FIELD AND GREENHOUSE STUDIES ON THE REACTION OF MAIZE TO DROUGHT AND TEMPERATURE EXTREMES

by

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INTRODUCTION

Agriculture has been the basis of nearly all cultural advancement. It is interesting to note that maize is the only cereal in the world that could have formed the basis for a highly developed agriculture in America. Smaller cereals require the preparation of the entire surface of a field for their profitable production, a process that is feasible only by the aid of large laboring animals. Large plants, needing more room for development, and consequently having smaller numbers on a given area of land, can be grown in hills and require only a slight cultivation about each hill. The aboriginal American, having no large beast of burden, and thus being forced to perform all tillage of the soil by his own labor, found that maize, the largest of all cereals, was admirably suited to his needs. Thus maize became the basic crop of the New World.

Maize was widely distributed throughout America when the white settlers first arrived. Today it is to be found in all parts of this country and in all suitable agricultural areas of the world. The spread of agriculture into the more arid regions of this country has brought maize into an environment quite different from its original sub-tropical surroundings.

Kondo (1931) stated that in selecting a crop plant for a region where drought is an important limiting factor, one should choose a type in which the critical stage does not coincide with the most adverse meterological factors. Maize requires the full growing season for best development, and therefore does not fit into this scheme of selection very well. Its period of flowering comes at a time when the most adverse conditions of the entire season are apt to prevail. Damage done at this stage can never be repaired. Hodges (1931) showed a significant positive correlation between yield and July rainfall, and a negative correlation between yield and July temperature, although the former is more striking. Robb (1934) showed that the correlation of rainfall and yield of corn in northeast Kansas during the period of July 12 to 21 was higher than for any other ten-day period and that the average date of tasseling was July 14. He therefore concluded that time of tasseling is the most critical period in the life cycle.

In spite of the apparent unsuitability of corn to regions of low rainfall and high temperatures, it still remains a crop of considerable importance in these areas. It is therefore the task of the plant breeder to investigate the reactions of this crop to these conditions of heat and drought and to produce strains that are better able to survive the hot, dry climate so different from the humid sub-tropical environment under which maize first came into being as a distinct species.

Modern corn breeding has as its basis the isolation of pure lines or strains from the heterozygous and variable open-pollinated varieties by continued inbreeding. After a few years of self-pollination, as they approach homozygosity, these inbred lines become much reduced in size and vigor. However, when crosses are made between certain selected self-pollinated strains of corn, the resulting progeny is often superior in vigor, yielding ability and other desirable qualities to the open-pollinated corn from which the inbred lines originated. These crosses can be made in many different combinations involving different numbers of inbred lines, and thus form the hybrid corn which has come to be important in recent years. The millions of acres of hybrid corn grown today on farms throughout the United States testify to the success of this method of corn improvement.

Since these isolated strains or inbred lines are the basic material from which all hybrids are produced, the success or failure of any corn breeding program rests largely upon the skill with which the plant breeder has succeeded in fixing desirable qualities into his breeding material. Besides having yielding ability, sturdy roots, strong stalks, and resistance to disease and insect pests, the inbred lines produced in areas of limited rainfall must possess drought-resisting qualities to enable them to withstand periods of adverse weather. In fact, this latter character may be the most important of all, for without ability to withstand drought, a plant may never be able to manifest its other desirable characters.

Field selection for drought resistance is a very long and laborious task because the problem is complicated by many interacting factors. The reaction of a plant in the field is not the result of any one causal agent but rather the interaction of many factors, all of which influence the final expression of the genetic potentialities of the plant.

Aamodt (1935) mentioned two types of drought, soil and atmospheric. Soil drought occurs when the moisture content of the soil falls so low that it can no longer provide the plant with sufficient water to take the place of that lost by transpiration. Atmospheric drought is the result of hot, dry winds which may produce desiccation and killing of tissues even when there is abundant moisture in the soil. Soil drought is usually the more harmful of the two, but, when both of them occur together, as so often is the case in Kansas, disastrous results may be expected. It is impossible in the field to determine whether damage has been due to extreme temperatures or to insufficient moisture in the soil or in the atmosphere.

The uniform appearance of a field of corn or of a selected nursery row is not in itself an indication that each plant in the field or row has the same genetic makeup. The failure of one plant to appear different from the rest may be due merely to the lack of proper environmental conditions. One would not expect to find plants segregating for drought resistance under favorable conditions. Thus in selecting inbred lines for drought resistance, the plant breeder is forced to wait for suitable years in order to have the proper conditions of heat and drought to bring out the differences in his material.

The production of drought-tolerant crop varieties is important, but since field selection is such a difficult and uncertain method, agronomists and plant breeders have searched for an alternate means of selection. The substitution of artificial conditions of drought by use of a heat chamber was attempted by Shirley (1934) and has met with approval by many other workers using several different crops. Shirley and Meuli (1939) listed five points in favor of machine tests over field survival results:

1. Tests in the machine are free from other biological influences which disturb field tests.

2. Machine tests can be made any time, while field tests can be conducted only during dry periods.

3. Close control over environmental factors in the machine tests reduces variability of results.

4. Tests in the machine are of short duration and are thus well suited to study the fundamental nature of drought resistance.

5. Direct machine tests can be duplicated by workers in other regions, thus making possible a united attack on the intricate drought resistance problem.

Since corn requires the full growing season for its best growth and development, it is occasionally planted early enough so that a late spring frost or an extended period of cool weather may cause considerable damage. While this is a much more serious problem farther north, it would be worthwhile to note the reaction of corn to spring frost injury in this area. Of particular interest would be the comparison of lines of corn for relative tolerance to heat and cold injury.

The object of this study is to investigate the reaction of corn to drought and temperature extremes and particularly to study the correlation of field reaction with artificial tests conducted under greenhouse conditions.

REVIEW OF LITERATURE

Drought resistance has been considered in various ways by many different workers. Perhaps one of the best definitions is given by Maximov (1929b) who considered the principal basis of drought resistance to be the capacity of a plant to endure a greater loss of water and recover from serious wilting with a minimum of injury.

Much of the early work on drought resistance dealt with attempts to find some simple means of classifying plants into resistant or susceptible groups. The fact that plants normally adapted to desert conditions possess certain morphological modifications such as waxy surfaces, sunken and reduced stomata, and reduced leaf area has led workers to look for morphological differences between crop varieties that would indicate varying abilities to withstand drought conditions.

Vasiliev (1929) found no connection between drought resistance in wheats and stomata size or geographic origin. He believed that a study of the internal character of the plant was the only means that might lead to a knowledge of the properties of drought resistance. Haber (1938), working with inbred lines of sweet corn, found that transpiration rate, number of vascular bundles, number of stomata, and root volume all failed to give any indication of the drought reaction of the lines. Thus no anatomical or physical character studied offered a means of classifying strains for drought resistance.

Much early work indicated considerable variation in the water content of the soil at the time of wilting of different plants. This was interpreted to mean that some plants were capable of reducing the moisture content of a given soil to a lower level than were others and thus survive longer in times of drought. Briggs and Shantz (1912) grew plants in sealed containers with controlled amounts of water and found the variation in the water content of the soil at the time of wilting of different plants was much less than had been supposed and that it was insignificant compared to the range of water retentiveness exhibited by different soils. Their work (1914, 1917) showed also that the water economy of plants was not a suitable index of their drought reaction. Both corn and sorghum have lower water requirements than do certain Agropyrons and Brome grass although the latter are native to arid regions. Kiesselbach (1926) concluded that in selecting strains of corn for drought areas, water requirement tests need not be conducted since relative field performance under drought conditions is a more certain index of suitability for these conditions.

Haber (1938) reported that a pure line of corn isolated by Dr. M. T. Jenkins called rootless and having a root system so poor that it would not support the plant unaided was still fairly resistant to drought. This is interesting in view of the fact that considerable stress is given to the root systems of plants in relation to their drought reaction.

Shirley (1934) constructed a chamber in which entire plants could be exposed to drought conditions. His was perhaps the first apparatus of this type. Temperature was controlled by electric heating units and humidity by the use of calcium chloride. Young spruce trees were tested in the chamber and the length of survival under controlled conditions of temperature and humidity was used as a measure of drought tolerance.

Aamodt (1935), using a "drought machine", found, that under exposures of 110° F. at 14 per cent relative humidity for periods of 8 to 15 hours, plants known to be drought resistant from field reaction showed less injury than those that were known to be drought susceptible.

At the Kansas Station, Hunter, Laude, and Brunson (1936) were able to distinguish among strains of corn for drought resistance by exposing 14-day-old seedlings to a temperature of 140° F. and a relative humidity of 30 per cent for six and one-half hours. The same order of relative resistance was obtained with seedlings thus tested as was noted in the field for mature plants. They found that lines susceptible to base firing under field conditions were injured most quickly and showed least recovery. Lines susceptible to top firing were injured after a longer period of time and had intermediate recovery, while lines resistant in the field showed very little injury at the end of the test and made the best recovery.

Working with spring wheat, Bayles, Taylor, and Bartel (1937) exposed eight varieties, grown in four-inch pots, to a current of warm air and determined the relative water loss by weighing the pots at intervals.

Exposing various forage grasses and legumes to high temperature and low humidity for periods of 10, 16, and 20 hours, using both seedlings and sod, Schultz and Hayes (1938) were able to obtain satisfactory agreement between reaction to these artificial tests and field data over a period of two years. Haber (1938) found that the heat chamber made a satisfactory laboratory test for classifying his strains into resistant and susceptible groups.

At the Kansas Station, Heyne and Laude (1940) used the heat chamber to study drought reaction of inbred lines of corn. They found the stage of seedling development to have an important influence on the reaction of the plant to heat injury. At 10 days of age the seedlings were most resistant, after which time they decreased in resistance up to the 20-day stage. This was the most susceptible age for the seedlings, the resistance increasing somewhat after this time. Decapitation tests indicated that at 20 days of age the seedling had used up the reserve food in the endosperm and was independent of it for existence. Their work also indicated that exposure to light tended to increase the resistance of plants to heat injury.

Their results with the heat chamber showed a close agreement with field reaction. Lines that were most resistant in the field showed, as a rule, the least damage in the heat chamber. They concluded that the heat chamber is a useful supplement to field observations for selecting drought-resistant breeding material and that it can be relied upon with considerable assurance for distinguishing genetic differences in the drought tolerance of different strains of maize.

Tumanov (1926), Krasnosselsky-Maximov and Kondo (1933), and Shirley and Meuli (1939), working with different crops, found that hardening plants to moderate soil drought made them much more resistant to wilting. Aamodt and Johnson (1936) found this to be true with both resistant and susceptible strains of spring wheat. Varietal differences were minimized by hardening before exposure to drought. It seemed possible, however, according to these workers, that greater varietal differences might have been apparent had exposures been more severe so as to overcome the somewhat tolerating influence of the hardening process.

Kondo (1931) found that hardening plants of the sunflower and soybean did not lead to equally positive effects. It might be that the capacity for hardening was a specific magnitude for each plant. Kondo believed that subjecting plants to wilt could give an idea of only one of the most important properties of the plant and not an exhaustive diagnosis of its behavior during drought.

Krasnosselsky-Maximov (1931) found it necessary to distinguish between "windburn", provoked by disturbance of the water balance of the plant, and "scorch", the result of the influence of high temperature. Results of this work showed that plants suffered from dry wind differently at different stages of development. They were least injured at time of waxy ripeness. Dry wind was found to injure plants more the greater the soil moisture deficiency. Thus plants on soil of low water-holding capacity were injured more than those on soil of high water-holding capacity.

In an extensive study of wilting, Tumanov (1929) found that plants varied a great deal in their ability to withstand desiccation. Millet was able to withstand a water deficit of 80 per cent, while oat leaves died with a water deficit of 60 per cent, and beans were unable to survive a deficit of 27 to 33 per cent. Plants varied a great deal in their ability to recover from drought. With good conditions millet was able to recover from long and severe wilting and yield almost as well as control plants, while oats under the same conditions, after wilting, showed no further accumulation of dry substance.

Under conditions of hot, dry weather in Iowa, Jenkins (1931) noted marked differences in the resistance of inbred lines of corn and their single crosses to leaf burning. One inbred line apparently carried dominant factors for resistance, for all the single crosses in which it occurred were resistant to leaf burning. Comparable crosses involving another line were all susceptible, indicating that it must have carried dominant factors for susceptibility. Unfortunately a cross between the resistant and the susceptible line was not available. It was interesting to note that the line carrying dominant factors for resistance was also well above average in yield. These data indicated that much might be accomplished in breeding for drought resistance.

Extensive work on the physico-chemical nature of drought resistance was conducted by Newton and Martin (1930). They reported that under exposure to frost, desiccation occurred as a result of water streaming from the interior of cells to form ice crystals in the intercellular spaces; while under ordinary conditions of drought, the force of crystallization was replaced by the force of evaporation, and water was lost into the atmosphere. Any force that opposed the abstraction of water would act as a resisting agent against drought injury. They regarded the imbibition pressure of hydrophilic colloids as the most significant of such factors.

Since withdrawal of water from the plant tissues is one of the causes of injury from both drought and frost, Lebedinzev (1929-30) considered that there was a relationship between the cold and drought resistance of plants and their capacity to retain water. Winter wheat plants that were hardened to drought had a greater water-retaining capacity than those not so hardened. Likewise, when winter wheats were hardened to cold, the most cold-resistant lines had a greater water-retaining capacity than did the non resistant lines.

Maximov (1929b) gave two principal methods of studying the correlation of drought and frost resistance in plants: first, a study of the processes taking place during the hardening of the plant to frost and drought, and, second, a comparison of the chemical composition and physical properties of plants systematically allied as closely as possible but differing in their degree of frost and drought resistance. Drought studies are the more complex because of the greater diversity of methods by which plants avoid too great a loss of water. If the external means of protection of the plant from desiccation are overlooked and the fundamental statement assumed that drought resistance is the capacity of enduring permanent wilting, then there is a rather close analogy between the ability of a plant to resist cold and drought. The protective influences of the accumulation of water-soluble substances in the plant cell and of the greater accumulation of hydrophilic colloids operate in both drought and cold resistance. Maximov cautioned, however, that this analogy between cold and drought injury must not be understood as an absolute identity since drought-resistant plants are not always frost resistant and vice versa.

Spring frost injury to the spring grains in the northern part of this country and southern Canada is usually not serious enough to warrant attention, the damage being manifested only as the shriveled tips of the upper leaves of the seedlings. In some years, however, the damage may be quite severe. Waldron (1931) estimated a reduction of 38 per cent in the yield of Hope, a spring wheat, as a result of injury from a late spring frost. He arranged five varieties tentatively in the order of their resistance to frost and found, in general, a positive relationship between frost and drought resistance using yields under semi-arid conditions as a measure of drought reaction. Harrington (1936) in a report of a late frost in Saskatoon, Canada, found that spring wheats with a large amount of warm climate ancestry tended to be susceptible, while those varieties whose ancestors were mostly from a cold climate tended to be resistant.

Inbred lines of corn were found to react quite differently to low temperatures by Smith (1935) working at Wisconsin. When grown at temperatures of 61° to 66° F., one inbred line was a normal green color, while another was virescent, having very little chlorophyll. Both were normal green at 74° F. At the cooler temperatures the virescent seedling was quite susceptible to Gibberella seedling blight, while the other one maintained its resistance. The F_1 progeny were as resistant as the resistant parent. It is interesting to note, however, that the resistant x susceptible cross showed more resistance than did the reciprocal.

Sherwood (1937) believed that cold tolerance in corn is a function of proteins, variations in reaction being due to nutritional differences. The proteins may vary in quality, in quantity, or both. Exposure to certain chemical salts may cause differences in cold response, the reaction being attributed to the effect upon nutrition. If a protein not needed for an immediate function were injured in the plant, this injury would probably not show up until later in life when the normal function of the plant necessitated use of the particular protein injured. This, according to Sherwood, may account for cold injury effects which are not apparent at the time of exposure but which show up later in the life of the plant.

Sellschop and Salmon (1928) found that cowpeas, peanuts, maize, and velvet beans exposed to chilling temperatures above the freezing point were far more severely injured in wet than in dry soil. Working with wheat seedlings, Klages (1926) found that, due to the greater vegetative activity of plants grown in moist soils, killing from exposure to cold begins on them sooner but progresses more slowly than on plants grown in dry soil. Plants grown in dry soil have retarded vegetative activity which exerts a protective influence during the first part of exposure but after killing sets in, it progresses rapidly. The per cent survival was higher on the moist soil in these tests than in dry soil.

Reducing soil moisture as low as incipient wilting did not markedly harden any of the alfalfa varieties that Tysdal (1933) worked with. However, plants kept severely wilted for 10 to 14 days and then frozen in the severely wilted condition were very much more resistant to cold than those watered normally. His data showed that hardening brought out greater varietal differentiation in the resistance to cold of alfalfa.

Suneson and Peltier (1934b) studied the age of wheat seedlings in regard to their response to cold. Very young seedlings still dependent on the endosperm excelled all others in cold tolerance, while those on the verge of endosperm dependence were least hardy. This was in line with Kalges' (1926) work which showed that wheat seedlings became more susceptible to low temperatures as they grew older.

Dunn (1937) reported that individual plants within a group varied in their reaction to cold. Growing cabbage at different levels of soil moisture did not eliminate variations in hardiness within a group, nor did it increase the average hardiness of any group. Likewise, high and low levels of the nutrients nitrogen, phosphorus, or potassium did not affect the degree or uniformity of hardiness in cabbage. Cool growing temperatures for potatoes and cabbage did not eliminate individual variations within a group but did cause greater average survival from freezing as compared with plants grown at warmer temperatures.

Investigations on the effect of several environmental factors on the hardening of plants led Dexter (1933) to conclude that hardening of plants to cold was favored by conditions which tended toward the accumulation or conservation of reserve foods; that is, which furthered photosynthesis and lessened respiration and extension of vegetative parts.

Suneson and Peltier (1934a) grew four varieties of winter wheat in flats out of doors at Lincoln, Nebraska. These were tested periodically in a cold chamber to determine their resistance to cold. As winter progressed they became more hardy up until January after which time hardiness decreased. Also the relative hardiness of the varieties changed as the season progressed. This relative change in hardiness may explain some discrepancies in local field trials. These investigators cautioned workers against a general application of results based upon one particular period or any one specific field condition.

The frost resistance of winter wheat seedlings depends a great deal on the temperatures at which they were germinated according to work by Tumanov and Borodin (1929). Their work showed a close correlation between frost resistance as determined by artificial freezing and as determined by observations of field conditions. The only divergences were when the differences were very small and these were explained by the fact that in the field it was not so much frost resistance as winter hardiness that was determined.

Scarth and Levitt (1937) believed that in the case of cold injury temperature may be only indirectly associated with the cause of death since soil heaving, smothering by ice and physiological drought all may be involved. The time factor would seem to involve a mechanism different from that responsible for immediate killing. They listed several changes that are associated with hardiness. A complicated hydrolytic breakdown of carbohydrates increases the osmotic pressure of the cell. Due to changes in the protoplasmic colloids the whole cytoplasm probably, and the plasmic membrane almost certainly, become more hydrated. As a consequence of this change, the viscosity of the protoplasm is lowered. Because of this change in the membranes, the cell permeability is increased. The significance of all of these changes is not known, nor is their relation to each other fully worked out. These workers felt that much more work is necessary on this subject.

Two types of freezing in plant cells were listed by Siminovitch and Scarth (1938). In intracellular freezing, ice crystals formed first in the protoplasm and then in the vacuole. In extracellular freezing the ice formed outside the cell from water in the cell. The resulting dehydration of the cell caused it to collapse, the opposite walls coming together and squeezing the contents to the periphery. Intracellular freezing was fatal to all cells by mechanical disruption of the protoplasm and vacuole and occurred less in hardy tissues than in non-hardy tissues. Extracellular freezing induced by slow cooling was fatal to all unhardy cells in trees and shrubs at all temperatures below freezing, but not to cells of hardy trees and shrubs. Intracellular freezing tended to be prevented in hardy plants by an increased permeability.

MATERIALS AND METHODS

In order to study the effect of drought and temperature extremes on corn, this problem was approached in several different ways. Factors on which it seemed desirable to collect information were: (1) the effect of drought damage on the actual grain yield of the plant: (2) correlation of field data with greenhouse tests of drought and cold reaction; (3) the effect on the severity of damage to the plant of the time in its life cycle that the drought occurs; and (4) the location of chromosomes carrying factors for drought resistance.

To study the effect of drought damage on the yield of grain, a number of crosses were made between inbred lines of corn that differed in their reaction to drought. These crosses were self-pollinated, and the F_2 seed thus obtained was planted in the spring of 1939 at the Agronomy Farm, Manhattan, Kansas. The corn was surface planted in rows 42 inches apart with the plants spaced 21 inches apart in rows. Two seeds were dropped at each place and later thinned to one plant so as to insure a uniform stand. About 100 plants of each F_2 population were grown, depending upon the supply of seed available.

It was expected that each cross would segregate in the F_2 generation for a number of characters, one of which would be its reaction to drought. By classifying the plants into various grades of resistance or susceptibility and by recording the weight of grain produced by each plant, it was hoped to gain evidence on the degree of correlation, if any, between heat and drought damage and the yield of grain.

July, 1939, was extremely hot and dry. As a result, the drought damage was so severe that many of the plants failed to reach maturity, and very few produced any grain at all. Although there was considerable difference in the degree of damage between plants in the same population, the degree of injury was too severe to permit accurate classification. Since the plants which produced grain were so few and the amount produced was so small, there was no opportunity to make correlations between drought damage and yield as had been originally intended. Therefore, no data were collected from this test.

A source of data concerning this problem was found, however, in the results of the Kansas Corn Tests by Clapp, Jugenheimer, Hollembeak, and Skold (1939). The Kansas Corn Performance trials were conducted in five districts of the eastern half of the state in 1939. About 70 varieties and hybrids from several states were grown in replicated yield tests, two fields being planted in each district. Data were obtained in only four districts and in some cases from only one field of each district due to the adverse growing conditions throughout the summer in many of the areas.

Notes were taken during the first week in July on the degree of firing of each hybrid in the test. Firing is defined as the relative amount of leaf tissue killed as a result of heat and drought. Grain yields were taken in the fall when the plants were fully matured. All of this procedure and the data are included in the report of these tests, Clapp et. al. (1939). In the present study these data were used to make a statistical analysis of the correlation between drought damage and grain yield.

The study of the correlation between field and greenhouse data was made primarily for the purpose of determining whether or not subjecting seedlings to artificial tests of drought in the greenhouse is an accurate index of their reaction to drought in the field. A secondary objective was to determine whether or not lines resistant to drought damage would also be resistant to cold injury.

For this study lines were selected from the breeding material of the corn improvement project at Kansas State College. Four lines were used and were selected on the basis of their field records in the inbred nursery over a period of years. Since these lines had been selected and developed with drought resistance in mind, undoubtedly they all carried factors for resistance. However, this selection has been more successful with two of the lines than with others, Ind. 38-11 and K 148 being considered as drought resistant and K 214 and K 151 as susceptible.

Of the four lines used, three were developed at this station. The records of their performance in the selfing nursery could be traced back as far as 1932. In only a few years, however, were growing conditions suitable to show differences in reaction, some being too severe and some too favorable for the variations in reaction to be apparent. The one line developed away from the Kansas Station originated at Indiana and has been used extensively in Kansas in recent breeding work. Its reaction in the selfing nursery at Manhattan the past two years showed it to be resistant to drought.

Crosses were made between these lines to include four single crosses, the F_2 lines of these single crosses and eight backcrosses. This series of 20 entries, including the four inbreds, was planted in the field at Manhattan, Kansas, in 1939 in single row plots 19 plants long. Plants were spaced 21 inches apart in the row and the distance between rows was 42 inches. Two seeds were dropped at each place and later thinned to a single plant to insure a more perfect stand. The test was replicated five times, distribution of entries in each replication being random. Since the inbred lines were smaller and less vigorous than the crosses, it was felt that the border effect between adjacent rows of an inbred and a cross might cause unfair competition between them. Therefore, when the plot arrangement was such that an inbred came next to a cross, two border rows, one an inbred and one a cross, were planted between them.

The date at which one-half of the plants in each plot shed pollen and the date at which silks emerged was recorded for all replications, the plots being checked every other day. The grade of firing of each plot was also taken on this test. This was recorded in ten grades, a grade of one indicating less than ten per cent of the leaf area fired, a grade of ten indicating 91 to 100 per cent injury and the eight intermediate grades referring to corresponding degrees of damage.

The same series of 20 entries was tested in the seedling stage in the greenhouse during the past winter by application of artificial drought and cold tests. The seedlings were grown in a uniform sandy loam soil in four-inch clay pots. Seven seeds were planted in each pot and later thinned to five. The pots were kept at approximately optimum moisture content, although no attempt was made to control this accurately. The arrangements of the pots on the greenhouse bench was changed every few days to lessen the possibility of more favorable locations on certain pots.

Since Heyne and Laude (1940) found that seedlings are most susceptible to drought damage at 20 days of age and that differences between lines are then most apparent, the seedlings were tested at this stage.

A heat chamber was used to produce conditions of artificial atmospheric drought for this test. It consisted of a room six feet long, five feet wide and nine feet high. The room was heated by air blown over a steam radiator. The velocity of air movement in the room could be regulated but was kept at 81.5 feet per minute for these tests. Relative humidity was increased by allowing steam to escape from a nozzle into the air stream and decreased by admitting fresh air from the outside. This latter method also served to decrease the temperature. A series of baffles and dampers controlled the path of the air and were regulated by a thermostat and humidistat which thus controlled the temperature and relative humidity of the air in the room. The seedling plants were set on a turntable five feet in diameter located in the center of the room and driven by an electric motor at a speed of 1.2 revolutions per minute. Although the heat chamber was not illuminated for these tests, it could be lighted by four 250-watt bulbs.

The table in the heat chamber readily accommodated 80 four-inch clay pots. Therefore four series of the 20 entries were run in each test. The test was repeated five times so that in the entire test 20 pots of each kind of corn were exposed to artificial drought. Distribution of the pots within each series was at random, but the four series were arranged in concentric circles around the table. The plants were put in the chamber at about nine o'clock in the morning and left six and one-half hours. Temperature was kept as close to 130° F. as possible and relative humidity at 22 per cent.

The pots were watered thoroughly the night before the test and again the morning following the test. Drying was not excessive, and it is believed that atmospheric drought was the only type of drought injury involved, although high temperature was undoubtedly the cause of a great deal of the damage. Three days after the test, readings were taken on the percentage of injured leaf tissue, with the pot taken as the unit. About ten days after the test the percentage of plants surviving in each pot was recorded.

Tests for cold injury were made in the greenhouse in a chamber especially constructed for low temperature studies. The interior of the chamber was about ten feet long, four feet wide, and three feet deep. The walls were insulated by cork and protected by cement, the entire thickness being about 12 inches. The cooling coils were about six inches away from the four walls and the floor. Support for the pots was furnished by boards running lengthwise just above the cooling coils on the floor. Opening into the chamber was furnished by doors 42 by 24 inches on the top of the chamber.

Cooling was effected by a carbon dioxide refrigeration plant thermostatically controlled. It was possible to maintain the desired temperature within 2° or 3°. Pots were kept at least six inches away from the coils. Distribution of pots was at random in the chamber within each series. The chamber accommodated 40 pots very well so that two complete series could be run each trial. For the last few trials an electric fan was put in one end of the chamber to keep the air circulating in order to reduce possible temperature differences in various parts of the chamber. Baffles were provided to keep a direct current of air from falling on the plants.

The temperature was set as close as possible to 31° F., however, it fluctuated from 1° to $1\frac{1}{2}$° each way from this. A run of eight and one-half hours gave a satisfactory test, producing about the desired amount of injury. There was considerable difference in the degree of damage between trials, however; in some trials all the plants being badly injured and in other trials none of them receiving much injury. Of 14 trials, only six were considered to be at the correct level of injury for satisfactory comparisons, and only these are reported here. At the end of each test the top one-fourth inch of soil of each pot would be frozen solid. Undoubtedly the temperature was so near to the critical point that slight differences in temperature or in the resistance of the plants made a great deal of difference in the amount of injury produced. Time of day was also a factor. Of the six trials used in this study, all were started between 10 o'clock in the morning and noon. The pots did not dry much during the exposure to cold; watering the evening before the test and the morning after kept them at about the optimum moisture content. The data were recorded for these cold tests in the same manner as for the heat tests, as per cent of leaf area damaged three days after the test and per cent survival ten days after. The same series of 20 entries was tested for cold tolerance that had been tested for drought tolerance in the field and in the heat chamber.

To study the water economy of these same lines of corn and their ability to withstand wilting, a test was conducted using controlled amounts of water. The four inbred lines and their F_1 single crosses were the only ones used in this test because of the limited facilities. They were grown under limited moisture conditions until wilting, and, finally, death occurred.

Soil for this test was mixed thoroughly and 1750 gms. added to each of 30 one-half gallon porcelain crocks. Then 250 cc. of water was added to each crock and the surface sealed by pouring a thin layer of melted paraffin over it. While the paraffin seal was still soft, 13 holes were punched in the surface of each pot and seeds were planted in the holes. The stand was later reduced to eight plants per pot. Four pots were planted to each inbred line and three to each single cross. The remaining two were left unplanted to check on the amount of water lost by evaporation through the holes in the seal.

Distribution of water in the pots may not have been entirely uniform since the soil was not wet enough to insure thorough distribution. However, since no means of aeration was provided, it was felt that it would be unwise to bring the soil moisture to an excessively high level and thus exclude too much air from the soil. Growth proceeded normally so that lack of air in the soil probably was not a factor. No more water was added to the crocks, and the seedlings, after a period of normal growth, wilted and died. Data were taken on the relative severity of wilting, the amount of water used, and the amount of dry matter produced.

The third main objective in this study of drought resistance was to investigate the effect on the severity of damage to the plant depending upon the time in its life cycle that drought occurs. For this study ten inbred lines that had been top-crossed with the Hays Golden variety were selected. These were planted in a replicated test in the field at Manhattan, Kansas, in 1939. Plantings were made at two-week intervals, the first date being March 18, and the last June 24. At each date of planting the ten top-crossed lines were planted in adjacent plots in each of the three replications. The lines were randomized within each date of planting, and the planting dates were distributed at random within each replication. Plots were two hills wide and five hills long, the hills being 42 inches apart each way. Three kernels were dropped at each hill and later thinned to two plants at each place.

The original plan was to plant early enough so that the first date of planting would receive some frost injury. Then later observations of the injured plants and plants of the same lines planted later in the season might indicate to what extent early frost injury affected the drought reaction of the plant and to what extent frost resistant lines tended to be drought resistant. By having widely spaced planting dates, the lines of corn would also be exposed to the most severe drought while they were at different stages of development. Thus data might be obtained as to the effect of the stage of development on the damage done by drought.

No frosts after March 18 in 1939 caused injury to corn, so it was not possible to secure data on the differential frost tolerance of the lines. Stand counts were taken a week after emergence and also after thinning. Date of pollen shedding and silking was recorded as well as the height of the mature plant. Plant height was recorded as an average for the plot and taken to the nearest six inches. The stands for the earliest dates of planting were very poor and in the later dates of planting the corn was still young when a severe infestation of chinch bugs occurred. These factors, together with the extremely hot and dry weather of July which prevented normal plant development, made all of the data of doubtful value. Firing data were taken for all plots, but it is not known whether the differences were due to differential chinch bug injury and abnormal competition due to poor stands or due to inherent differences in the ability of the plants to resist drought. The data on plant height and dates of pollen shedding and silking were also influenced by these factors.

Studies on the inheritance of drought resistance were started by using seed furnished by E. G. Heyne. During the winter of 1936-37 Heyne (1938), in a study of the inheritance of drought resistance in corn, made a number of crosses involving translocation stocks obtained from Dr. E. G. Anderson of the California Institute of Technology. In the various translocation stocks used, all ten chromosomes were represented. These stocks were used as susceptible parents and crossed with various lines of known drought resistance. The seed from these greenhouse crosses, heterozygous for drought reaction and for the translocation chromosomes, was planted in the field the following summer, and these plants were backcrossed to inbred lines of known drought resistance and of known drought susceptibility.

If the resistant condition of drought reaction is dominant, the progeny of the translocation hybrids crossed on to the susceptible inbreds would be expected to segregate for drought reaction and if the susceptible condition is dominant, the progeny of the crosses with resistant inbreds would segregate. Since the F_1's of the first cross between the translocation stocks and the normal resistant inbreds were all heterozygous for the translocation chromosomes, the progeny of the second cross on to the normal inbreds would be one-half normal and one-half heterozygous for the translocation chromosomes. Plants heterozygous for the translocation chromosomes exhibit semi-sterility in the ear and in the pollen. Thus a group of crosses was developed that contained progeny segregating for drought resistance and for semi-sterility.

Since the semi-sterile or translocation chromosomes came from the susceptible parent, if the plants in the progeny of a certain cross segregate for drought reaction and the semi-sterile plants are the susceptible ones, it would be good evidence that one or both of the chromosomes involved in the translocation carry factors for susceptibility. Thus by using several translocation stocks in making the crosses, it might be possible to locate the chromosome or chromosomes that are concerned with the inheritance of resistance to d rought.

Seed of 43 of these crosses, representing translocations involving all ten chromosomes, was planted in the field in 1939 at Manhattan, Kansas. The plan was to grade the plants in each cross for the degree of firing and to examine the pollen of each plant for semi-sterility. If an association appeared between drought susceptibility and semi-sterility in some of the crosses, it would shed light on the genetic basis of the inheritance of drought resistance and indicate that certain chromosomes were essentially concerned with the inheritance of drought resistance. However, the unduly hot and dry weather during the month of July severely injured all of the plants, most of which tended to be rather susceptible, and made classification of injury impossible because it was all too severe. In some of the rows more than 90 per cent of the leaf surface was burned and many of the plants failed to shed any pollen at all. Thus no useful information was obtained from this test.

EXPERIMENTAL DATA

The daily rainfall and maximum air temperature at the Agronomy Farm, Manhattan, Kansas, for the months of June and July, 1939, are shown in Table 1.[1] The temperatures in June were about normal and the rainfall was greatest since 1929. July was very hot and dry, the rainfall being well below normal and the temperature considerably above. The severity of weather conditions during this month was sufficient to invalidate much of the experimental work of this problem.

The effect of firing on the actual grain yield of corn is shown by data taken from Clapp, et al. (1939). Replicated yield trials were planted in the spring of 1939 in five districts of the state, the locations of which are shown in Fig. 1. Varieties and hybrids from several states were included in these tests, and there were 60 or 70 kinds of corn in each district. No data were collected in district three because of poor stands and non-uniform conditions which made the test unreliable. The data used were the yields of grain in bushels per acre and the per cent of firing for each kind of corn. These data are presented in Table 2.

Using this information, a statistical analysis was made to determine the degree of correlation between yield and firing in these

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[1] Weather records of the Agronomy Department, Kansas Agricultural Experiment Station.

Table 1. The daily rainfall and maximum air temperature at the Agronomy Farm, Manhattan, Kansas, for the months of June and July, 1939.

Date	June		July	
	Temperature	Rainfall	Temperature	Rainfall
1	90		87	.37
2	89	.49	79	
3	79		88	
4	80		93	
5	85		98	
6	89		103	
7	96		105	
8	97	.71	102	
9	88	.18	93	
10	88	1.62	95	
11	68		96	
12	71	.03	104	
13	72	.23	110	
14	77	.02	104	
15	89		105	
16	96		107	
17	99		106	.04
18	96		103	
19	98	3.17	91	.15
20	82		91	
21	83	.38	101	
22	83	.02	100	
23	84		92	.01
24	90		93	.05
25	84	.35	95	
26	87	.17	104	.66
27	87		100	
28	90		102	.03
29	90		92	
30	87		88	
31			95	
	Mean 86.4	Total 7.37	Mean 97.5	Total 1.31

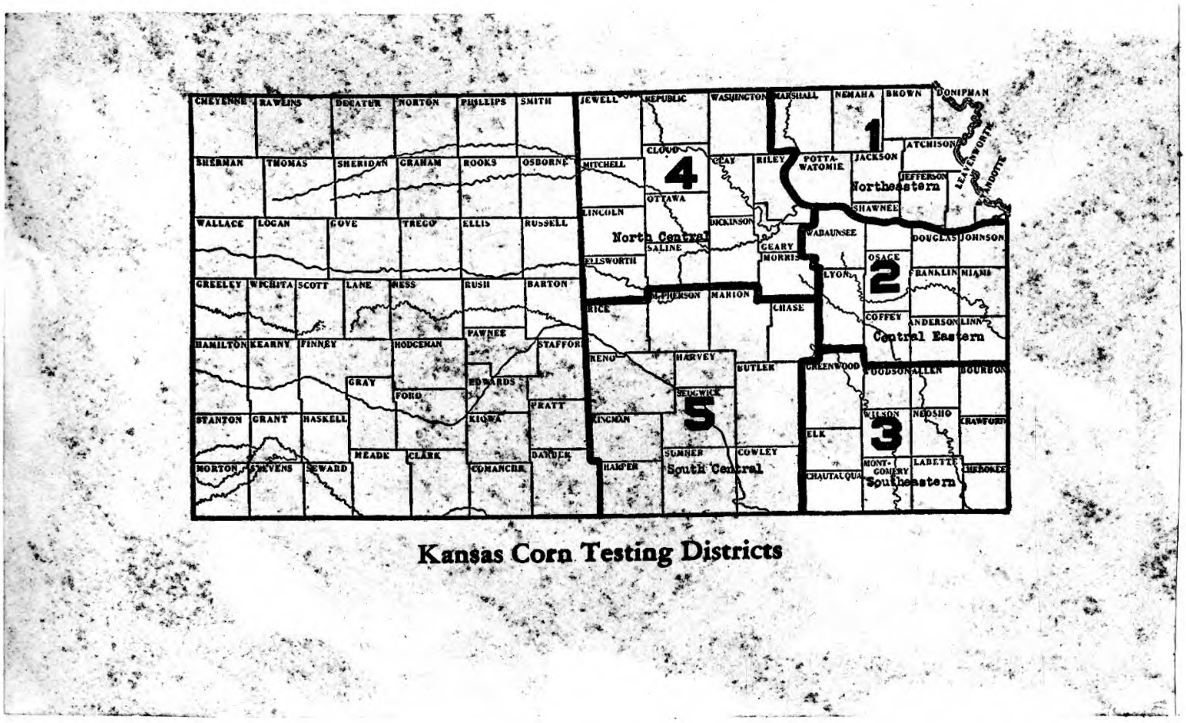


Figure 1. Location of the districts in which replicated yield trials were conducted for the Kansas Corn Tests, 1939.

Table 2. The yield of grain in bushels per acre and the per cent leaf surface fired of each kind of corn entered in the Kansas Corn Performance Tests, 1939.

District 1				District 2			
Yield	Firing	Yield	Firing	Yield	Firing	Yield	Firing
84.3	18	71.3	15	45.7	25	29.7	25
84.3	13	71.0	15	44.4	30	29.7	35
83.1	15	69.4	15	41.6	25	29.6	30
82.6	15	68.2	18	40.1	30	29.3	25
81.9	20	68.2	15	40.1	20	29.2	45
81.0	15	68.0	23	40.0	30	29.2	35
80.9	10	67.8	12	39.7	20	28.4	30
80.5	18	67.2	12	39.4	30	28.4	30
79.9	15	67.0	15	38.7	30	28.2	30
79.3	15	66.6	15	38.7	30	28.1	25
78.6	10	66.6	12	38.5	40	28.0	45
77.8	18	66.2	18	38.0	30	27.6	30
76.9	13	66.0	18	37.2	25	27.3	35
76.7	20	65.9	15	37.0	35	27.2	35
76.6	20	65.4	12	36.4	25	27.1	40
76.4	12	65.4	25	36.4	40	26.5	30
76.1	28	64.9	15	35.2	25	26.3	55
75.3	15	64.8	15	34.9	30	26.2	20
75.2	20	64.5	15	34.6	25	26.2	35
75.0	15	64.0	18	34.1	35	25.5	45
74.8	12	63.8	15	33.7	35	25.5	25
74.6	10	63.3	15	33.7	30	25.3	30
74.6	18	62.9	12	33.5	35	24.2	35
74.4	20	62.8	12	33.1	20	24.0	30
74.4	12	62.0	12	32.8	35	24.0	35
74.1	15	61.8	20	32.4	45	23.0	40
74.0	12	61.5	23	32.3	40	23.0	25
73.8	15	61.4	12	32.2	30	22.7	35
73.3	23	61.0	15	32.2	30	22.6	20
73.2	15	59.5	15	30.8	30	21.0	30
73.1	15	59.4	10	30.8	30	20.6	35
72.9	15	54.6	25	30.5	25	20.2	35
72.6	12	54.5	23	30.3	35	18.9	30
71.9	12	53.5	15	30.1	35	17.6	35
71.8	12	53.0	18	29.9	30	15.1	30

Table 2. (Continued)

District 4				District 5			
Yield	Firing	Yield	Firing	Yield	Firing	Yield	Firing
23.2	20	14.4	20	41.8	14	34.6	34
23.1	22	14.3	30	40.5	12	34.2	34
22.7	20	14.0	34	40.2	30	33.8	16
22.0	16	14.0	34	40.1	18	33.7	24
21.9	26	13.8	34	39.5	14	33.5	24
21.2	26	13.7	34	39.5	14	33.3	18
21.0	22	13.6	30	39.4	14	33.3	46
20.9	18	13.5	30	39.3	30	33.3	28
20.8	26	13.3	30	38.7	18	33.1	26
20.5	22	13.2	34	38.1	20	33.0	20
20.5	24	12.9	40	38.1	44	33.0	22
20.2	28	12.5	36	37.8	24	32.9	28
20.2	16	12.3	24	37.6	24	32.9	46
20.0	24	12.2	36	37.6	18	32.7	26
19.8	20	12.2	40	37.4	36	32.6	34
19.2	20	11.9	32	37.4	20	32.4	20
19.0	20	11.7	30	37.3	12	32.2	46
18.0	18	11.3	34	36.8	52	32.2	40
17.9	26	11.2	22	36.7	18	32.1	16
17.7	36	10.6	36	36.7	28	31.9	42
17.6	30	10.5	22	36.7	32	31.7	62
16.8	32	9.8	30	36.7	16	31.7	20
16.7	20	9.5	32	36.5	18	31.5	22
16.7	32	9.5	28	35.7	20	30.4	14
16.0	34	9.4	26	35.6	20	29.0	34
15.8	28	8.9	32	35.4	16	29.0	30
15.5	32	8.8	30	35.2	30	28.9	44
15.4	34	8.2	34	35.2	22	27.4	30
15.4	28	8.2	34	35.0	36	27.0	48
14.8	38	7.7	26	34.8	12	27.0	16

District	Number of Observations	r value	Level of Significance	
			5% level	1% level
1	70	-.671**	.232	.305
2	70	-.214	.232	.305
4	60	-.568**	.250	.325
5	60	-.353**	.250	.325

**Highly significant difference

performance trials. The correlation equation used in this study was

$$r = \frac{SAX - (SA)\ Mx}{\sqrt{SA^2 - (SA)\ Ma}\ \sqrt{SX^2 - (SX)\ Mx}}$$

In the equation r refers to the coefficient of correlation, X to the yield of grain, A to the per cent of firing, and S and M are statistical symbols referring to summation and mean respectively. The level of significance was obtained from tables in Fisher (1936). The results of these analyses, shown also in Table 2, indicate a highly significant negative correlation between yield and firing in three of the four districts studied. This indicates that types of corn resistant to drought have an advantage in yield over non-resistant types during years when drought damage occurs.

The study of the correlation of field and greenhouse data was undertaken using four inbred lines. These lines, selected from the Kansas breeding material are all being used at the present time in the corn improvement work at this station. Many of the experimental hybrids now being tested contain one or more of these inbred lines. Notes taken in the selfing nursery since 1932 show the reaction of three of these lines. The other line, developed at Indiana, has been included in the nursery in more recent years. Designations of these lines and their drought reaction, as indicated by observations in the selfing nursery over a period of years, are shown in Table 3.

A detasseling block was planted in 1939 to obtain seed of the cross R1 x S2. Plate I shows a picture of this field. S2 is planted

Table 3. Drought reaction in the selfing nursery over a period of years for the four inbred lines used in field and greenhouse studies of drought and temperature extremes.

Drought Reaction in:	Official and Temporary Designation of Lines			
	Ind. 38-11 R1	K 148 R2	K 214 S1	K 151 S2
1939	Resistant	Resistant	Susceptible	Susceptible
1938	Very Resistant	Very Resistant	Susceptible	Medium
1937			Medium	Top Firing
1936		Very Resistant	Quite Resistant	Susceptible
1935				Some Top Firing
1934		Resistant		Severe Firing
1933		Some Top Firing		Top Firing
1932				
1931				Slight Top Firing
1930			Top Firing	

EXPLANATION OF PLATE I

Differences in field firing of two inbred lines. S2, planted every third row, shows marked top firing. R1, the other line, shows very little drought injury.

PLATE I

every third row and shows a great deal of top-firing while R1 does not show an appreciable amount of drought damage. Illustrations are not available of R2 and S1, but they might be expected to show about the same differences.

A field test involving ten inbred lines, top-crossed with the Hays Golden variety, and planted at eight different dates, was described previously in this paper under a different section. The four inbred lines described in Table 3 were included in this test. Their relative behavior to drought is shown in Table 4 which gives the order of their ranking of drought resistance for the eight dates of planting. A rank of one indicates the most resistant of the four lines for a certain planting date, and a rank of four, the most susceptible. These data indicate that R2 is most resistant, followed in order by R1, S1, and S2.

A series of 20 entries involving these four inbreds and crosses between them was planted in the field in 1939 after the manner described earlier in this paper. Data on firing, days from planting to one-half pollen, and days from planting to one-half silking, recorded as average conditions for each plot, are presented in Table 5.

Analyses of variance for these data are shown in Table 6. It will be noted that the relative differences in firing between the entries is not statistically significant. However, the analysis shows a considerable trend in that direction. The ranking of the entries is entirely in accord with the data shown in Table 4 for the relative

Table 4. Relative rank in firing of four inbred lines topcrossed with the Hays Golden variety and planted at various dates at Manhattan, Kansas, 1939. A rating of one is best, and four is poorest.

	R1	R2	S1	S2
March 18	1	2	3	4
April 1	2	1	3	4
April 19	2	1	4	3
May 1	3	1	1	4
May 13	3	2	1	4
May 27	1	2	3	3
June 10	1	3	2	3
June 24	1	1	3	3
Mean	1.8	1.6	2.5	3.5

Table 5. Per cent firing, number of days from planting to one-half pollen, and number of days from planting to one-half silking for four inbred lines and 16 crosses grown at Manhattan, Kansas, 1939.

Kind of Corn	Per cent Firing						Days to One-half Pollen						Days to One-half Silking					
	Replication						Replication						Replication					
	1	2	3	4	5	Mean	1	2	3	4	5	Mean	1	2	3	4	5	Mean
R1xR2	10	20	50	10	10	20	67	67	69	69	67	68	73	75	91	75	73	77
R1xS1	20	20	50	20	20	26	76	72	71	73	71	73	82	77	90	78	79	81
R2xS2	20	40	60	20	20	32	71	67	67	67	66	68	85	89	93	87	75	86
S1xS2	30	20	70	40	20	36	69	68	66	69	69	68	73	72	99	73	72	78
(R1xR2) F_2	20	20	40	30	20	26	73	69	71	72	71	71	77	79	88	89	79	82
(R1xS1) F_2	30	30	40	20	20	28	77	77	75	77	73	76	81	81	87	81	81	82
(R2xS2) F_2	10	50	40	20	20	28	71	70	67	71	69	70	80	98	93	84	73	86
(S1xS2) F_2	60	20	50	30	20	36	70	70	68	70	70	70	94	81	98	77	77	85
(R1xR2)xR1	20	20	50	20	20	26	75	75	71	75	72	74	81	83	91	82	85	84
(R1xR2)xR2	30	10	30	20	20	22	66	69	66	68	67	67	81	86	99	88	89	89
(R1xS1)xR1	20	60	40	20	20	32	81	72	73	78	73	75	86	84	85	84	79	84
(R1xS1)xS1	30	20	40	40	30	32	81	75	75	78	77	77	89	80	87	88	83	85
(R2xS2)xR2	20	20	50	20	20	26	66	66	64	66	65	65	79	90	99	91	93	90
(R2xS2)xS2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
(S1xS2)xS1	30	30	50	20	20	30	78	75	72	74	72	74	88	84	91	79	78	84
(S1xS2)xS2	30	30	50	20	20	28	65	68	68	68	67	67	73	71	95	75	74	78
R1	20	20	30	20	10	20	73	78	75	78	79	77	80	81	81	83	83	82
R2	20	10	20	20	20	18	73	71	70	71	73	72	79	74	91	75	75	79
S2	30	30	30	30	20	28	74	71	70	71	71	71	77	77	74	75	75	76
S1	20	20	30	20	20	22	85	90	82	83	82	84	90	92	86	87	86	88
Mean	24	26	43	23	19	27	73	72	70	72	71	72	82	82	90	82	79	83

Table 6. Analyses of variance of per cent firing, days from planting to one-half pollen shedding, and days from planting to one-half silking for four inbred lines and 16 crosses grown at Manhattan, Kansas, 1939.

Data	Source of Variation	Degrees of Freedom	Mean Square	F Value	Level of Significance 5% Level	1% Level
Per cent firing	Entries	18	134.03	1.47	1.78	2.26
	Replications	4	153.84	1.69	2.50	3.60
	Error (ExR)	72	91.20			
	Total	94				
Days to one-half pollen shedding	Entries	18	1081.60	345.56**	1.78	2.26
	Replications	4	21.09	6.74**	2.50	3.60
	Error (ExR)	72	3.13			
	Total	94				
Days to one-half silking	Entries	18	85.75	3.19**	1.78	2.26
	Replications	4	349.29	13.00**	2.50	3.60
	Error (ExR)	72	26.86			
	Total	94				

**Highly significant difference.

firing at various planting dates, and it also agrees with data from previous years as to rank of resistance, although the differences were not nearly as great as had been anticipated from observations of their performance in past years.

These data were taken primarily for the purpose of correlating field observations with greenhouse data. However, the data as shown in Table 5 presents an excellent opportunity to investigate drought damage from another angle, namely, the effect of the severity of firing on the time of pollen shedding and of silking. Using the same correlation equation that has been previously described, correlations were calculated between the per cent of firing and the days to one-half pollen, the per cent of firing and the days to one-half silking, and the per cent of firing and the days elapsed between pollen shedding and silking. For these correlations, the data were taken from individual plots rather than the means of the five replications. This gave a larger number of paired values and permitted use of actual observations rather than averages.

The results of these correlations, shown in Table 7, indicate that more severe drought injury tends to retard the date of silking of corn but has little effect on the date of pollination. There was a slight tendency, not statistically significant, for the date of pollination to be hastened somewhat by drought injury. Fig. 2 shows a graphic representation of the relationship of these characters.

The greenhouse seedling data for the same series of four inbreds

Table 7. Correlation between the per cent of firing and days to one-half pollen shedding, days to one-half silking, and days elapsed between pollen shedding and silking for four inbred lines and 16 crosses growing at Manhattan, Kansas, 1939.

Per cent Firing Compared with:	Number of Observations	r Value	Level of Significance 5% Level	1% Level
Days to one-half pollen shedding	95	-.137	.205	.267
Days to one-half silking	95	.549**	.205	.267
Number of days from pollen shedding to silking	95	.567**	.205	.267

**Highly significant correlation

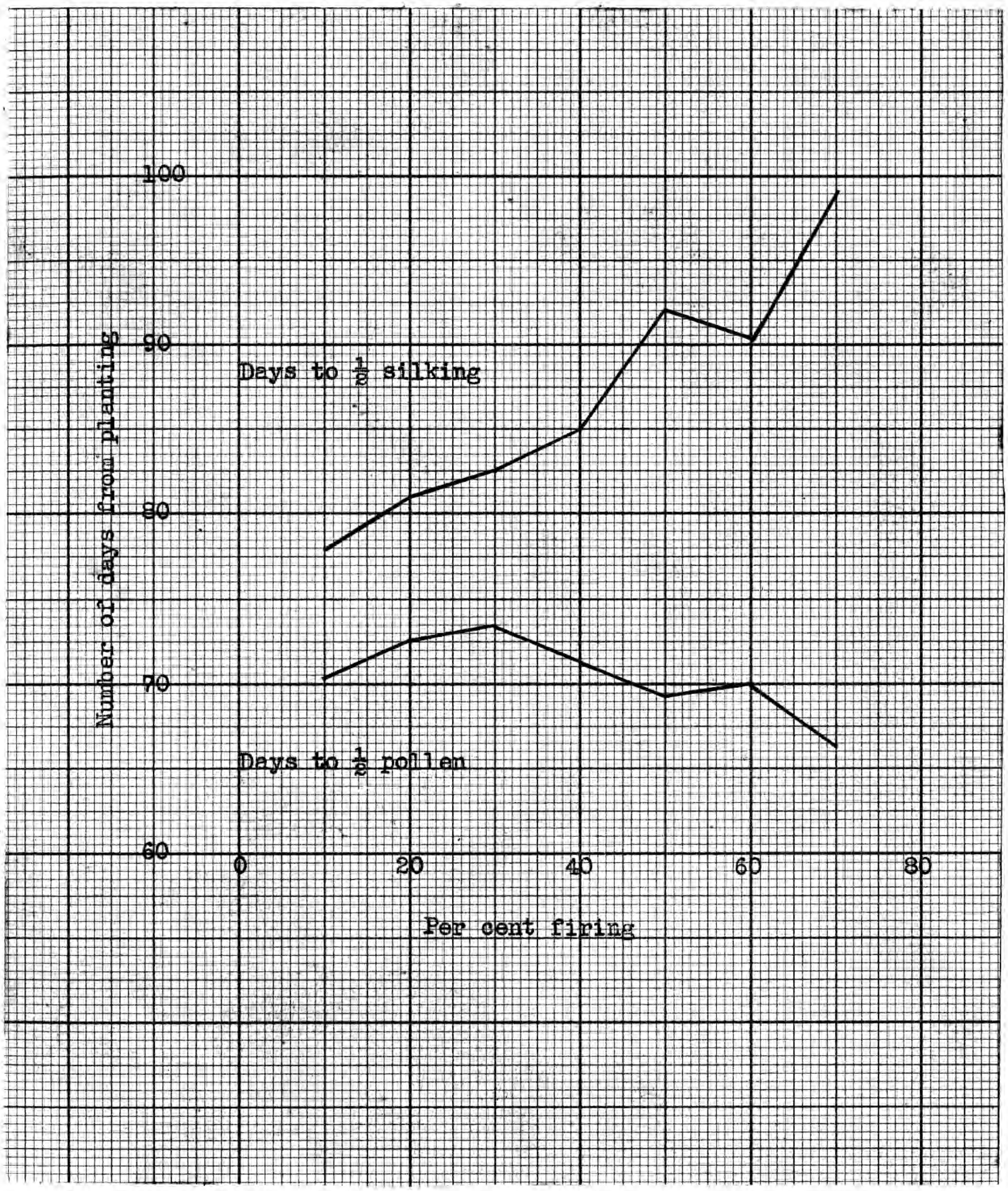


Figure 2. The influence of the severity of firing on the time of pollen shedding and silking using four inbred lines and 16 crosses at Manhattan, Kansas, 1939.

and 16 crosses were taken as described earlier in this paper. The heat chamber data for per cent injury are shown in Table 8, and for the per cent survival in Table 9. Data from the cold chamber studies are shown in Table 10 for per cent injury and in Table 11 for per cent survival. The analyses of variance for these tests, shown in Table 12, indicate that the lines showed very significant differences in their reaction to artificial atmospheric drought both in the amount of tissue injured and in the per cent of plants surviving the treatment. However, the lines did not show significant differences in their reaction to cold. The relative injury to the inbred lines, the single crosses, and the F_2 generation of the single crosses is shown in Plates II and III. These pictures were taken ten days after the plants had been treated in the heat and cold chambers respectively.

Table 13 shows the degree of correlation between per cent of injury and per cent survival for both the heat and cold chamber tests. The very high correlation indicates that the number of plants still living ten days after treatment gives about the same measure of relative reaction as does the amount of injured tissue three days after treatment.

The experiment on the economy of water utilization and relative time of survival under conditions of limited water resulted in the data presented in Table 14. Only inbreds and single crosses were used for this test. It will be noted that the lines did not differ significantly in the amount of water used. This means that they were

Table 8. Per cent of leaf surface of four inbred lines and 16 single crosses injured by exposure for six and one-half hours in the heat chamber at 130° F. and 22 per cent relative humidity.

Kind of Corn	Trial 1 Pot No.					Trial 2 Pot No.					Trial 3 Pot No.					Trial 4 Pot No.					Trial 5 Pot No.					Average
	1	2	3	4	Mean	1	2	3	4	Mean	1	2	3	4	Mean	1	2	3	4	Mean	1	2	3	4	Mean	
R1 x R2	57	49	41	61	52	38	60	90	18	52	98	83	66	71	80	60	89	58	68	69	46	51	63	44	51	60.6
R1 x S1	79	54	77	49	65	75	87	83	56	75	95	92	97	87	93	61	84	71	64	70	58	78	49	94	70	74.5
R2 x S2	60	28	2	81	43	92	60	60	54	65	75	88	100	86	87	88	83	58	70	77	62	62	22	40	46	63.6
S1 x S2	77	20	21	54	43	93	62	70	49	68	75	90	81	70	79	74	73	97	69	78	53	29	45	44	43	62.3
(R1 x R2) F_2	86	48	16	75	56	91	83	93	38	76	88	86	80	87	85	70	83	77	82	78	59	54	35	45	48	68.8
(R1 x S1) F_2	96	30	23	85	58	95	89	57	80	80	100	72	92	97	90	95	69	97	80	85	62	84	64	54	66	76.0
(R2 x S2) F_2	77	80	27	22	52	40	55	44	37	44	68	83	91	86	82	71	67	70	56	66	36	68	34	27	41	57.0
(S1 x S2) F_2	84	43	7	51	46	80	45	44	61	48	83	75	84	96	84	73	68	60	82	71	37	47	47	37	42	60.2
(R1 x R2) x R1	53	49	15	72	47	79	70	96	86	83	65	87	96	93	85	47	76	87	72	70	40	48	31	58	44	66.0
(R1 x R2) x R2	92	47	10	82	58	85	61	50	76	68	82	75	85	76	80	48	54	44	69	54	50	39	45	41	44	60.6
(R1 x S1) x R1	91	46	29	55	55	90	63	25	87	68	96	94	93	97	95	36	55	70	86	62	68	46	39	90	61	67.8
(R1 x S1) x S1	37	29	25	49	35	100	63	94	26	71	100	96	94	98	97	86	60	81	80	77	45	53	49	61	52	66.3
(R2 x S2) x R2	70	9	7	82	42	40	49	30	59	44	84	65	89	82	80	67	64	59	57	62	31	58	35	45	42	54.1
(R2 x S2) x S2	31	4	35	40	28	79	15	18	55	42	93	90	70	98	88	66	31	54	46	49	46	59	28	39	43	49.8
(S1 x S2) x S1	31	21	17	34	26	88	44	91	44	67	93	95	92	72	88	94	69	72	65	75	48	60	55	38	50	61.2
(S1 x S2) x S2	49	25	67	60	50	94	58	64	54	68	86	80	90	68	81	76	70	58	80	71	51	35	30	43	40	61.9
R1	20	45	30	45	35	62	45	20	30	59	90	94	94	75	88	66	90	75	60	73	45	90	64	46	61	59.3
R2	82	7	31	65	46	69	47	47	78	60	100	94	100	94	97	84	55	72	94	76	61	58	46	66	58	67.5
S1	91	27	40	80	60	86	24	96	84	75	100	92	100	100	98	80	76	85	98	85	47	73	48	92	65	76.0
S2	70	2	15	65	38	18	36	49	76	45	89	60	93	90	83	62	60	60	51	58	49	49	42	38	44	53.7

Table 9. Per cent of plants of four inbred lines and 16 crosses surviving ten days after exposure for six and one-half hours in the heat chamber at 130° F. and 22 per cent relative humidity.

Kind of Corn	Trial 1 Pot No.					Trial 2 Pot No.					Trial 3 Pot No.					Trial 4 Pot No.					Trial 5 Pot No.					Average
	1	2	3	4	Mean	1	2	3	4	Mean	1	2	3	4	Mean	1	2	3	4	Mean	1	2	3	4	Mean	
R1 x R2	100	100	100	100	100	100	80	60	100	85	40	100	100	100	85	100	40	100	100	85	100	100	100	100	100	91.0
R1 x S1	60	100	20	100	70	20	40	40	60	40	20	100	20	80	55	100	80	80	100	90	100	80	100	20	75	66.0
R2 x S2	100	100	100	40	85	20	40	100	100	65	80	60	0	60	50	40	60	100	80	70	60	80	100	100	85	71.0
S1 x S2	60	100	100	40	75	20	100	80	100	75	100	60	80	60	75	100	100	0	60	65	100	100	100	100	100	78.0
(R1 x R2) F_2	40	100	100	100	85	20	80	40	100	60	60	60	100	80	75	100	80	60	80	80	100	100	100	100	100	80.0
(R1 x S1) F_2	20	100	100	40	65	20	20	80	60	45	0	40	40	20	75	80	60	0	60	50	80	40	100	100	80	53.0
(R2 x S2) F_2	60	20	100	80	65	80	60	100	100	85	100	60	40	80	70	80	80	80	100	85	60	60	100	100	80	77.0
(S1 x S2) F_2	60	100	100	80	85	20	100	80	100	75	100	80	80	20	70	60	80	80	60	70	100	100	100	100	100	80.0
(R1 x R2) x R1	80	100	80	40	75	40	60	20	80	50	100	80	60	80	80	100	80	100	100	95	100	100	100	60	90	78.0
(R1 x R2) x R2	40	100	100	100	85	80	100	100	100	95	100	100	100	100	100	100	100	100	100	100	100	100	100	80	95	95.0
(R1 x S1) x R1	40	100	100	80	80	20	60	100	20	50	20	20	40	20	25	100	100	80	100	95	80	100	100	40	80	66.0
(R1 x S1) x S1	80	100	100	40	80	0	80	20	100	50	0	20	40	20	20	100	100	80	100	95	100	100	100	100	100	69.0
(R2 x S2) x R2	60	100	100	20	70	100	100	100	100	100	80	100	60	80	80	80	80	100	100	90	100	80	100	80	90	86.0
(R2 x S2) x S2	100	100	100	100	100	40	100	100	100	85	40	60	100	0	50	80	100	100	100	95	100	100	100	100	100	86.0
(S1 x S2) x S1	100	100	100	100	100	20	80	0	80	45	20	20	20	80	35	60	80	60	80	70	100	100	100	100	100	70.0
(S1 x S2) x S2	60	80	60	80	70	20	60	80	100	65	60	60	80	100	75	60	100	100	60	80	100	100	100	100	100	78.0
R1	100	100	100	80	95	80	100	100	100	95	40	20	40	100	50	100	80	80	80	85	100	40	40	100	70	79.0
R2	40	100	60	60	65	60	80	80	60	70	0	40	0	20	15	100	100	80	40	80	80	80	100	80	85	63.0
S1	20	40	40	0	25	20	100	0	40	40	0	40	0	0	10	60	40	40	0	35	80	60	100	0	60	34.0
S2	60	100	100	80	85	100	100	100	60	90	40	100	20	60	55	100	100	80	100	95	100	100	100	100	100	85.0

Table 10. Per cent of leaf surface of four inbred lines and 16 crosses injured by exposure for eight and one-half hours in the cold chamber at 30 - 32° F.

Kind of Corn	Trial 1 Pot No.			Trial 2 Pot No.			Trial 3 Pot No.			Trial 4 Pot No.			Trial 5 Pot No.			Trial 6 Pot No.			Average
	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean	
R1 x R2	95	23	59	7	22	14	9	38	24	5	14	9	7	64	36	96	75	86	37.9
R1 x S1	100	100	100	45	75	60	42	46	44	55	65	60	13	30	22	74	40	57	57.1
R2 x S2	82	85	84	33	58	46	19	6	12	24	29	26	32	55	44	35	16	26	39.5
S1 x S2	76	84	80	57	77	67	3	45	24	80	80	80	6	100	53	25	3	14	53.0
(R1 x R2) F_2	97	70	84	33	98	66	40	88	64	20	0	10	42	6	24	60	100	80	54.5
(R1 x S1) F_2	93	24	58	23	50	36	46	4	25	34	0	17	2	42	22	30	100	65	37.3
(R2 x S2) F_2	80	97	86	64	12	38	15	7	11	8	79	44	2	9	6	75	100	88	45.7
(S1 x S2) F_2	100	85	92	37	40	38	42	54	48	20	60	40	21	13	17	40	85	62	49.8
(R1 x R2) x R1	34	30	32	10	44	27	2	3	2	20	42	31	0	62	31	80	100	90	35.6
(R1 x R2) x R2	100	40	70	100	4	52	2	20	11	20	78	49	40	14	27	50	100	75	47.3
(R1 x S1) x R1	88	20	54	80	60	70	61	85	73	24	40	32	0	50	25	68	60	64	53.0
(R1 x S1) x S1	100	100	100	100	26	63	2	92	47	40	0	20	8	60	34	50	70	60	54.0
(R2 x S2) x R2	100	100	100	25	6	16	7	5	6	65	33	49	13	100	56	50	100	75	50.3
(R2 x S2) x S2	55	97	76	23	20	22	3	84	44	20	0	10	0	75	38	40	100	70	43.1
(S1 x S2) x S1	100	100	100	44	20	32	60	20	40	22	0	11	19	24	22	4	0	2	34.4
(S1 x S2) x S2	90	100	95	41	11	26	100	74	87	60	53	56	16	50	33	40	35	38	55.8
R1	30	100	65	42	56	49	6	0	3	33	30	32	20	70	45	16	50	33	37.8
R2	96	94	95	63	60	62	26	100	63	100	8	54	6	30	18	45	14	30	53.5
S1	46	100	73	45	23	34	83	20	52	80	50	65	2	12	7	40	24	32	43.8
S2	82	88	85	55	61	58	65	33	49	65	40	52	16	85	50	100	100	100	65.8

Table 11. Per cent of plants of four inbred lines and 16 crosses surviving ten days after exposure for eight and one-half hours in the cold chamber at 30 - 32° F.

Kind of Corn	Trial 1 Pot No.			Trial 2 Pot No.			Trial 3 Pot No.			Trial 4 Pot No.			Trial 5 Pot No.			Trial 6 Pot No.			Average
	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean	1	2	Mean	
R1 x R2	20	80	50	100	80	90	100	60	80	100	100	100	100	100	100	20	20	20	73.3
R1 x S1	0	0	0	60	20	40	60	60	60	60	40	50	100	100	100	40	60	50	50.0
R2 x S2	40	0	20	80	40	60	80	100	90	40	80	60	100	60	80	60	100	80	65.0
S1 x S2	60	20	40	40	40	40	80	60	70	20	20	20	100	0	50	100	100	100	53.3
(R1 x R2) F_2	0	60	30	80	0	40	60	20	40	80	100	90	80	100	90	60	0	30	53.3
(R1 x S1) F_2	0	80	40	100	60	80	60	100	80	60	100	80	100	80	90	80	0	40	68.3
(R2 x S2) F_2	40	0	20	60	100	80	80	100	90	100	20	60	100	100	100	60	0	30	63.3
(S1 x S2) F_2	0	20	10	80	60	70	60	40	50	80	40	60	100	100	100	80	0	40	55.0
(R1 x R2) x R1	80	80	80	100	60	80	100	100	100	80	40	60	100	60	80	20	0	10	68.3
(R1 x R2) x R2	0	60	30	0	100	50	100	80	90	80	20	50	100	100	100	80	0	40	60.0
(R1 x S1) x R1	20	60	40	20	40	30	40	20	30	80	60	70	100	60	80	40	40	40	48.3
(R1 x S1) x S1	0	0	0	0	80	40	100	40	70	60	100	80	100	60	80	0	20	10	46.7
(R2 x S2) x R2	0	0	0	80	100	90	100	100	100	40	80	60	100	0	50	80	0	40	56.7
(R2 x S2) x S2	40	0	20	80	80	80	100	20	60	80	100	90	100	40	70	60	0	30	58.3
(S1 x S2) x S1	0	0	0	60	80	70	40	80	60	80	100	90	100	80	90	100	100	100	68.3
(S1 x S2) x S2	0	0	0	60	80	70	0	40	20	40	40	40	100	80	90	80	80	80	50.0
R1	40	0	20	60	40	50	100	100	100	40	40	40	80	40	60	100	80	90	60.0
R2	0	0	0	20	40	30	80	0	40	0	100	50	100	100	100	60	100	80	50.0
S1	60	0	30	80	80	80	20	60	40	20	40	30	100	100	100	60	80	70	58.3
S2	20	20	40	40	60	50	80	60	70	40	60	50	80	60	70	0	0	0	43.3

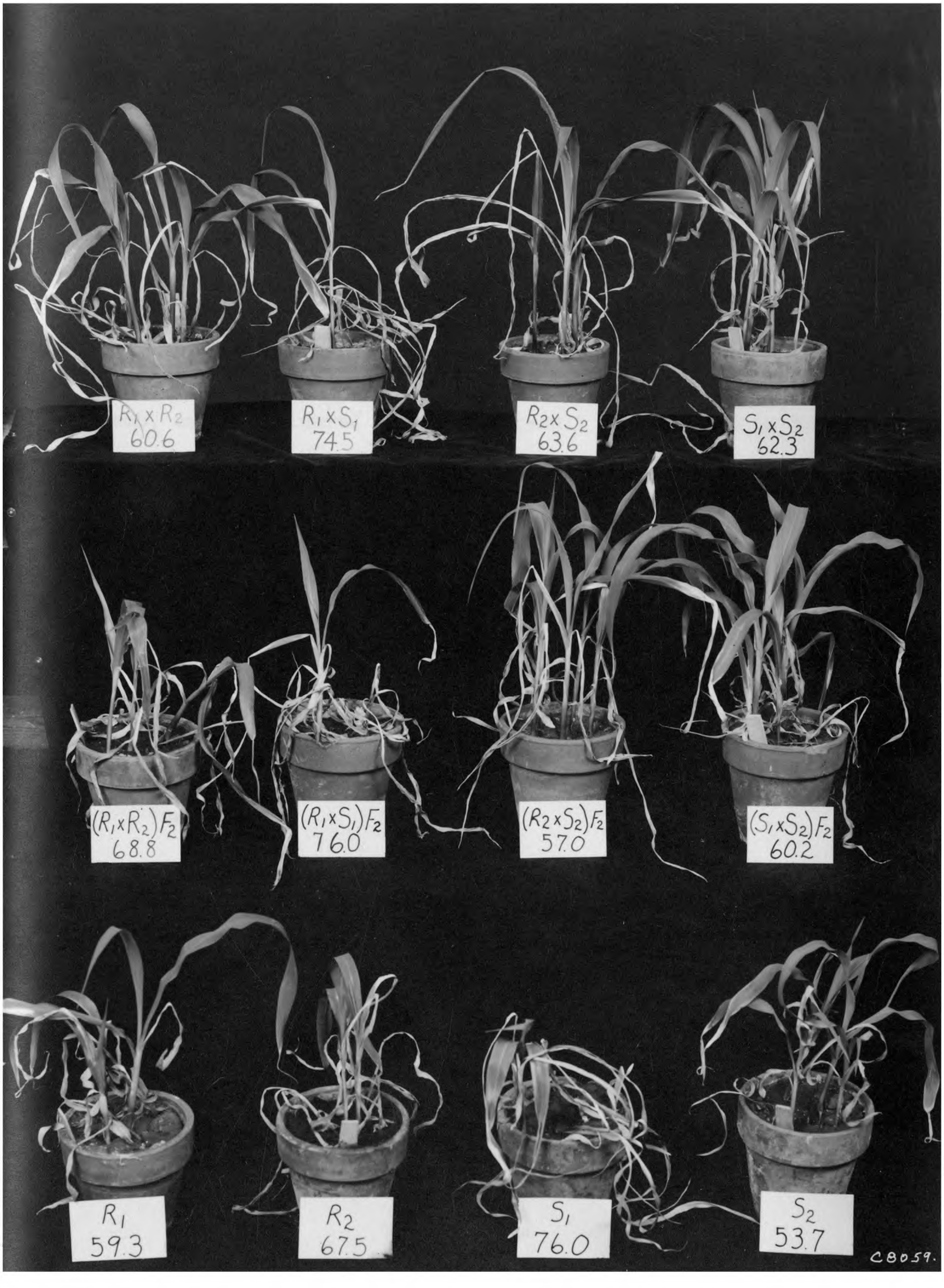
Table 12. Analyses of variance of per cent of leaf surface injured and per cent of plants surviving of the four inbred lines and 16 crosses tested in the heat and cold chambers.

Data	Source of Variation	Degrees of Freedom	Mean Square	F Value	Level of Significance 5%	Level of Significance 1%
Heat chamber, per cent leaf surface injured	Entries	19	1,030.33	3.07**	1.70	2.08
	Trials	4	20,933.70	62.34**	2.42	3.41
	E x T	76	259.61	0.77	1.14	1.21
	Error (Pots, ExP, TxP, ExTxP)	300	335.80			
	Total	399				
Heat chamber, per cent plants surviving	Entries	19	3,822.89	6.15**	1.70	2.08
	Trials	4	13,846.25	22.27**	2.42	3.41
	E x T	76	840.20	1.37**	1.14	1.21
	Error (Pots, ExP, TxP, ExTxP)	300	621.67			
	Total	399				
Cold chamber, per cent leaf surface injured	Entries	19	885.86	1.11	1.75	2.20
	Trials	5	13,214.33	16.63**	2.32	3.23
	E x T	95	890.71	1.12	1.28	1.43
	Error (Pots, ExP, TxP, ExTxP)	120	794.79			
	Total	239				
Cold chamber, per cent plants surviving	Entries	19	833.33	0.99	1.75	2.20
	Trials	5	16,944.00	20.17**	2.32	3.23
	E x T	95	1,089.96	1.30	1.28	1.43
	Error (Pots, ExP, TxP, ExTxP)	120	840.00			
	Total	239				

EXPLANATION OF PLATE II

The per cent injury of four single crosses, F_2's of these single crosses, and four inbred lines as a result of exposure in the heat chamber at 130° F. and 22 per cent relative humidity for six and one-half hours. The pot labels refer to the pedigree of the seedlings and to the average injury of the lines. This picture was taken ten days after exposure in the heat chamber.

PLATE II


R₁ x R₂
60.6
R₁ x S₁
74.5
R₂ x S₂
63.6
S₁ x S₂
62.3
(R₁ x R₂) F₂
68.8
(R₁ x S₁) F₂
76.0
(R₂ x S₂) F₂
57.0
(S₁ x S₂) F₂
60.2
R₁
59.3
R₂
67.5
S₁
76.0
S₂
53.7
CB059.

EXPLANATION OF PLATE III

The per cent injury of four single crosses, F_2's of these single crosses, and four inbred lines as a result of exposure in the cold chamber at 30° - 32° F. for eight and one-half hours. The pot labels refer to the pedigree of the seedlings and to the average injury of the lines. This picture was taken ten days after exposure in the cold chamber. Note that the differences are much less marked than in Plate II.

PLATE III


$R_1 \times R_2$
37.9
$R_1 \times S_1$
57.1
$R_2 \times S_2$
39.5
$S_1 \times S_2$
53.0
$(R_1 \times R_2) F_2$
54.5
$(R_1 \times S_1) F_2$
37.2
$(R_2 \times S_2) F_2$
38.2
$(S_1 \times S_2) F_2$
49.8
R_1
37.8
R_2
53.5
S_1
43.8
S_2
65.8
C806

Table 13. Correlations between the per cent of leaf surface injured and the per cent of plants surviving of four inbred lines and 16 crosses tested in the heat and cold chambers.

Test	Number of Observations	r Value	Level of Significance 5% Level	Level of Significance 1% Level
Heat chamber	400	-.698**	.098	.128
Cold chamber	240	-.934**	.128	.160

**Highly significant correlation

Table 14. Amount of water used, amount of dry matter produced, and the relative resistance to wilting of four inbred lines and four single crosses.

Kind of Corn	cc. of Water Used				mg. of Dry Matter Produced				Number of Days until Complete Wilting
	Pot No.				Pot No.				
	1	2	3	Mean	1	2	3	Mean	
R1	203	184	194	193.7	685	755	720	720.0	28
R2	206	199	201	202.0	645	640	620	635.0	26
S1	207	202	185	198.0	535	535	505	525.0	30
S2	207	199	196	200.7	955	975	950	960.0	21
R1 x R2	204	196	200	200.0	795	755	810	786.7	23
R1 x S1	200	194	197	197.0	775	710	805	763.3	25
R2 x S2	193	174	190	185.7	810	825	930	855.0	26
S1 x S2	202	198	206	202.0	875	860	780	838.3	21

Analyses of Variance

Data	Source of Variation	Degrees of Freedom	Mean Square	F Value	Level of Significance	
					5% Level	1% Level
Amount of water used	Entries	7	90.80	1.75	2.78	4.30
	Error (Pots, ExP)	16	51.72			
	Total	23				
Amount of dry matter produced	Entries	7	54,999.41	36.89**	2.78	4.30
	Error (Pots, ExP)	16	1,490.62			
	Total	23				

**Highly significant difference

all able to reduce the soil moisture to about the same level before severe wilting and death occurred. This is in accord with the work of Briggs and Shantz (1912) who found that plants vary but little in their ability to reduce the soil moisture beyond a certain level. The amount of dry matter produced on a given amount of water did differ between the lines as did their ability to withstand wilting. However, the plants that produced the most dry matter tended to wilt first, so that the relative seedling vigor of the plants probably accounted for the differences in their ability to remain unwilted over a longer period of time. To get conclusive data on this subject would require a test more elaborate than the one conducted in these experiments.

The data on the reactions to drought in the field and to drought and cold in the greenhouse are summarized in Table 15. Correlations of the greenhouse data with field results are shown in Table 16. It will be noted that the lines which were best in the field are not the best in the greenhouse. Since the lines did not differ measurably in cold reaction, one would not expect a significant correlation between reaction to cold and artificial drought. It is, however, interesting to note that the reaction to field firing and to artificial drought does not give a significant correlation.

The date of planting test, outlined, as described previously, for the purpose of studying the effect of the stage of growth on drought resistance, did not result in any data on this subject because of poor stands, chinch bug damage, and extremely adverse weather. While the

Table 15. Summary of data for field firing and greenhouse data of drought and cold resistance using four inbred lines and 16 crosses.

Kind of Corn	Field Firing	Heat Chamber Data: % Leaf Surface Injured	Heat Chamber Data: % Plants Surviving	Cold Chamber Data: % Leaf Surface Injured	Cold Chamber Data: % Plants Surviving
R1xR2	20	60.6	91.0	37.9	73.3
R1xS1	26	74.5	66.0	57.1	50.0
R2xS2	32	63.6	71.0	39.5	65.0
S1xS2	36	62.3	78.0	53.0	53.3
(R1xR2) F_2	26	68.8	80.0	54.5	53.3
(R1xS1) F_2	28	76.0	53.0	37.3	68.3
(R2xS2) F_2	28	57.0	77.0	45.7	63.3
(S1xS2) F_2	36	60.2	80.0	49.8	55.0
(R1xR2)xR1	26	66.0	78.0	35.6	68.3
(R1xR2)xR2	22	60.6	95.0	47.3	60.0
(R1xS1)xR1	32	67.8	66.0	53.0	48.3
(R1xS1)xS1	32	66.3	69.0	54.0	46.7
(R2xS2)xR2	26	54.1	86.0	50.3	56.7
(R2xS2)xS2	-	49.8	86.0	43.1	58.3
(S1xS2)xS1	30	61.2	70.0	34.4	68.3
(S1xS2)xS2	29	61.9	78.0	55.8	50.0
R1	20	59.3	79.0	37.8	60.0
R2	18	67.5	63.0	53.5	50.0
S1	22	76.0	34.0	43.8	58.3
S2	28	53.7	85.0	65.8	43.3

Table 16. Correlations of field firing with greenhouse tests of drought and cold resistance using four inbred lines and 16 crosses.

Field Firing Compared with:	Number of Observations	r Value	Level of Significance	
			5% Level	1% Level
Heat chamber, per cent of leaf surface injured	19	-.100	.456	.575
Heat chamber, per cent of plants surviving	19	.017	.456	.575
Cold chamber, per cent of leaf surface injured	19	.194	.456	.575
Cold chamber, per cent of plants surviving	19	.002	.456	.575

original purpose of the test was not realized, some very interesting observations did result from it. The effect of the date of planting on the length of the life cycle of the plant is shown by Fig. 3 which gives the number of days to pollen shedding for each of eight planting dates. Plant height as affected by date of planting is shown by Fig. 4.

This curve is probably not typical since the summer of 1939 was quite abnormal. It is interesting to note that corn matured and produced some grain when planted as early as March 18 and as late as June 24, a spread of more than three months.

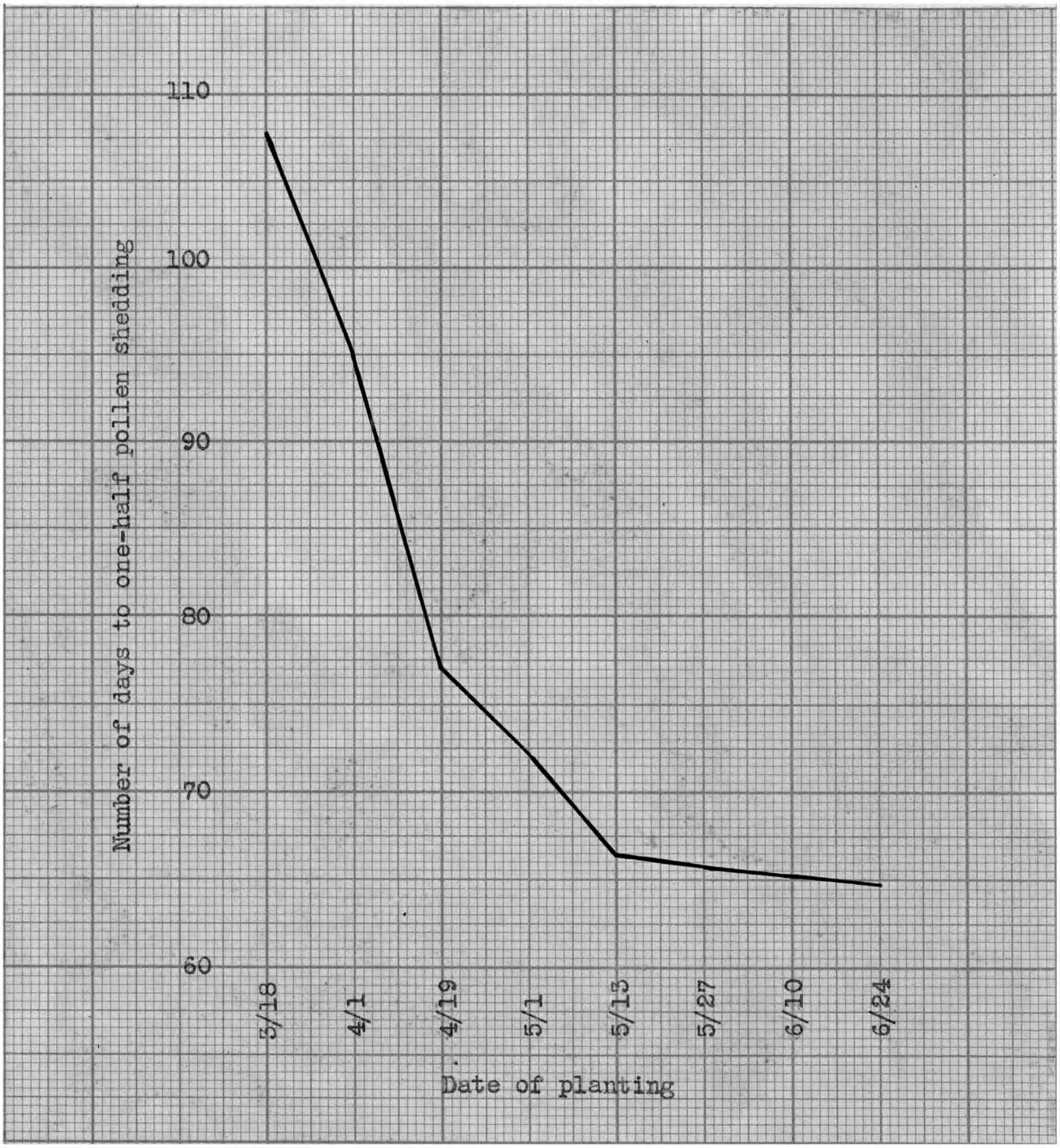


Figure 3. The effect of the date of planting on the number of days to one-half pollen shedding for ten top crosses grown at Manhattan, Kansas, 1939.

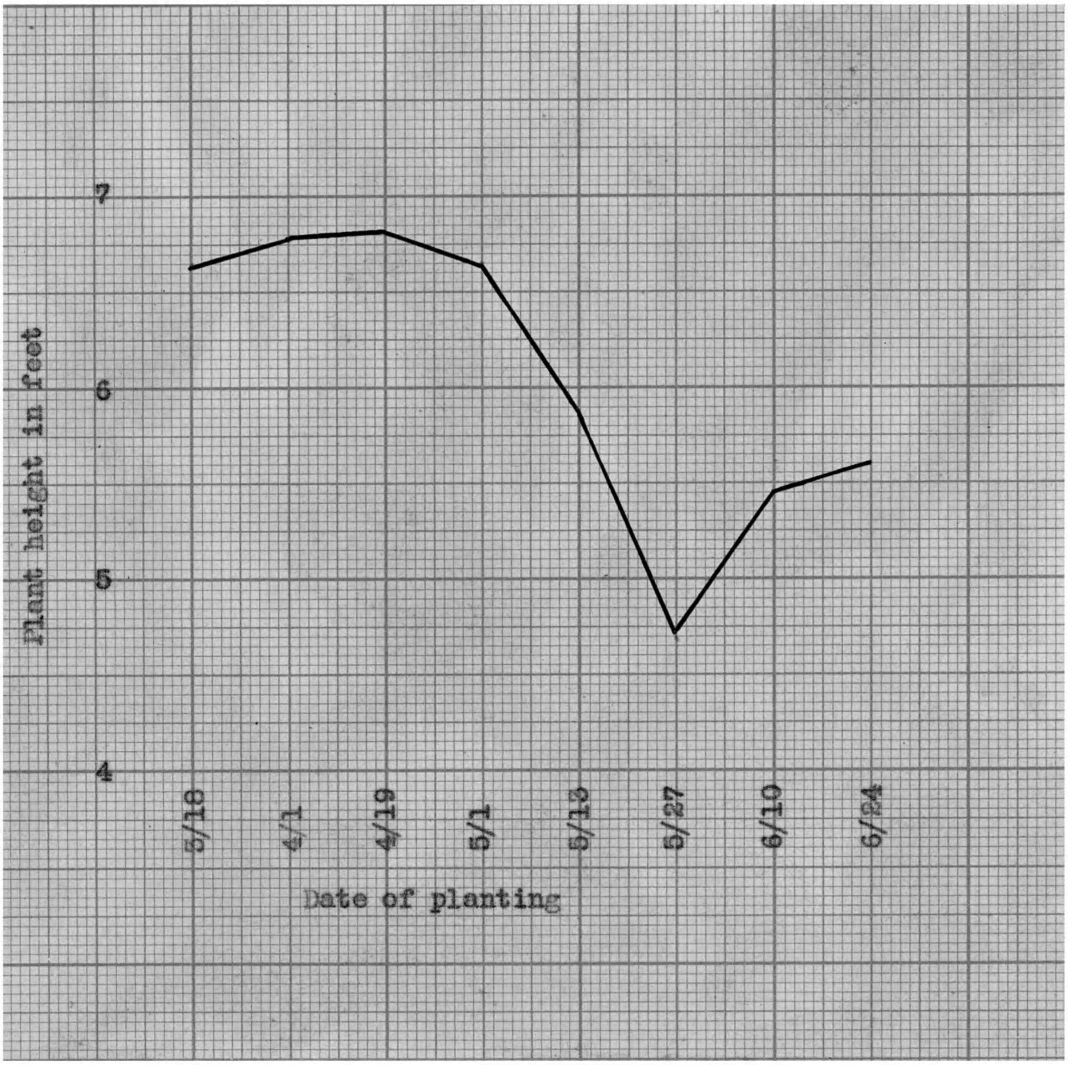


Figure 4. The effect of the date of planting on plant height. Data for ten top crosses.

DISCUSSION

Drought may well be considered one of the greatest hazards to crop production in the middle west. Corn, being of sub-tropical origin and requiring the full growing season for its best development, is neither drought resisting nor drought escaping. It has, however, taken its place as a leading crop in some regions where drought is a major problem.

Various varieties and types of corn, particularly where breeding and selection have been practiced, may be seen to exhibit considerable difference in reaction to drought. In regions, such as Kansas, where drought is a major factor in crop production, much time and effort are directed, in the corn breeding program, toward the selection of inbred lines of corn that are resistant to drought injury. That this selection is justified is shown by data presented from the Kansas Corn Performance Tests, 1939. These data, statistically treated, show a significant negative correlation between drought injury and yield in three out of four experimental fields in eastern Kansas. This indicates that, while those several factors in the genetic complex of a corn plant which tend to make it more resistant to drought may not be directly concerned with yield, they at least operate in such a manner as to permit the ultimate yield potentialities of the plant to be better expressed during periods of adverse weather conditions than if they were not present.

In a corn improvement program in which many strains of corn are being selected and tested, one of the many comparisons that must be made is the relative length of the life cycle of the inbred lines and hybrids under observation. The index of maturity most commonly used is the number of days from planting to time of flowering, both date of pollen shedding and silking being recorded. Under normal conditions, the silks emerge three or four days after the plant begins to shed pollen. This relationship is changed, however, by drought injury. Data presented in this paper show that the date of silking is delayed a great deal by drought injury, the amount of delay being proportional to the severity of drought damage. The date of pollination was found to be much less affected than was the date of silking, but the tendency is for it to be advanced somewhat by hot, dry weather. Thus, one effect of drought is to increase the length of the time between pollen shedding and the time of silking. Since this occurs, data taken on relative maturity during favorable years will be markedly different from the data taken during adverse years. Inasmuch as the date of silking is greatly retarded by drought and the date of pollen shedding only slightly advanced, it is concluded that the date of pollination is a much better index of relative maturity between strains of corn than the date of silking. Besides this, considerable time and expense would be saved by taking notes only on the date of pollination. It must be realized, however, that this applies only to comparisons of maturity and not to all types of data because the time of silking may be an important observation in certain comparisons.

While the date of planting test was not successful in showing the data for which it was originally intended, it did illustrate the effect of the time of planting on the length of the life cycle of the plant. The earliest date of planting, March 18, took an average of 108 days to reach the pollen shedding stage, while the latest date, June 24, took only 65 days. The intermediate dates fell in between the extremes for time of pollination. Length of day and warmer temperatures were probably the main influencing factors that brought about this shortening of the life cycle, but whatever the causal agents were, it may be seed that the date of planting, as well as the drought injury previously mentioned, may affect the number of days required for a plant to reach the flowering stage. It is interesting to note also that mature grain was obtained from these plots of corn planted at dates spread over extremes of nearly 100 days.

The use of artificial drought tests to supplement field observations in the classification of crop plants for drought resistance has found increasing favor among agronomists in recent years. The work of Aamodt (1935), Aamodt and Johnston (1936), Hunter, Laude, and Brunson (1936), Schultz and Hayes (1938), Haber (1938), Shirley and Meuli (1939), and Heyne and Laude (1940) all shows a very close relationship between field observations and artificial greenhouse tests. If the artificial tests could be used to replace or to supplement field observations, it would greatly facilitate the selection of drought resisting plant breeding material.

The basis for such close relationships is the assumption that plants will react to artificial drought in the seedling stage in the same relative manner that they will react to drought in the field. For artificial drought tests in the greenhouse, all conditions can be controlled quite well. The growing conditions such as temperature and soil moisture can be regulated, the age of the plants at the time of testing is uniform for all trials, and the severity of the drought test itself may be regulated. The drought may be either edaphic or atmospheric depending on the type of test desired. In the field, however, conditions are much different. The plants are apt to be any age when drought occurs and the stress may be of long or short duration. There is no way of controlling, under ordinary field conditions, the type of drought that occurs or even being sure whether the damage is due to high temperature or to low soil or atmospheric moisture or to a combination of these. The plants themselves, in their root systems, vascular tissues, leaf surfaces, osmotic values, cell permeability, hydrophilic colloids, and many other characters possibly associated with drought resistance, may be quite different in the seedling stage from the plants at later stages of growth.

In order to check the accuracy of the heat chamber as a means of testing corn for drought resistance, material was selected which had shown small but quite consistent differences in drought reaction over a period of years. Much of the previous work done on this subject has involved material that showed very marked differences. The lines used here, however, all exhibit some degree of resistance and show promise of having commercial value. These four selected lines, top-crossed with Hays Golden variety, and planted in 1939 at various dates, showed, as an average for all planting dates, a division into susceptibility and resistance in line with their performance in previous years, although the differences were much smaller than had been expected. The four inbred lines and a series of 16 crosses between them, planted in the field in 1939, showed about the same results, the expected division into resistant and susceptible groups with the crosses between the two falling into an intermediate classification. However, the differences were not statistically significant for the conditions under which these tests were conducted.

The same lines and crosses tested in the heat chamber showed significant differences in reaction but not in the same relative order as they had in the field. The correlation between the two was not significant.

The same lines and crosses, tested for their reaction to cold, failed to show any measurable differences at all.

In these studies there was a very high correlation between the relative number of plants surviving two weeks after the test and the relative amount of leaf surface killed in both the heat and cold chamber tests. The survival data are much more easily and quickly taken than are the data on the amount of injury. Since the two show such a high correlation, perhaps the former observation might be used in this type of work.

Most data have shown that cold resistance is quite closely related to drought resistance. Maximov (1929a) said that the analogy between the two must not be interpreted as an identity because, although drought and cold tolerant plants have many physiological properties in common, the plants that are resistant to one are not always resistant to the other. This was the situation found in these studies, although, had wider differences in reaction to drought or cold been present, the results might have been different.

Suneson and Peltier (1934a), studying cold tolerance in winter wheat, found that the relative level of tolerance shown by various varieties changed during the winter. They, therefore, cautioned investigators against a general application of results based on one particular period or on any one specific field condition. These conclusions might well apply to the data obtained in this study. At the levels of injury used in the heat chamber, with only atmospheric drought being considered and with temperatures of 130° F. and relative humidity at 22 per cent, the results were probably different from those that might have been obtained at different levels of temperature, humidity, and soil moisture. Whether these greenhouse data or the field data express the true condition of resistance is not known. Possibly each measures those factors of resistance which operate under the specific conditions studied and for the stage of growth under observation.

The validity of the correlations made in this study between field and greenhouse data as measures of drought resistance may be open to question because the data taken in the field and compared with the heat chamber data did not show significant differences. While the lines fell into the same rank of resistance that previous observations had suggested and into the same rank that they did when compared as top crosses studied at several dates of planting, there is considerable question as to the logic of correlating data showing significant differences, as the heat chamber data did, with data not showing significant differences, such as the field firing data.

In spite of these limitations, there is some reason to believe that the heat chamber data may not coincide with field observations when differences in drought reaction between lines are not great. Until more adequate data can be secured, the heat chamber, as a means of selecting drought resistant plants, or of measuring drought resistance, should be regarded with caution.

Future research on this subject should be directed toward studying the resistance of lines and crosses at different levels of injury, using both soil and atmospheric drought, high and low humidity and various temperature levels. More lines of corn should be used than were represented in these trials and should include extremes of resistance as well as some lines in which the differences are small. Accurate field notes covering several years should be used to check the greenhouse data.

SUMMARY AND CONCLUSIONS

1. Corn improvement programs in regions such as Kansas where drought is apt to occur must be concerned with the reaction of corn to drought and with the production of strains that are more resistant to it.

2. Studies of drought injury and its effect on yield, using F_2 segregates of various crosses between resistant and susceptible lines of corn, were unsuccessful because of adverse weather conditions during July, 1939. Using data from the Kansas Corn Tests in 1939, a negative correlation was found between yield and firing in three of four districts in eastern Kansas.

3. Strains of corn that are resistant to drought tend to produce better than do strains that are susceptible in years when drought is a factor. While the factors which make a plant resistant to drought may not be directly concerned with yield, they so operate as to permit the plant to better express its yield potentialities in adverse years.

4. An attempt was made to locate the chromosomes concerned with the inheritance of drought resistance by use of translocation stocks. Several crosses, using translocations involving all ten chromosomes, were planted, but no data were obtained because of the adverse weather conditions.

5. A series of four inbred lines, two of which were resistant to drought and two susceptible, and a series of 16 crosses involving them

The basis for such close relationships is the assumption that plants will react to artificial drought in the seedling stage in the same relative manner that they will react to drought in the field. For artificial drought tests in the greenhouse, all conditions can be controlled quite well. The growing conditions such as temperature and soil moisture can be regulated, the age of the plants at the time of testing is uniform for all trials, and the severity of the drought test itself may be regulated. The drought may be either edaphic or atmospheric depending on the type of test desired. In the field, however, conditions are much different. The plants are apt to be any age when drought occurs and the stress may be of long or short duration. There is no way of controlling, under ordinary field conditions, the type of drought that occurs or even being sure whether the damage is due to high temperature or to low soil or atmospheric moisture or to a combination of these. The plants themselves, in their root systems, vascular tissues, leaf surfaces, osmotic values, cell permeability, hydrophilic colloids, and many other characters possibly associated with drought resistance, may be quite different in the seedling stage from the plants at later stages of growth.

In order to check the accuracy of the heat chamber as a means of testing corn for drought resistance, material was selected which had shown small but quite consistent differences in drought reaction over a period of years. Much of the previous work done on this subject has involved material that showed very marked differences. The lines used

10. A date of planting test to study the effect, on the degree of injury to the plant, of the growth stage during which drought occurs was not successful in its original purpose because of poor stands, too severe drought damage, and chinch bug injury. It was possible to get mature grain from corn planted as early as March 18 and as late as June 24. The earliest planting took 108 days to reach the pollen shedding stage, while the latest took only 65 days.

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LITERATURE CITED

Aamodt, O. S.
A machine for testing the resistance of plants to injury by atmospheric drought. Canad. Jour. Res. 12(c): 788-795. 1935.

Aamodt, O. S., and Johnston, W. H.
Studies on drought resistance in spring wheat. Canad. Jour. Res. 14(c): 122-152. 1936.

Bayles, B. B., Taylor, J. W., and Bartel, A. T.
Rate of water loss in wheat varieties and resistance to artificial drought. Jour. Am. Soc. Agron. 29: 40-52. 1937.

Briggs, L. J., and Shantz, H. L.
The relative wilting coefficients for different plants. Bot. Gaz. 53: 229-235. 1912.

__________ and __________
Relative water requirements of plants. Jour. Agr. Res. 3: 1-63. 1914.

__________ and __________
The water requirement of plants as influenced by environment. Proc. Second Pan-Amer. Sci. Cong. 1915-1916. 3(3): 95-107. 1917.

Clapp, A. L., Jugenheimer, R. W., Hollembeak, H. D., and Skold, L. N.
Kansas corn tests, 1939. Kans. Agr. Expt. Sta. Bul. 288. 29 p. 1939.

Dexter, S. T.
Effect of several environmental factors on the hardening of plants. Pl. Physiol. 8: 123-129. 1933.

Dunn, Stuart.
Factors affecting cold resistance in plants. Pl. Physiol. 12: 519-526. 1937.

Fisher, R. A.
Statistical methods for research workers. Edinburgh. Oliver and Boyd. 339 p. 1936.

Haber, E. S.
A study of drouth resistance in inbred strains of sweet corn <u>Zea mays, var. Rugosa</u>. Iowa Agr. Expt. Sta. Res. Bul. 243. 72 p. 1938.

Harrington, J. B.
Varietal resistance of small grains to spring frost injury. Jour. Am. Soc. Agron. 28: 374-388. 1936.

Heyne, E. G.
Inheritance studies of heat and drought tolerance in maize. Unpublished thesis. Kans. State Col. Agr. and Appl. Sci. 96 p. 1938.

Heyne, E. G., and Laude, H. H.
Resistance of corn seedlings to high temperatures in laboratory tests. Jour. Am. Soc. Agron. 32: 116-126. 1940.

Hodges, J. A.
The effect of rainfall and temperature on corn yields in Kansas. Jour. Farm Econ. 13: 305-318. 1931.

Hunter, J. W., Laude, H. H., and Brunson, A. M.
A method for studying resistance to drought injury in inbred lines of maize. Jour. Am. Soc. Agron. 28: 694-698. 1936.

Jenkins, Merle T.
Differential resistance of inbred and crossbred strains of corn to drought and heat injury. Jour. Am. Soc. Agron. 24: 504-506. 1931.

Kiesselbach, T. A.
The comparative water economy of selfed lines of corn and their hybrids. Jour. Am. Soc. Agron. 18: 335-344. 1926.

Klages, K. H.
Relation of soil moisture content to resistance of wheat seedlings to low temperatures. Jour. Am. Soc. Agron. 18: 184-193. 1926.

Kondo, J. N.
The influence of external factors, as well as the stage of development, on the resistance of plants to dehydration. (In Russian with English summary.) Bul. Appl. Bot., Genet., and Pl. Breed. 27(5): 129-156. 1931.

Krasnosselsky-Maximov, T. A.
Physiological analysis of windburn by means of artificial dry wind. (In Russian with English summary.) Bul. Appl. Bot., Genet., and Pl. Breed. 25(3): 1-44. 1931.

Krasnosselsky-Maximov, T. A., and Kondo, J. N.
Physiological analysis of windburn by means of artificial dry wind. (In Russian with English summary.) Bul. Appl. Bot. and Pl. Breed. Ser. III, 3: 191-215. 1933.

Lebedinzev, E. V.
Experiments on the water-holding capacity of plants in relation to drought and frost resistance. (In Russian with English summary.) Bul. Appl. Bot., Genet., and Pl. Breed. 23: 1-28. 1929-30.

Maximov, N. A.
Internal factors of frost and drought resistance of plants. (In Russian with English summary.) Bul. Appl. Bot. and Pl. Breed. 22 (1-2): 40-41. 1929a.

____
The plant in relation to water; a study of the physiological basis of drought resistance. (In Russian.) Authorized English translation, edited, with notes by R. H. Yapp. London. Allen and Unwin. 451 p. 1929b.

Newton, R., and Martin, W. M.
Physico-chemical studies on the nature of drought resistance in crop plants. Canad. Jour. Res. 3: 336-427. 1930.

Robb, A. D.
The critical period of corn in northeastern Kansas. U. S. Dept. Agr. Monthly Weather Rev. 62: 286-289. 1934.

Scarth, G. W., and Levitt, J.
The frost hardening mechanism of plant cells. Pl. Physiol. 12: 51-78. 1937.

Schultz, H. K., and Hayes, H. K.
Artificial drought tests of some hay and pasture legumes in sod and seedling stages of growth. Jour. Am. Soc. Agron. 30: 676-682. 1938.

Sellschop, P. F., and Salmon, S. C.
The influence of chilling, above the freezing point, on certain crop plants. Jour. Agr. Res. 37: 315-338. 1928.

Sherwood, L. V.
Physiological study of cold tolerance in corn. Jour. Am. Soc. Agron. 29: 1022-1030. 1937.

Shirley, H. L.
A method for studying drought resistance in plants. Science, 79: 14-16. 1934.

Shirley, H. L., and Meuli, L. J.
Influence of moisture supply on drought resistance of conifers. Jour. Agr. Res. 59: 1-21. 1939.

Simonovitch, D., and Scarth, G. W.
Study of the mechanism of frost injury to plants. Canad. Jour. Res. 16(c): 467-481. 1938.

Smith, O. F.
The influence of low temperature on seedlings of inbred lines of corn. Jour. Am. Soc. Agron. 27: 467-479. 1935.

Suneson, C. A., and Peltier, G. L.
Cold resistance adjustments of field hardened winter wheats as determined by artificial freezing. Jour. Am. Soc. Agron. 26: 50-58. 1934a.

__________ and __________
Effect of stage of seedling development upon the cold resistance of winter wheats. Jour. Am. Soc. Agron. 26: 687-692. 1934b.

Tumanov, I. I.
Deficiency of water supply and wilting of the plant as a means of increasing its drought resistance. (In Russian with English summary.) Bul. Appl. Bot., Genet., and Pl. Breed. 16(4): 293-399. 1926.

____
Wilting and drought resistance. (In Russian with English summary.) Bul. Appl. Bot., Genet., and Pl. Breed. 22(1-2): 107-146. 1929.

__________ and Borodin, Irene.
Investigations on frost resistance of winter crops by means of direct freezing and by indirect methods. (In Russian with English summary.) Bul. Appl. Bot., Genet., and Pl. Breed. 22(1-2): 395-440. 1929.

Tysdal, H. M.
Influence of light, temperature, and soil moisture on the hardening process in alfalfa. Jour. Agr. Res. 46: 483-513. 1933.

Vasiliev, I. M.
The investigation of drought resistance in wheat. (In Russian with English summary.) Bul. Appl. Bot. and Pl. Breed. 22: 146-218. 1929.

Waldron, L. R.
Frost injury to spring wheat with a consideration of drought resistance. Jour. Am. Soc. Agron. 23: 625-637. 1931.