FIELD AND LABORATORY STUDIES OF LODGING AND DROUTH RESISTANCE IN CORN

by

JAMES WILLIAM HUNTER

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INTRODUCTION

Corn production usually is limited in the Great Plains area by rainfall and the yield varies from year to year because of the close relation existing between midsummer rainfall and yield. Recent studies (5) indicate a correlation of $0.67 \pm .05$ between July rainfall at Manhattan and the yield of corn in Riley County, Kansas, during the years 1873 to 1932. A quick and accurate method that would differentiate between resistant and susceptible strains would aid materially in breeding drouth resistant types with which to stabilize corn production in the more arid sections.

More and more attention is being paid by corn breeders and corn growers to factors other than yielding ability. One of these factors which causes both actual losses and inferior quality is the tendency of the stalks to fall over or lodge before husking. Injury from this source is more pronounced in the corn belt proper than here because of more wet weather in the fall and because of the increasing use of mechanical pickers.

With the methods for corn improvement used at present it may be difficult to determine resistance to lodging or drouth tolerance with any degree of certainty. The process at best is long and costly since it ordinarily requires several years of testing in the field.

Much of the research in resistance to drouth in other plants has consisted of studies of the physical, physiological and anatomical basis of resistance. This type of study is fundamental and would aid greatly in the technique of breeding for resistance to drouth or to lodging.

Plants have become modified to meet xerophytic conditions in many and varied ways including physiological and structural modifications as pointed out clearly by Eames and MacDaniels (3). Plants that are adapted to growing in dry situations may develop an extraordinarily large and deeply penetrating root system. A fibrous root system is also a xerophytic adaptation, enabling the plant to absorb the moisture from the soil to better advantage. Reduction in leaf area aids the plant in resisting drouth by cutting down transpiration. Xerophytes ordinarily have a higher osmotic concentration within the plant than is found in the common mesophytes, thus enabling the plant to take better advantage of the soil moisture.

Lignification and cutinization of the epidermis and subepidermis are among the most common of xerophytic adaptations. Xerophytes generally have a larger proportion of sclerenchyma in their leaf structure than is found in normal mesophytes. Transpiration is frequently lessened by the reduction of the number of stomata either by reduced leaf surface or smaller number per unit area. The presence of a covering of matted hairs on the under side of the leaves often is indicative of xerophytes.

Improved methods for differentiating between resistant and susceptible strains will aid the plant breeder materially in selecting non-lodging and drouth resistant strains which at the same time have other desirable economic characters.

With the present methods it is necessary to spend an entire season to determine the desirability of a given strain, and even then if the conditions have not been favorable for the development of lodging or injury by drouth the plant breeder has accomplished nothing in selecting for the desirable traits. In many cases it is necessary to go to the expense of propagating a strain for several years only to have it prove susceptible to lodging, to drouth, or to some other undesirable character. Laboratory or other controlled tests that indicate resistance to lodging or to drouth would materially aid in the development of superior varieties of corn. This paper deals with studies having that objective.

REVIEW OF LITERATURE

Garber and Olson (4) refer to the work of Moldenhawker who found the number of vascular bundles to be a distinguishing characteristic for different sorts of wheat and barley, and that non-lodging sorts could be selected with reasonable success by choosing the plants containing the greater number of vascular bundles.

They also quote Albrecht as accepting without question the breaking strength of straw as an index to lodging. The conclusions of Albrecht are based on measurements of individual plants of one variety of winter wheat grown at Köngsberg, Germany, in 1905. Evidence is presented showing: (a) A fairly high correlation between breaking strength and the weight of culm, (b) fairly consistent correlations between breaking strength and total area of cross section of the vascular bundles, (c) correlations between breaking strength and thickness of culms, and (d) correlation between breaking strength and thickness of sclerenchyma.

Experimental date presented by Garber and Olson (4) show no striking differences among the various strains of a cereal with regard to the length of the lignified cells in relation to lodging. There was an indication that winter wheat possesses longer lignified cells than the other cereals although only small differences were observed among the different cereals. In oats, rye, and winter wheat straw the relation between length of lignified cells and lodging proved to be inconsistent.

Considering both early and late oats, positive correlations are reported between non-lodging and thickness of sclerenchyma cell walls. No important correlation of this character with lodging could be found in barley.

Clark and Wilson (2) give a complete review of the literature on lodging in small grains, emphasizing the importance of the breaking strength of straw as a measure of resistance to lodging.

According to Maximov (6) western European investigators hold the opinion that xerophytes are distinguished by a low rate of transpiration. As a result of his extensive investigations on the vegetation of the Russian Steppes, Maximov came to the conclusion that xerophytes are not characterized by a low rate of transpiration, but rather by the ability to endure a considerable loss of water.

Briggs and Shantz (1) proved very conclusively that most plants have the same wilting coefficient. The fluctuations in their experimental data exceeded but little the limits of the probable error.

Miller (7) found no consistent relationship between the water requirements of various crops and their ability to produce a yield of grain in agricultural practice under conditions of limited and uncertain rainfall.

Shirley (9) describes a method for studying drouth resistance in plants. The plants were placed in an illuminated chamber, the temperature of which was controlled by a thermoregulator. The air was passed over calcium chloride as a dehydrating agent. The length of time each plant survived, together with the moisture content of the soil, was used as a criterion of drouth resistance. The plants tested were white spruce, _Picea canadensis_. The temperatures averaged 38° C. and the relative humidity about 10 per cent. The soil moisture at death was about 14 per cent in all pots.

Eames and MacDaniels (3) state that heavy cuticularization of the epidermis and even of the subepidermal cells is among the most common of xerophytic modifications. Frequently the walls of the epidermal cells themselves are cutinized and sometimes those of the underlying cells also. Different degrees of lignification of the cells of the epidermis and those immediately beneath this layer are frequently found along with well developed cutin layers.

MATERIAL AND METHODS

The strains of corn used in these experiments were selected on the basis of their lodging and drouth reactions under field conditions in the corn improvement project on the Agronomy Farm of the Kansas Agricultural Experiment Station. Resistance to lodging and to drouth were studied in the 23 strains of corn listed in Table I.

The strain number is a temporary number and is used only as a convenience for reference in this paper. The nursery number is the pedigree number of the row in the corn breeding nursery from which field data and samples for laboratory studies were taken. The crossing block number is the permanent line number assigned to each strain for use in making crosses. The data regarding lodging and firing of the plants were secured in field experiments on the Agronomy Farm and show the general reaction of each strain with respect to these characteristics. The height of plants gives the average for the three years in which height measurements were taken.

The strains except Nos. 22 and 23 had been inbred for three or more years. Strain No. 1 was derived from Illinois 2-ear, Nos. 2 and 11 to 17 from Pride of Saline, and Nos. 3 to 10 and 18 to 21 from Yellow Selection No. 1. Nos. 22 and 23 were open pollinated strains of Pride of Saline.

Studies of Lodging

The lodging study included the 21 inbred lines and the

Table I. Strains of corn studied for resistance to lodging and to drouth.

Strain number	Nursery number	Crossing block no.	Variety or selection	Field behavior: Lodging	Field behavior: Firing	Ht. in.
1	9018		Illinois 2-ear	R	R	59
2	7286	PS41	Pride of Saline	R	R	61
3	9019		Yellow Sel. #1	S	S	61
4	9813	YS48	" " "	R	R	62
5	10391	YS53	" " "	R	R	61
6	10448	YS66	" " "	R	R	55
7	10423	YS58	" " "	S	S	65
8	9802		" " "	R	R	88
9	10438	YS64	" " "	S	S	63
10	9842	YS52	" " "	S	S	66
11	7289		Pride of Saline	S	S	66
12	7295	PS44	" " "	R	R	72
13	7208	PS11	" " "	S	S	80
14	7284	PS51	" " "	R	R	66
15	7220	PS31	" " "	S	S	52
16	7318	PS47	" " "	R	R	60
17	7261	PS48	" " "	R	R	70
18	8680		Yellow Sel. #1	R	S	78
19	8475		" " "	R	S	52
20	8731	YS75	" " "	R	R	66
21	8646		" " "	R	R	72
22	P. of S.	Open Poll.	Pride of Saline	R	R	80
23	P. of S.	" "	" " "	S	S	80

R = resistant
S = susceptible

two open pollinated strains of Pride of Saline. Both susceptible and resistant strains were represented among the selfed lines and in the open pollinated Pride of Saline.

The studies relative to lodging were divided into two major parts: (a) Field observations and measurements, and (b) anatomical studies in the laboratory.

The field data include time of maturity, height of plant, and general phenological observations. The anatomical work included studies of differences in the structure and the degree of lignification in the stems of mature plants. Seedlings also were studied but differences did not appear to be significant at that stage.

The second internode above the surface of the soil and the first leaf below the ear of nearly mature plants with grain in the soft dough stage were sampled for anatomical studies. The samples were killed in a solution of two per cent formaldehyde in 75 per cent alcohol and were left in this solution.

The material was sectioned with a hand microtome equipped with an extra heavy razor. Most of the sections were stained in safranin. Other strains as oesin, Delafields haemotoxylins, gentian violet and grams iodide were employed. Xyol was used as the clearing agent for the most part. Safranin which stains lignin a bright red proved to be the most useful stain. Generally the material was studied from temporary mounts, although several permanent mounts of strains resistant to lodging were made. It was almost impossible to make satisfactory permanent mounts of the weak types. Further discussion of this feature will be included under experimental data.

Studies of Drouth Resistance

The drouth resistant studies included ten inbred lines, Nos. 1 to 10 inclusive, part of which had been observed to be susceptible and part resistant to drouth under field conditions. The studies were divided into four parts: (a) Electrical conductivity of living tissue, (b) anatomical features of the stem and leaves, (c) water utilization and water requirement studies, and (d) high temperature tests. The electrical conductivity measurements were made with a D'Arsnovalls sensitive galvanometer. Three fourteen day old seedlings of each strain, grown in 4-inch clay pots were used for the conductivity tests. The samples of the stems were segments 4 centimeters long taken just above the crown. Four centimeter segments of the second and third leaves also were used, making a total of six leaves from each strain for the leaf test. The stem and leaves were tested and weighed separately, the weight being used for obtaining a unit of mass of the material. No definite results were obtained, although a relation appeared to exist in some of the strains. The variance of duplicate measurements was high and further study will be necessary to find the cause of this variation.

Plate I shows two representative strains growing under

Plate I

Two month old plants growing under drouth conditions.

9018 is strain No. 1, resistant to drouth. Note the green turgid leaves.

9019 is strain No. 3, a top firing type. Note uniform firing of all the plants.

Plate I

drouth conditions in the field in 1932. Row 9018 is strain No. 1 and 9019 is strain No. 3 used in these studies. These strains were about two months old at the time this picture was taken. Strain No. 1 which is resistant to drouth does not show injury to the leaves, while strain No. 3 which is susceptible, shows top firing very badly. The leaves of No. 3 that appear white in the photograph were dead and dry. The uniform injury in No. 3 indicates that susceptibility to drouth is homozygous.

The anatomical study included observations and measurements of plants grown under natural conditions in the field. The height of plants, date of pollination, degree of lodging and firing were recorded. A representative lot including four strains, two of which were drouth resistant and two which were susceptible to drouth were grown under irrigated and dry land conditions. Observations and measurements of representative plants from both series were taken. The material for the histological study was sampled and handled in the same manner as for the lodging study. The general structure of the stem and leaves was studied.

For the water utilization and water requirement determinations plants in triplicate series were grown for 30 days in one-half gallon jars. The jars were sealed with a mixture of equal parts of petrolatum and paraffin. This combination made an excellent seal that did not crack or break away from the sides of the jar and was of such a pliable consistency as to permit the sealing substance to be worked around the plants without injury to the tissue. The plants were watered through pipes which extended to the base of the jar. A heavy layer of coarse sand was placed in the bottom of the jar, thus allowing free distribution of the water through the soil. The amount of water added to bring each pot to its optimum soil moisture each day was recorded.

The pots were sealed when the plants were ten days old. In order to obtain the weight of the plants before they were sealed representative plants were cut from each pot. Four normal plants were left in each pot. In ten days two more plants were sampled and both green weight and dry weight were again recorded. At the end of 30 days the two plants were harvested and weighed. The total water utilized per pot was determined and from this and the dry weight the water requirement was calculated. The per cent moisture in the green plants was also determined.

A series representing four strains of corn was grown to determine the wilting coefficient. For this purpose plants were grown in normal soil for three weeks after which no moisture was added. The per cent of moisture in the soil when death occurred, was taken as the wilting coefficient.

EXPERIMENTAL RESULTS

Resistance to lodging in certain strains and susceptibility in others are manifested clearly in the corn breeding nursery every year. Some strains have the ability to resist lodging even in case of severe storms, while other strains lodge readily under ordinary conditions.

There are two distinct types of lodging: (a) A type where the plant is uprooted and the stem may or may not be broken, and (b) the type in which the roots remain intact and lodging is due to breaking of the stalk.

It has been observed that in general a strain that manifests lodging by uprooting will breed true for this type of lodging with suitable weather conditions. Likewise the type that breaks tends to breed true for that particular type of lodging.

Of the strains studied, No. 13 was the only strain that consistently lodged by uprooting. Nos. 3, 9, 10, 11 and 15 lodged by breaking of the stalk.

Nos. 1, 2, 4, 5 and 6 consistently bred true for resistance both to lodging and to drouth. Strain No. 8 consistently has shown the tendency to top fire but has not manifested the pronounced tendency to lodge exhibited by the other susceptible strains.

The data show a positive correlation between lodging and firing in the particular strains that were studied. However, the assumption that such a relation prevails in general cannot be made on the basis of only 21 strains. Field observations of numerous varieties show that lodging frequently is not accompanied by firing. Likewise, an erect sturdy plant may fire severely under drouth conditions.

The consistency with which resistance or susceptibility to drouth and lodging are inherited is shown in Table II since the respective strains manifest nearly the same characteristics each year.

Table II. Field observations and measurements of 10 inbred strains of corn grown under field conditions on the Kansas Agricultural Experiment Station. 1931-1934.

Strain number	Lodging				Firing				Height of plants Inches			
	1931	'32	'33	'34	1931	'32	'33	'34	1932	'33	'34	Av.
1	-	E	E	E	-	0	0	0	62	64	52	59
2	E	E	E	E	-	0	0	0	63	66	54	61
3	L	L	L	L	Tf	Tf	Tf	Tf	64	66	52	61
4	E	E	E	E	0	0	0	0	70	68	52	62
5	E	E	E	E	0	0	0	0	74	68	42	61
6	E	E	E	E	0	0	Bf	0	60	66	40	55
7	Z	Z	Z	L	0	0	0	Tf	76	74	44	65
8	Ls	Ls	Ls	Ls	Tf	Tf	Tf	Tf	90	94	82	88
9	Ls	L	L	L	Bf	Bf	Bf	Bf	68	70	42	60
10	Ls	L	L	-	Bf	Bf	Bf	-	64	62	61	63

E = Erect
Ls = Moderate lodging
L = Extreme lodging
Tf = Top firing
Bf = Base firing
Z = Zig-zag culm

It is also shown in Table II that there is no pronounced relation between height of plants and resistance to lodging or drouth. With the exception of strain No. 8 all of the lines were between 55 and 65 inches tall as an average for three years. Within this range occurred extremes both for drouth tolerance and lodging behavior. Although there are obvious possible physical relationships between drouth resistance and leaf area which usually is correlated with height of plant, and again between height of plant and tendency to lodge, the studies herein reported indicate that there are other factors in the internal economy of the plant which are of the utmost importance in determining its behavior.

It is generally recognized that the time of flowering is a critical period in the life of the corn plant and that the plant is particularly susceptible to drouth injury at this stage. In comparing strains differing markedly in time of flowering it is conceivable that variations in injury might be due to fortuitous weather behavior by which one strain could be injured much worse than another by a few days of unfavorable weather at an especially critical period. In the strains considered in this study, however, such differences did not exist, since all of the lines were of the same general type and all flowered at approximately the same time.

The year 1934 was the hottest and driest on record at Manhattan. Most of the lines studied maintained their previous relative behavior even under these extreme conditions. Strain No. 7, however, succumbed to top firing while still very immature, and consequently lodged. There is some indication that segregation was still taking place in this line, since in 1931 and 1933 it was characterized by zig-zag culms while in 1934 the stalks were practically straight.

Studies of Lodging

There were marked differences in lodging shown by the various strains in the corn breeding nursery. Twenty-one representative strains were selected for this study from the nursery in 1931 on the basis of their reaction in the field in 1929 and 1931. These strains have been listed in Table I.

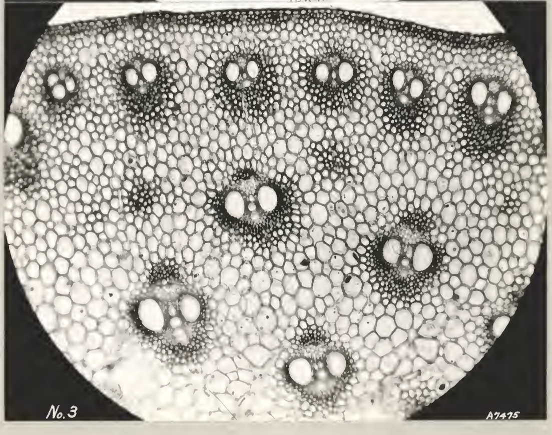
Structure of Stem in Relation to Lodging. There was a very marked difference in the resistance to cutting offered by the resistant and susceptible types when sectioned with the razor. The vascular elements remained erect and rigid in the strong or resistant plants, making it much easier to cut a clean smooth section of the stem than in those susceptible to lodging. The vascular elements of the weak type of plants seemed to bend over and drag under the razor making a very ragged appearing section.

Plate II

Strain No. 1. Cross section of stem resistant to breaking type of lodging. Note large amounts of lignified sclerenchyma tissue around the vascular elements and in the subepidermis.

Strain No. 3. Cross section of stem which lodges by breaking of the stalk. Note small amounts of lignified sclerenchyma tissue around the vascular elements and in the epidermal layer.

Plate II



The sections of the strong plants remained flat when run through the alcohol-xylol series, but the sections of the weak type curled to such an extent it was almost impossible to make permanent mounts. After many trials it was possible to make a mount of a small portion of the stem of one of the weak plants, representative of the entire group of weak plants with the exception of No. 13. Strain No. 13 differed from the other lodging strains in that it lodged by uprooting rather than by breaking the stalk.

As shown in Plate II, microscopic examination of the stem of mature plants of strains Nos. 1 and 3 reveals the fact that the bundle sheaths surrounding the vascular bundles of the strong plants were several cells thick and very densely lignified. They also possessed a thick and very densely lignified subepidermal sclerenchyma layer. The cells were angular in shape with very small intercellular spaces. The weak plants had a narrow bundle sheath very lightly lignified, a thin layer of sclerenchyma in the subepidermis, and large intercellular spaces.

All the resistant types show large heavily lignified bundle sheaths and a wide densely lignified subepidermal sclerenchyma layer. All the strains that lodge by breaking possess only small amounts of lignified sclerenchyma. Strain No. 13 which lodged by uprooting, showed a larger amount of lignified sclerenchyma tissue as indicated in

Plate III

Strain No. 13. Cross section of stem which lodges by uprooting of the plant. Note large amounts of lignified sclerenchyma tissue.

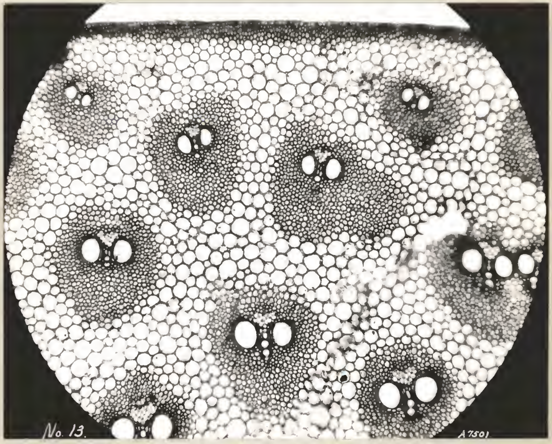

No. 13.
A 7501

Plate III than did the other weak types. This strain did not possess as much lignified sclerenchyma as the resistant strains but had decidedly more than the strains that lodged by breaking of the stem. This difference in the amount of lignified tissue is considered enough to account for the differences in lodging that occur under field conditions, and with a reasonable degree of certainty can be made the basis for selecting for resistance to lodging.

Studies of Drouth Resistance

The strains of corn studied are divided into three distinct types with respect to their response to drouth: (a) The top firing type in which the top leaves and tassel burn before the remainder of the plant. As the drouth progresses the plants fire downward and in severe cases death results. (b) The base firing type in which injury progresses in the opposite direction. In this type the lower leaves are injured first, leaving the upper leaves and tassel green and turgid. If the drouth continues the entire plant may finally die. Base firing is less injurious than top firing since in many cases the tassel is not injured, thus allowing pollination and the development of fairly good ears even under moderately adverse conditions. Base fired plants will recover more rapidly than top fired plants when the drouth is broken. (c) The resistant type which may endure a relatively long and severe drouth with little or no injury.

There was a marked difference among the strains in the area of cross sections of the stalks as shown in Table III. Strains Nos. 1 and 2 which are drouth resistant have significantly smaller stalks than strains Nos. 3 and 9 which are susceptible to drouth injury. This difference is shown in both the irrigated and non-irrigated series.

Table III. Area of cross section of four inbred lines grown under irrigated and non-irrigated conditions.

Strain number	Behavior	Area of cross section Square centimeters Average of two stalks		Difference between irrigated and non-irrigated
		Irrigated	Non-Irrigated	
1	non-firing	4.79	4.79	0.00
2	non-firing	6.42	4.83	1.59
3	top-firing	7.41	5.72	1.68
9	base-firing	7.06	6.42	0.64

It will also be noted that strain No. 1, a resistant strain, grew as large in the non-irrigated series as in the irrigated series. In No. 9 the difference was only .64 square centimeters. In strain No. 3 which is a top firing type the area of the stalk was increased 1.68 square centimeters by irrigation. Strain No. 2 also showed a significantly greater growth in the irrigated series. The fact that

Nos. 1 and 2 (resistant strains) have smaller stalks than Nos. 3 and 9 (susceptible strains) tends to show a relation between size of stalk and drouth resistance. Basing the assertion on field observations without making any definite measurements this hypothesis appears plausible, as non-firing strains Nos. 4, 5, 6, and 8 appear more slender than firing strains Nos. 3, 7, 9 and 10.

It was also noted that the root system of No. 1 was decidedly more fibrous in the non-irrigated series than in the irrigated series, although there was little or no difference in any of the other strains. On examination of the root systems of several strains in the corn breeding nursery no other strain was found that produced such a decidedly fibrous root system. This character manifested by No. 1, would aid the plant to take greater advantage of the soil moisture, and possibly deplete the soil of moisture to a greater extent than could strains that do not have this ability. The character may account for the fact that No. 1 did not show an increase in size of stalk in the irrigated series and it is possible that this character will account for a part of the extreme drouth resistance observed in this strain.

The fact that the stem of No. 9, a base firing type, showed but a small increase of .68 square centimeters in cross section in the irrigated series suggests that it has the capacity to take advantage of the soil moisture and conduct it through the stem at a rapid rate, but since it uses the water at such a rapid rate the soil is soon depleted of moisture and burning of the basal leaves occurs.

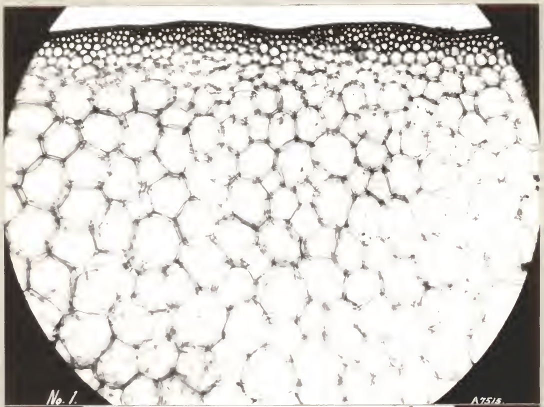
Histological Studies. As shown in Plate II strain No. 1 which is resistant to lodging and to firing has a very densely lignified sclerenchyma layer just under the epidermis. A study of the leaves (Plate IV) showed a similar densely lignified epidermal layer on both the upper and the lower leaf surfaces near the midrib of strain No. 1. The contrasting appearance of leaves from a top firing type is shown in the photomicrograph of strain No. 3 in which the epidermal layer is not lignified to as great an extent as in the resistant strains. The greater amount of lignin in the resistant strains may be expected to assist the plants in controlling water loss under conditions of low rainfall or in periods of hot dry winds which often occur in the Great Plains area. Relatively high water loss would be expected in the top firing strains with only a small amount of lignin in the epidermal layer. The stem of this type apparently does not have the capacity to conduct water as rapidly as it is transpired from the leaves and thus dessication of the leaves of the plant may result. The base firing type may

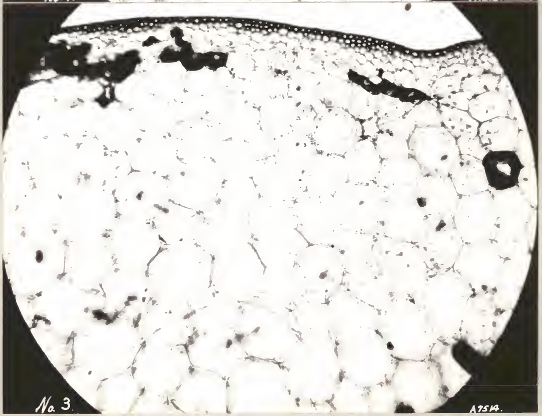
Plate IV

Strain No. 1. Cross section of upper side of midrib of leaf. Note large amounts of lignified sclerenchyma in the epidermal layer.

Strain No. 3. Cross section of upper side of midrib of leaf. Note small amounts of lignified sclerenchyma tissue in the epidermal layer.

Plate IV





not possess lignified epidermis but it has a capacity for conducting large amounts of water through the stem, thus enabling the plant to endure hot dry winds to a marked degree providing sufficient moisture is in the soil. This type apparently fires because of depletion of the soil moisture rather than the inability of the plant to carry water.

Water Utilization and Water Requirement. In addition to field observations and histological studies, direct determinations of water efficiency and ability of the lines to withstand dessication and high temperatures were made under controlled conditions in the greenhouse. Because of the limited facilities available, these determinations had to be made on seedlings or on plants in early stages of growth. Under actual growing conditions in the field the severe tests of drouth resistance usually come after the plants have tasseled. It must be recognized, therefore, that the validity of the conclusions drawn in the following paragraphs rests on the assumption that the juvenile and mature reactions of a given strain to drouth are the same.

The data presented in Table IV show no relation between total utilization and drouth resistance. No. 3, a top firing strain, and No. 5, a resistant strain, each utilized 77 c.c. per plant (on the basis of series 1 and 2 only).

Table IV. Water utilization and water requirement of strains of corn grown 30 days in the greenhouse.

	Water utilization					
Strain number	Series 1 c.c.	Series 2 c.c.	Series 3 c.c.	Total c.c.	Per plant c.c.	H_2O requirement
3	220	402	33 (1)	655	77	147
4	364	629 (2)	352	1345	112	202
5	276	344	160 (1)	780	77	215
6	356	398	306	1160	98	204
7	351	374	499	1224	102	186
8	462	860 (2)	433	1755	112	231
9	573	467	404	1444	124	226
10	521	489	397	1407	117	247

(1) Plants of strain No. 3 in the third series, and two plants of strain No. 5 in the third series died before completion of the experiment. The dry weights of the plants were taken and used in the calculations of the water requirement.

(2) These values were not used in calculating the water utilization per plant since the abnormal behavior of the plants in these pots makes the data questionable.

No. 4, a resistant strain, used 112 c.c. per plant (based on series 1 and 3) which is not significantly more than used by No. 7, a top firing strain. No. 6, a resistant strain was about the same as No. 7, a top firing strain. Nos. 9 and 10 which are both base firing strains used about the same amount of water. Although no definite relation existed between water utilization and drouth resistance, the resistant and top firing strains Nos. 3 and 8 used less water than did the base firing strains, Nos. 9 and 10. This would tend to support the theory that the base firing type fires because of insufficient moisture in the soil rather than because of its inability to conduct water through the stem into the leaves.

The water requirement of Nos. 3 and 7, top firing strains, was low, being 147 and 186 respectively. In contrast to this Nos. 4, 5, and 6, resistant strains, had water requirements of 202, 215, and 204 respectively. No. 8 shows a relatively high water requirement of 231 which is undoubtedly brought about by the abnormal behavior in series 2. Strains Nos. 9 and 10, base firing strains, had significantly high water requirements of 226 and 247 respectively.

It may be possible that the water requirement of a plant is related to the available supplies of water in the leaves as determined by the water gathering power of the roots and the carrying capacity of the vascular system of the plant. The top firing type has the lowest water requirement, the drouth resistant type an intermediate water requirement, and the base firing type the highest water requirement. It is suggested, therefore, that the top firing strains may fire because they cannot gather and transport water rapidly enough to satisfy high transpiration rates, whereas the base firing strains may fire because of a too efficient water gathering and transporting ability whereby they have exhausted the available supply of moisture in the soil prematurely. On this basis, the drouth resistant plants should have a conducting system of medium capacity, coupled of course with the other desirable qualities such as fibrous roots, lignification of sclerenchyma and perhaps other characteristics as previously suggested.

High Temperature Studies. A series of high temperature studies was conducted to find a relation between resistance to high temperature in the greenhouse and the reactions of the same strains grown in the field under drouth conditions. Eight strains, Nos. 3 to 10 inclusive, were studied. Information as to their relative resistance to drouth in the field for four years, 1931 to 1934, has been presented in Table II. The strains arranged in order according to drouth resistance in the field in 1934 from most resistant to most susceptible are Nos. 4, 6, 5, 8, 3, 7, 9 and 10. Segregation for drouth resistance apparently accounts for the difference in response of strain No. 7 in 1934 compared to previous years. The same seed was used in high temperature studies as was planted in the field in 1934, and therefore it seems desirable to compare the artificial tests with the field tests of that year.

Fourteen day old seedlings grown under comparable conditions in four inch clay pots were placed in the heat chamber with the temperature at 140° F. and relative humidity of approximately 30 per cent, the range being from 28 to 32 per cent. They were kept under these conditions for 6.5 hours.

The experiment was first made December 1, 1934. For this test the soil was brought to an optimum moisture content when placed in the heat chamber. At the high temperature the soil dried rapidly and at different rates in the various pots. These differences in soil moisture though slight appeared to be a factor in the results of this experiment. Therefore in the succeeding tests the soil was saturated shortly before placing the plants in the chamber and saturation was maintained by placing the pots in a shallow tray of water. The experiment was replicated four more times between December 12, 1934, and February 13, 1935. Following each test the strains were arranged in order of injury from least to most as shown in Table V. The results of the experiment, except in the test on December 1, were extremely uniform considering the fact that it was impossible to control the relative humidity accurately.

Nos. 4 and 6, the most drouth resistant strains under field conditions resisted high temperature to a very marked degree, showing practically no injury in the last four tests. When placed under optimum growing conditions those

Table V. Injury to eight inbred lines of corn by exposure to drouth in the field compared with artificially produced high temperatures.

Date	Treatment	Strain numbers arranged in order of injury from low to high
1934 season	Drouth conditions in the field	4-6-5-8-3-7-9-10
12/1/34	Heat chamber	6-5-4-8-9-3-10-7
12/12/34	Heat chamber	4-6-5-8-3-7-9-10
12/28/34	Heat chamber	4-6-8-5-3-7-9-10
1/11/35	Heat chamber	4-6-5-8-3-7-9-10
2/13/35	Heat chamber	4-6-5-8-3-7-9-10

strains recovered 100 per cent. Nos. 5 and 8 which are moderately resistant to drouth under field conditions showed marked resistance to high temperature and when placed under optimum growing conditions showed recovery of from 50 to 75 per cent. Nos. 3 and 7, top firing strains under field conditions showed injury to the tips of the leaves in three hours and were severely wilted within 6.5 hours. When placed under optimum growing conditions they recovered from 0 to 25 per cent. No. 9, a base firing type, resisted the high temperature to a marked degree, for a period of five hours during which there was little or no apparent injury. However, injury developed quickly and the plants appeared to be dead at about six hours. None of them recovered when placed under optimum conditions for growth. No. 10 which was the most susceptible to drouth injury in the field was killed by the high temperature treatment within six hours.

During the time the plants were in the chamber it was noted that No. 3 and No. 7 which are top firing strains were the first to show injury. Burning at the tips of the leaves occurred within three hours and the plants were severely injured or dead by the end of the treatment. The injury to these strains was probably due to the inability of the plants to gather and carry water fast enough to prevent dessication.

The condition of the plants three days after exposure to the high temperature is shown in Plate V. The pots, bearing numbers which correspond to the strain numbers, are arranged in order of increasing injury from 4 to 10. Strain No. 4 shows no appreciable injury. In strain No. 6, the extreme leaf tips were injured slightly. The tops of the plants in strain No. 5 were injured about 50 per cent. No. 8 also shows about 50 per cent injury which affected more of the plant. The plants of No. 3 were practically dead, and those of Nos. 7, 9 and 10 were killed.

These experiments indicate that relative drouth resistance of strains of corn may be determined by exposing seedlings to high temperature.

Plate V

Eight inbred strains after exposure to a temperature of 140° F. with relative humidity of 30 per cent for 6.5 hours. Strains Nos. 4 and 6 are most resistant to drouth in the field; Nos. 5 and 8 are moderately resistant; Nos. 3 and 7 top fire, and Nos. 9 and 10 burn at the base.

Plate V

Wilting Coefficient Determinations. Strains Nos. 4, 6, 3, and 9 were grown for the purpose of determining the wilting coefficient. The plants were grown in soil with optimum moisture for a period of three weeks, after which time no more water was added. A moisture sample of the soil was taken when the plants were permanently wilted. The moisture content of the soil was reduced to 11 per cent in each case, thus showing no relation between wilting coefficient and drouth resistance. The strains differed, however, in the time at which they reached the wilting coefficient. Strain No. 9, a base firing type with large stalks, reached the wilting coefficient 48 hours before the resistant strains, Nos. 4 and 6, while No. 3, a top firing strain, reached the wilting coefficient at about the same time as Nos. 4 and 6.

SUMMARY AND CONCLUSIONS

Studies were made to determine the causes of the diverse reactions of different inbred lines of corn with respect to their resistance to lodging and to drouth. It was desired to find structural differences which might be used to differentiate between erect and lodging types and anatomical, physiological or ecological differences to distinguish among strains differing in drouth resistance. With the present methods it is necessary to spend an entire season to determine the reaction of a given strain to lodging or drouth and even then if the conditions are not favorable for the development of lodging or injury by drouth the plant breeder has no basis for selection of desirable traits.

Field observations for a number of years in the corn improvement experiments on the Agronomy Farm have shown that inbred lines naturally fall into three types with respect to lodging: (a) The type that lodges by breaking of the stalk, (b) the type that lodges by uprooting the plant, and (c) the erect type. The consistency of the field behavior over a four year period of the inbred lines representing these three types leaves little doubt that a very distinct tendency to the characteristic lodging reaction of a line is inherited.

Marked differences were noted in the structure of the stems of the different strains. The erect type possessed thick layers of lignified sclerenchyma, both around the vascular elements and in the subepidermis. This characteristic was noted in all of the plants with strong stalks. The strains that were susceptible to the breaking type of lodging possessed small amounts of lignified sclerenchyma both around the vascular elements and in the subepidermis. The strain subject to the uprooting type of lodging possessed larger amounts of lignified sclerenchyma than the type that lodged by breaking, but less than the resistant type. The cause of lodging in the uprooting type was due to deficient root development.

Inbred lines also may be grouped into three types with respect to drouth resistance: (a) The type which fires at the top of the plant first, (b) the type in which the basal leaves fire first, and (c) the resistant type which endures moderately severe drouth conditions with little or no injury. Here again field observations extending over several dry years give conclusive evidence of the hereditary basis of the characteristic reactions of the inbred lines studied.

Electrical conductivity of plant tissue of the various lines was studied for possible correlations with drouth tolerance. The variability in the electrical conductivity measurements was too great to give significant differences among the strains. This paper therefore does not include the results of those experiments.

A greater degree of lignification was observed in the epidermis of the stem and leaves of the drouth resistant types than in the susceptible types.

The differences in the amount of water utilized per plant were not consistent with differences in drouth resistance. The water requirement, however, was lower for the top firing strains than for the resistant or base firing types. The strain most susceptible to base firing had a higher water requirement than the resistant type. Thus the resistant type was intermediate in water requirement between the top firing and base firing types.

The wilting coefficients of the four strains studied were found to be the same. The base firing type reached the wilting coefficient 48 hours sooner than the non-firing or top firing types due to a higher rate of utilization of water.

By testing 14 day old seedlings for 6.5 hours in a high temperature chamber with temperature controlled at 140° F. and relative humidity at 30 per cent, it was possible to separate accurately the three different types.

The top firing type showed marked injury in three to five hours, the base firing type in four to six hours, and the resistant type showed little or no injury after 6.5 hours. When placed under optimum growing conditions following the exposure to high temperature the survival of plants was 0 per cent in the base firing type, 0 to 25 per cent in the top firing type, and 50 to 100 per cent in the resistant type.

The differences reported in the structure of stems afford a possible means of selecting strong stalks which will aid materially in developing non-lodging varieties.

The study of seedlings of corn has shown marked differences among inbred lines in resistance to high temperature. The close relation between temperature response and drouth reactions in the field seems to give a simple and practical way of estimating drouth resistance among different inbred lines of corn. These methods require but a short time, are reasonably accurate, and can be employed at very moderate expense.

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