking strength but is not considered as good an index as weight per unit of culm. Date of maturity was recognized as a factor in lodging but for the data presented did not appear to influence the correlation of breaking strength and lodging except in 1934. Height of plant was found to be correlated to some extent with lodging each year. In 1934 when height of plant was quite variable, the correlation of breaking strength and lodging was increased to the point of significance by removing the variability due to height by means of partial correlation coefficients. The length of the lower internode was not found significantly correlated with lodging except in 1934. As height of a given variety increased the length of the lower internode increased.

In a study of the influence of stand on breaking strength of straw and development of the plant, it was found that not only breaking strength but all plant parts increased in size as the planting rate was decreased. This emphasizes the importance of uniform stands in comparing any series of varieties for breaking strength or any morphological character.

Commercial fertilizers as well as barnyard manure were shown to be instrumental in increasing lodging. The weaker straw of the plots receiving high applications of fertilizer was accompanied by longer internodes and taller plants. In 1932 and 1933 applications of fertilizer lacking in nitrogen produced the weakest straw while applications lacking in phosphorus produced the strongest straw.

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