VARIABILITY IN THE RESISTANCE OF BROMEGRASS (*BROMUS INERMIS* LEYSS.) STRAINS TO HIGH TEMPERATURES

by

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INTRODUCTION

Agricultural research has followed the dictates of American Agriculture. Formerly the plant breeders' attention was focused on the cash crops and until recent years, fundamental research concerning agronomic and genetic behavior of the forage grasses has been lacking. The recent drought and its aftermath of erosion, abandoned farms, and economic instability have overthrown that complacency with which both agriculturist and scientist had viewed grass breeding. More emphasis is being placed on the value of grass in stabilizing the soil and on the wise use of grass in the farm program.

Bromegrass (Bromus inermis Leyss.), a species that has been assuming more and more importance in recent years, was introduced into the United States from northeastern Europe. Russia is usually considered to be its place of origin and from there it has spread to the countries of Norway, Sweden, Denmark, Germany, France, Belgium, and Holland. Since its introduction into this country in 1884 (Doll and Gross, 1938), it has proven valuable in meadows and pastures over a wide area in the central United States (Plate I). However, it is not, as this map indicates, recommended for northwestern Kansas by the Kansas Agricultural Experiment Station. Drought conditions of the 1930's and the search for a desirable grass for reseeding have increased interest in this species. Drought has depleted or destroyed many of the native grass pastures.

Savage and Jacobson (1935) studied the effect of heat and drought on blue grama and buffalo grass in pastures and lawns after the drought of 1934 and found the average mortality had been 74.8 percent on closely grazed and heavily trampled areas, 64.6 percent on moderately grazed areas, and 44.4 percent on dry land lawns in comparison to lawns well watered in 1934. Weaver and Albertson (1936), reporting on a similar study, stated "The most severe drought ever recorded in the prairies of eastern Nebraska, western Iowa, and Kansas occurred in 1934". They found that the ungrazed prairies of south-central Kansas had lost 60 percent of the basal cover; various types moderately grazed, 33 percent; and others heavily grazed, 74 percent. Losses under comparable intensities of grazing in north-central Kansas were 50, 54, and 91 percent, respectively. Conditions were most severe in the west-central part of the state where ungrazed prairies lost 85 percent, moderately grazed areas 72 percent, and heavily grazed areas 91 percent.

Deficient soil moisture, coupled with extremely high temperatures and low humidities, and supplemented by wind and burial by dust, was the cause of the destruction. This is a typical observation made in their report: "At Hebron (Nebr.)

losses varied from 95 percent on upper and middle slopes of south facing hills to 10 percent near their foot".

As stated, this depletion in cover has, for the most part, been on the more rolling land of the farm unit. Lack of suitable cover on such land has decreased the livestock carrying capacity and permitted greatly accelerated erosion.

Re-establishment of native grass pastures by reseeding is, at present, difficult because of an insufficient seed supply and because of frequent failures to obtain sufficient stands. Bromegrass, because of its drought resistance, high yield of palatable forage, and ability to fit well in a pasture rotation with native grasses, merits attention. This grass is a heavy seed producer and is easily harvested. Relatively little difficulty is experienced in establishing stands either pure or in mixtures with other grasses and legumes when seeded on properly prepared seedbeds. Of signigicant importance is the root system of bromegrass which, because of its aggressiveness and matting habit of growth, is of great value in binding the soil to prevent erosion.

Hitchcock (1935) reported that bromegrass is recommended for canal banks and Doll and Gross (1938) stated that it forms a dense sod which is an excellent soil binder and withstands considerable abuse from trampling by livestock. The profusely branched root system not only holds soil effectively while grass is growing, but it also adds much organic matter and fiber to the soil, making it more resistant to erosion after the sod has been plowed and the cultivated crops are planted (partly due to improved physical condition as a result of organic matter). At Lincoln, Nebr. a four-inch layer of sod from a four-year-old bromegrass field contained 3,740 pounds of dry matter per acre. The roots of bromegrass may penetrate to a depth of seven or eight feet, but the general working level is the upper three and one-half feet of soil.

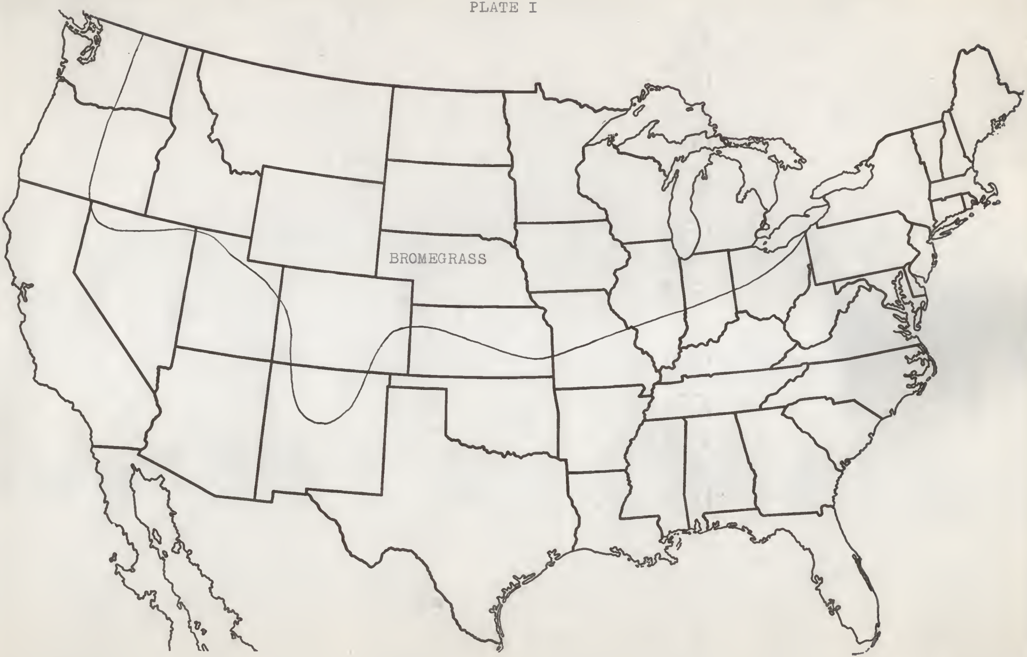
Drought and other contributing factors have intensified the condition which now needs to be rectified. Droughts may be expected in the future and it is important, therefore, that measures be taken to prevent recurrence of the damage experienced in the past. This research was begun in anticipation of obtaining strains of bromegrass with increased resistance to heat and drought. Present bromegrass strains tend to become dormant during the hot summer months, producing most of their growth during the cooler spring and fall months. It would be desirable to produce a strain with a much shorter period of dormancy so as to furnish more uniform production throughout the entire growing season.

The increased ability of bromegrass to withstand heat and drought would be of importance for various reasons. In the seedling stage, greater drought resistance would manifest itself in improved stands and vigor when the seedings had been made in dry seasons. In the later stages of growth, drought and heat resistance would result in higher seed or forage production during dry periods and would aid in the maintenance of a suitable basal cover. Increased drought resistance would permit successful stands and profitable growing of bromegrass in drier habitats than is now practical. Heat resistance would lessen the damage to seedling bromegrass stands due to hot weather in fall and spring before the grass has become established. Profitable production of this grass might well be extended further south and west as a result of increased heat resistance and other factors. At present bromegrass is not grown extensively in the southern half of Kansas (Plate I). A more heat and drought resistant strain would be desirable in this area.

EXPLANATION OF PLATE I

Map of the United States showing regional adaptation of Bromus inermis. Copied from U. S. Department of Agriculture Yearbook, 1937.

PLATE I



REVIEW OF LITERATURE

Drought has a variety of definitions as the term is commonly used. According to Miller (1938), the term "drought" may be defined in various ways depending upon the point of view from which it is considered. He offered these definitions: 1. "Physiological drought" or the inability of the plant to absorb water from the soil, although an abundance is present. 2. "Soil or edaphic drought" is the lack of water in the soil, and 3. "Atmospheric drought" refers to the desiccation of the plant to a point of injury under conditions of relatively high soil moisture. This last definition of drought is the one chosen for the present study.

Many studies of the nature of drought resistances have been reported. Maximov (1938) stated that the capacity of a plant to endure permanent wilting is probably connected with an increased content of osmotically active substances and hydrophilic colloids in the cells of drought-resistant plants.

In previous studies (1929b), Maximov reported that the center of interest in the problem of drought resistance is tending to be transferred to specific properties of the protoplasm of different plants. The problem falls within the purview of colloidal chemistry, together with other phenomena depending on the stability of the protoplasm, such as power to resist frost, to resist injury by salts or poisons, and even to resist attacks by the plant or animal parasites.

In regard to drought resistance of crop plants he stated:

> Physiologically these peculiarities are for the most part associated with intense assimilation, intense transpiration, reduced growth in height, high osmotic pressure, etc. But these relatively easily observable peculiarities appear of secondary importance as compared with the capacity to endure without injury an intense loss of water--one of the most important properties of true drought resistant plants. This property is connected with the capacity of the protoplasm to endure considerable fluctuations in its degree of swelling, without the loss of vital activity and without the appearance of irreversible coagulation. This capacity of enduring water loss may completely mask the significance of other anatomical and physiological peculiarities, and thus mystify investigators who endeavor to find a strict correlation between drought resistance and these externam peculiarities (1929b).

After a study of wheats Vasil'ev (1931) observed that with wilting the hydrolysis of insoluble carbohydrates begins. Newton and Martin (1930) in their physico-chemical studies of drought resistance of crop plants reported that both grasses and wheat could be classified very satisfactorily with respect to drought resistance on the basis of the bound-water content of the fresh juice. In the grasses there was also found a relationship between drought adaptation and concentration and osmotic pressure of juice, but it is believed that this was the result more of collecting them in typical and distinctive habitats than of the characteristic difference in species. It seems probable that bound-water content is a more stable and characteristic property than osmotic pressure.

Maximov (1929a) noted the relationship of frost and drought resistance. By discounting the external means of protection and assuming the fundamental statement that drought resistance is:

> The ability to endure permanent wilting, then one can establish a pretty close analogy between the capacity of plants to resist frost and drought. We may observe the protective influence of the accumulation of water soluble substances in the cell sap; a greater accumulation of hydrophilic colloids is also a factor in drought resistant plants.

Waldron (1931) in a study of frost injury and drought resistance found a close correlation between the cold resistance and drought resistance. Four of the six varieties of wheat studied were in the same order in relation to drought resistance as they were in frost resistance.

Kondo (1931) worked with sunflowers and soybeans and reported that external factors influence drought resistance. Sunflowers previously allowed to wilt and plants grown in culture with a minimum moisture showed great resistance to drought.

Aamodt and Johnston (1936) substantiated these findings by their work on spring wheat. They summarized their findings thus: "Hardening of plants prior to exposure to atmospheric drought, by subjection to soil drought or limited periods of atmospheric drought, caused greater tolerance in both resistant and susceptible types".

Maximov (1938) stated that:

> Moderate humidity and even a temporary drought in the first stages of development, which contribute to a less vigorous development of the vegetative organs and besides harden the plants somewhat, similar to the hardening to frost by low temperatures, represents conditions that favor resistance to drought in later stages of development. In such years, arid regions produce their highest yields.

Laude (1939) working with corn and sorghum seedlings found that plants given an hour of light after a normal night of darkness acquired a marked resistance to heat over plants having had no light. The maximum heat resistance was usually reached within four hours after exposure to light following normal light. Heyne and Laude (1940) found that the heat resistance of corn seedlings kept in the dark for 12 to 18 hours was increased considerably by exposure of light for as short a period as one hour.

A plant's ability to resist both heat and drought is apparently due, to a large degree, to the nature of its protoplasm. When the proteins in the protoplasm are made up of hydrophilic colloids that can hold water against severe external conditions and thus prevent the precipitation of those proteins, the plant prevents death that would otherwise ensue because of the physical and chemical conditions brought about by this precipitation.

Heyne and Laude (1940) summarized their work on resistance of corn seedlings to high temperatures in laboratory tests thus:

> The reaction of corn seedlings to artificial heat was studied and this reaction was found to correlate well with the behavior of the same strains under field conditions. Seedlings 10 to 14 days old treated for 5 hours at 130° F, with a relative humidity of 25 to 30%, were more heat tolerant than those at the later stages of development. Decapitation experiments and decline in weight of seeds indicate that after the fourteenth day the young plants had exhausted most of the food material from the endosperm. The results indicate that the testing of seedlings for heat resistance can be relied upon with considerable assurance for distinguishing genetic differences in drought tolerance of larger plants of different strains of maize.

Schultz and Hayes (1938) summarized the results of their observations on some hay and pasture grasses and legumes in sod and seedling stages of growth. They tested forage grasses grown in field trials in central and branch stations in Minnesota for drought resistance in an artificial drought machine. The artificial test was found to correlate quite closely with the results obtained in field trials. Bromegrass and crested wheatgrass were found to be the most drought resistant of the grasses studied. Although it was not possible to compare directly the sod growth stage readings and those of the seedlings, there was a rather consistent agreement between all three stages (30 day, 60 day seedlings and sod). The older seedlings possessed considerably more resistance and the sod gave much greater resistance.

Hunter, Laude, and Brunson (1936) tested inbred lines of maize seedlings for 6.5 hours in a chamber with a controlled temperature of 140° F. and relative humidity of about 30 percent and found it possible to distinguish among strains with respect to drought tolerance. They believed this method to be valuable in testing for drought resistance in inbred lines, hybrids, or open-pollinated varieties since almost perfect agreement was obtained in the progressive order of field injury during the severe season of 1934 as compared with the order obtained with the seedlings in the heat chamber.

Sloan (1941) worked with bromegrass from various states and sources and found significant differences in the response of this grass to high temperature. He reported the percentage of tissue injured by the exposure to high temperature to correlate directly with the number of seedlings killed by the treatment. Those strains of Kansas origin exhibited the highest degree of tolerance to high temperature.

MATERIALS AND METHODS

In June, 1940, seed was selected from one or more plants of 11 representative progeny rows of various types of bromegrass which were under observation and study in the nursery at Manhattan, Kansas. A progeny row in the nursery consisted of a parent plant at the head of the row with its 20 progeny spaced at 30-inch intervals. These progenies were of two types, open-pollinated and self-pollinated. All except one of the progeny rows from which seed was selected are from lines grown in Kansas for many generations. This progeny row traces to a seed source in Pullman, Washington. However, since it has been interpollinated with Kansas strains for three generations in the breeding nursery, it undoubtedly contains considerable germ plasm of surrounding brome plants which were entirely of Kansas origin.

An effort was made to select progeny rows representative of many types and from sources more or less representative of the plants found in the nursery. Time and space would not permit testing the 200 odd types found in the nursery thoroughly in one experiment, however, these 11 selections were studied with a view to later selections and testing.

Seed from these 11 progeny row selections were planted in six-inch unglazed clay pots in the greenhouse on October 12, 1940. The pots were filled with soil which had been thoroughly mixed and screened in one operation to insure uniformity. Care and attention were taken to fill the pots to a uniform depth, provide for adequate drainage and for the settling of the soil in these pots. The pots were watered and the soil allowed to settle for three to four days before the seed was planted. A cardboard was then cut to fit inside the pots at the soil line. Round holes punched in this cardboard served as a guide in planting in order to space the seedlings uniformly in the pot. Seeds were planted at a depth of one-half inch. Sufficient seed was planted to insure the establishment of at least five seedlings and pots in which more than five seedlings emerged were thinned to that number.

In the first test, 24 pots of each selection or a total of 264 pots were planted. Thus, 1,320 seedling plants were grown; 120 seedlings of each selection. An attempt was made to maintain the greenhouse temperature at 70° F. or slightly above. To reduce losses from "damping off" a thin layer of sand was sprinkled over each pot and water was applied only when necessary depending upon the condition of the soil. The pots were permitted to remain dry on the surface for at least 12 to 24 hours between each watering and when watered were given a sufficient supply to fill the soil to its water-holding capacity.

The testing was started December 14, 1940. Groups of three pots, or 15 seedling plants, of each selection being placed in a temperature control chamber on successive days until all had been tested. These pots were watered thoroughly 12 to 16 hours before being placed in the temperature control chamber to insure a sufficient water supply above the wilting coefficient during the test. The temperature within the chamber was maintained thermostatically at 126-134° F., usually varying less than 2° in any one "run", while the relative humidity within the chamber varied little from its average of 60 percent. The seedlings were left in the chamber from five and one-fourth to 11 hours. No definite time of exposure was maintained from one trial to the next but observation of the plant tissue determined the time at which the plants were removed. Greater differences were obtained when 90 to 95 percent of the tissue of the more susceptible seedlings showed severe damage as exhibited by its change to a lusterless blue color.

After removal from the heat chamber, the pots were allowed to cool eight to 12 hours before the seedlings were watered. Seedling survival was determined by counts made five to 12 days after the heat treatment. Any plant showing green, living tissue at that time was considered to have survived the treatment.

Treatment of a second series of plants was begun on February 15, 1941. In this series 135 seedling plants of each strain were treated. Due to an insufficient seed supply, selection No. 10 was omitted. The pots used were four-inch unglazed clay instead of six-inch pots used previously and because of the size of the pots, only three seedlings were grown in each pot. In all other respects the procedure was the same as that followed in the previous test. Thus, in this series, 45 pots each of 10 selections, making a total of 450 pots of 1,350 seedling bromegrass plants, were tested.

A third series of plants was treated on November 8 to 14, 1941. In this series, 25 strains were studied and a total of 72 seedlings of each selection treated. This test included the 10 strains tested previously except selection No. 5, seed of which was not available for testing at the time. The remaining 15 strains were selections intended to increase the scope of the experiment. Each strain is described in detail under Experimental Results as to its source and the reason for including it in these tests. A short explanation should suffice at this point. Relationships studied were those of agronomic characters, sources, and mode of pollination (whether open-pollinated or bagged for selfing). Agronomic relationships were compared by securing seed from two types of plants in one progeny row and comparing the resulting seedlings. These types were classified as desirable, leafy, vigorous plants and undesirable, stemmy, weak-appearing plants.

The source relationships included a comparison of original sources, progeny of plants surviving the high temperature tests, and one selection that had experienced a brief period of acclimation. The pollination relationships in the test consisted of an inclusion of more selections that had been selfed some time in their development in the nursery.

EXPERIMENTAL RESULTS

Progeny groups of bromegrass (Bromus inermis Leyss.) exhibit wide differences in response to high temperatures when tested in the seedling stage. The first series of selections studied gave a highly significant difference in five of the 10 strains tested, with an additional selection serving as a check (Snedecor, 1940). In this experiment each selection was represented by 120 seedlings, or a total of 1,320 seedling bromegrass plants in the 11 lines.

The second series of the test included the same selections that were previously tested with the exception of No. 10. This line was discontinued because of the lack of seed although more seed was obtained later and the line was included in the third series. In this group two of the nine selections proved less tolerant than the check selection to a highly significant degree.

In the third series of tests, 15 new lines were included. Of the original 10, none exhibited highly significant differences. There were fewer seedlings of each selection in this experiment and a much smaller percentage of them were killed. Therefore, the differences were not so apparent. The trend in this series follows closely that of the first two series, selection No. 8 suffering the greatest damage and No. 6, as in previous tests, surviving the test with at least as many living seedlings as any of the original selections tested.

A composite of the three tests was made by summarizing the living and the dead seedlings of each test and analyzing these combined data. This analysis shows that three of the eight selections proved to be highly significant in their difference from the check and one significantly different when tested statistically (Snedecor, 1940).

Selection No. 6 was chosen as the check selection at the end of the first test because of its resistance to high temperatures and its desirable agronomic characteristics. Agronomic characters deemed desirable are those of leafiness, bunch habit of growth (debatable), vigor, lateness in maturity, rapid fall recovery after summer dormancy, high forage and seed production, and freedom from disease. Although the desirability of some of the above characters are self-evident, others might need a brief explanation. Leafiness is desirable from the nutritive and palatability standpoint either as pasture or hay. The desirability of the bunch or non-spreading habit of growth is much more difficult to explain, however, observation in the nursery indicated the possibility that this habit might be correlated with leafiness and high seed and forage production, at least in certain lines. On the other hand, failure to spread by rhizomes may result in a poor sod, unable to resist trampling and grazing. Vigor is a quality desired in all stages of growth from seedling to the mature plant. Lateness in maturity seems desirable because it permits longer season of grazing in the spring and delays the time at which palatability decreases in the summer. The character is closely correlated with the short summer dormancy as well. Quick fall recovery also shortens the summer dormancy and is important in a pasture grass of this type because of the low livestock carrying capacity and susceptibility to injury by close grazing during the summer dormant period. The desirability of such characteristics as heavy seed and forage production are quite evident as is that of freedom from such diseases as rust. Resistance to insect damage would be desirable but no differences in susceptibility or tolerance of bromegrass to grasshopper or other insect injury have been recorded in this material.

Selection No. 6 traces directly to the bromegrass fields of the Achenbach Bros. of Washington County, Kansas. Table 1 indicates the desirable agronomic characters of the seedlings. This line produced medium height seedlings, but the leaves were third in average width of all the selections. The average number of tillers per pot is an evidence of the rhizomatic activity of a selection and this table shows line No. 6 to be second lowest in this type of spreading.

Line No. 1, a third generation open-pollinated selection of southeastern Kansas origin, was selected as a typical or average bromegrass type found in the nursery. In field observations it appeared medium in height, medium in leafiness, vigor, length of summer dormancy, and other such agronomic characters as described in the check strain. Table 1 shows that it is medium in rhizomatic aggressiveness and has wide leaves. It did not exhibit any marked degree of resistance to heat, proving to be significantly less resistant than the check in the first and second series of tests (P less than 2) (Snedecor, 1940). In a composite of all tests, Table 5, chi square is three times that necessary for high significance.

Selection No. 2 was secured from the same location as that of selection No. 1. Its characteristics in general closely parallel those of the latter. In the nursery it exhibited moderate leafiness, medium vigor, and did not spread rapidly by rhizomes. Table 1 shows that in the seedling stage the line was sixth in rhizomatic activity, sixth in width of leaves, and tied for third and fourth places in height. This agrees quite closely to the field observation. In these tests it proved to be more susceptible to injury by high temperatures than the check. In the first series this difference was highly significant while in the second series of tests it was slightly below a significant level. (P. 20 percent). A composite of all tests, Table 5, shows this selection to be highly significant in its difference from the check selection.

Selection No. 3 is a third generation open-pollinated selection of seed obtained from a drought-resistant roadside strain found near Manhattan. This plant line had been carried in the bromegrass nursery because of its peculiar head type. The florets were grouped much more closely, due to their shorter pedicels. The progeny row from which this line was obtained consisted of plants that were extremely leafy and late in maturity, heading approximately four to five days later than the nursery average. In the seedling stage (Table 1) this line proved medium in height and rhizomatic aggressiveness placing seventh in both respects and fourth in width of leaves. In a composite of the three tests this selection, although somewhat more susceptible, did not prove significantly different from the check.

Lines No. 3 and 4 are from the same grandparental source, the mother plant of line 3 being an open-pollinated daughter and the mother plant of line 4 a self-pollinated (S_1) daughter of the same plant. The seed for these two lines was obtained under conditions of open-pollination. Thus, selection No. 4 resembles a top cross since its parent is a selfed plant pollinated by surrounding plants. The parent plants from which seed was obtained resembled one another in all respects except vigor. The size of the inbred plant was reduced to approximately 70 percent the size of the open-pollinated selection. The results of the observation of this line in the seedling stage points to its inferiority in height and rhizomatic aggressiveness (Table 1). In this latter characteristic it proved to be last in the 11 selections.

The results of this study indicate that selection No. 4 is slightly less resistant to high temperatures than the check but this difference is so slight that it may well be due to chance alone. In each series of the tests, survival of seedlings in this selection was superior to any of the other selections except the check. Its performance may indicate hybrid vigor since it appears to be more resistant to high temperatures than the closely related selection No. 3.

Selection No. 5 was a third generation selection secured from material originally obtained in Washington County, Kansas. This line has a few outstanding characters such as soft textured leaves and a bunch type growth free from excessive height and stemminess but when grown in the greenhouse, the seedling plants do not appear high in vigor. Although this line tied for third and fourth places in height (Table 1) the leaves were narrow and the rate of spread by rhizomes relatively low. These seedling characters correlate well with field observations. In the first series of high temperature studies, this selection differed from the check by a highly significant difference. In the second series the difference was much less. Seed of this selection was not obtainable for the third series of tests. Therefore, it is difficult to classify the heat resistance of this selection accurately.

Line No. 7 is a third generation selection that traces directly to seed obtained from a plant in the Achenbach field, Washington, Kansas. This seed was chosen from a coarse stemmed plant at that time (1935) and still retains this characteristic to a marked degree. Plants in this group are tall, wide-leafed and they spread rapidly by rhizomes. The character that merited its inclusion in this test was its heavy seed set. The number of fertile florets on plants in this progeny group was deemed important in future bromegrass breeding. Since increasing of a bromegrass strain involves considerable time and effort, any increase in seed yield of that strain will reduce the ultimate cost of producing and distributing such a strain.

Observations of this line, No. 7, in the seedling stage confirm some of the field observations. Table 1 shows this strain to be second in height, second in leaf width, and third in rhizomatic aggressiveness. The first two characteristics are desirable when the plant exhibits as much vigor as does this selection. Tallness in the seedling stage quite often foreshadows stemminess in the mature plant. The desirability of rhizomatic aggressiveness depends to some extent upon the use to which the grass is being put. Rapid spreading and vigorous growth may hasten the appearance of the so-called "sod-bound" condition that is caused by low availability of nitrogen and which reduces forage and seed yields. Alfalfa or other legume crops seeded with bromegrass retard the occurrence of the "sod-bound" condition for the number of years which those legumes remain in appreciable amounts, and in addition there may be a residual effect for some time after the disappearance of the legume.

This line, No. 7, gave satisfactory results in the high temperature tests. Seedlings of this line suffered only slightly more damage than did the seedlings of the check selection. In none of the series of tests did the difference prove significant.

Line No. 8 is a third generation selection from Pullman, Washington seed. In the field this plant exhibits extreme height, medium leafiness, and rhizomatic aggressiveness. This extreme height results in stemminess, and in this progeny group a "hollow center" characteristic is quite noticeable among the spaced plants in the nursery. This character is undesirable because the plant tends to grow around an ever widening crown that has few if any culms. The older the plant the more apparent this condition becomes. In its seedling stage the plant was one of the most vigorous studied. It produced the tallest seedlings, placed second in rhizomatic aggressiveness, and fifth in leaf width (Table 1).

In all three series of tests this selection proved least heat tolerant of the lines studied. The difference in the first and second series of tests was highly significant. The difference is most striking in the first test where, due to the severity of the treatment, a higher percentage of the population was killed.

Selection No. 9 is a second generation selection of material obtained from the Achenbach fields. At that time this seed was obtained from a plant with light bronze glumes and late maturity. This line has been grown for some time in isolation in an effort to obtain a pure strain for testing. Seed used in these tests came from plants of this selfed seed grown under conditions of open-pollination. This progeny group exhibits medium height, leafiness and rhizomatic aggressiveness in the field. Table 1 shows this line to be ninth in height, fifth in rhizomatic aggressiveness, and eighth or ninth in leaf width of the selections studied. This selection did not prove significantly different from the check selection in resistance to high temperatures. However, Table 5 shows the difference to have a probability only slightly above the five percent level.

Line No. 10 is a third generation selection originating from seed obtained in southeastern Kansas. There was sufficient seed for the first and third series of tests only. The selection exhibited a low spreading habit, medium rhizomatic aggressiveness, and narrow leaves in the nursery observations. This selection was eighth in both height and rhizomatic aggressiveness and eleventh in leaf width of the 11 selections observed (Table 1). In the first series of tests, this selection proved extremely susceptible to high temperatures and when compared to the check, the difference was highly significant.

Selection No. 11 is a third generation selection from brome obtained at the Achenbach fields. The seed was secured from a plant grown in a crossing block together with other plants selected as desirable from an agronomic standpoint. These plants were all of medium height and leafiness, and somewhat later than average in date of maturity.

In the seedling stage this line failed to show outstanding vigor and Table 1 shows it to be last in height, tenth in leaf width, but first in rhizomatic aggressiveness. In each of the series of tests it proved to be low in resistance to high temperature. When all three series of tests are considered it proved to be significantly less tolerant to high temperatures than the check selection (Table 5).

The third series of bromegrass heat resistance studies was conducted in an endeavor to discover other plants or plant progeny groups that might be of value in breeding for resistance to head as well as to test the progeny of certain lines that appeared desirable in the earlier part of the experiment. The selections No. 1 to 11 are those studied in the first two series, while the others are new lines added for testing.

Line No. 12 was grown from bulked seed from plants of selection No. 8 that survived the high temperature tests in the winter of 1940. As can be seen from Table 4, seedlings of this selection gave a higher survival than did those of the selection No. 8.

Line No. 13 was secured from plants of selection No. 1 which survived the high temperature tests in the winter of 1940. These plants were grown in isolation with plants of selection No. 8. In this case, as in the previous, seed from plants surviving the high temperature tests produced seedlings that appeared to be more tolerant to high temperatures than those of the original selection.

Selection No. 14 was secured from an isolated block of plants of Pullman, Washington origin but appeared to be more tolerant to high temperatures than No. 8, the other Pullman, Washington selection.

Selection No. 15 was obtained from seed of line No. 7 grown and selected for one more season. According to the number of seedlings that survived the high temperature test, it appears to be more resistant to heat than its parent.

Line No. S16 was a bulked sample of seed secured from three of the best plants in the progeny row I-8, a third generation selection from Pullman, Washington. These three plants were judged by observation to be leafier, more vigorous, and to have produced a larger amount of top growth than any of the other plants in the row.

Selection No. P16 was secured by bulking the seed of the three plants in the progeny row I-8 judged by observation to be the least leafy and vigorous, and to have produced the smallest amount of top growth in this progeny row. Fewer living seedlings remained in this line at the end of the test than in selection No. S16.

Selection No. S17 was obtained in the same manner as No. S16. Seed from three of the best plants in progeny row SA5 was used for this selection. It is a spreading, leafy type of Kansas origin, but in these trials it does not appear to exhibit sufficient tolerance to high temperature to be of value in breeding a heat resistant strain of bromegrass.

Line No. S18 was secured by bulking seed from two of the agronomically desirable plants in the progeny row of SB1. This row is a second generation selection of seed originally secured from southeast Kansas. The progeny row from which these two plants were chosen is an erect, bunch type desirable from an agronomic standpoint. High survival of the seedlings of this selection indicates its potential value in breeding for heat resistance.

Selection No. P18 was grown from seed of the poorest two plants in the progeny row of SB1. This selection emerged from the test with a greater number of living seedlings than did selection No. S18.

Line No. S19 was obtained from the best three plants in the progeny row of SC2, a selection originally secured from the locality of Manhattan, Kansas. The seedling survival after undergoing the high temperature test is extremely high, indicating that it might be of value in a breeding program.

Selection No. P19 was secured from the two plants poorest in agronomic characteristics in the progeny row SC2. In this case, these poor plants gave excellent seedling survival following the high temperature treatment.

Similar selections were made from the progeny row of SC3 selected originally along a roadside near the agronomy farm at Manhattan, Kansas. In this comparison, S20, the selection from the three best plants, produced seedlings that survived the high temperature somewhat better than did those of selection P20, obtained from two of the poorest plants in the row. This line shows promise as a source of breeding material.

Line No. S21 was obtained from a plant in the same progeny row as selection No. S4. The results serve as a check upon the method of selection used. All three plants used in these two selections were of the same agronomic type. The seedling survival of this line agrees closely to that of No. 4, Table 4.

The line No. S22 was selected from plants observed in the breeding nursery to produce large quantities of seed. The original source was a field in east-central Kansas. There are only two plants in the progeny row HS12 that furnished the seed for this last selection. The progeny row is medium in leafiness and taller than the average of the progeny rows. It does not evidence high temperature tolerance (Table 4).

Table 1. Average plant height, number of tillers*, and width of leaf of bromegrass strains tested.

Selection No.	Average height in cm	Average no. tillers per pot	Average width of leaf in mm
1	21.06	5.1	6.02
2	21.14	4.6	5.14
3	20.60	3.3	5.58
4	18.12	2.0	5.08
5	21.14	2.9	4.80
6	20.76	2.6	5.88
7	22.56	5.2	5.90
8	25.14	5.5	5.52
9	18.20	4.8	4.80
10	19.18	3.2	4.66
11	17.86	8.6	4.72

* Tillers per pot.

Table 2. Resistance of Bromegrass Seedlings to High Temperatures.
First series. December 14, 1940.

Selection No.	Nursery No.	No. of plants Alive	No. of plants Dead	Percent killed	Chi square (16)[1]
1	(1004)	27	93	77.5	24.212**
2	(1003)	29	91	75.8	21.486**
3	(G4)	54	66	55.0	1.668
4	(G4*)	62	58	48.3	0.067
5	(1006)	42	78	65.0	8.178**
6	(1101)	64	56	46.6	Check
7	(1301)	56	64	53.3	1.064
8	(1306)	10	110	91.7	56.966**
9	(1407)	48	72	60.0	4.296
10	(1516)	38	82	68.3	11.526**
11	(1402x)	46	74	61.7	5.436

[1] Chi square when statistical analysis is made between the check selection and each of the other selections.

** Highly significant statistical difference (1 percent level of significance).

Table 3. Resistance of Bromegrass Seedlings to High Temperatures.
Second series. February 14, 1941.

Selection No.	Nursery No.	No. of plants Alive	No. of plants Dead	Percent killed	Chi square (16)[1]
1	(1004)	41	94	69.6	5.71*
2	(1003)	49	86	63.7	1.86
3	(G4)	48	87	64.4	2.22
4	(G4*)	60	75	55.6	0.00
5	(1006)	63	72	53.3	0.14
6	(1101)	60	75	55.6	Check
7	(1301)	59	76	56.3	0.02
8	(1306)	24	111	82.2	22.4**
9	(1407)	53	82	60.7	0.75
11	(1402x)	57	78	57.8	0.12

[1] Chi square when statistical analysis is made between the check selection and each of the other selections.

* Significant difference in statistical analysis (5 percent level).

** Highly significant difference in statistical analysis (1 percent level).

Table 4. Resistance of Bromegrass Seedlings to High Temperatures.
Third series. November 22, 1941

Selection No.	Nursery No.	No. of plants: Alive	No. of plants: Dead	Percent killed
1	(1004)	48	24	33.3
2	(1003)	58	14	19.4
3	(G4) Nos. 3,6*	50	22	30.6
4	(G4*) Nos. 3,6*	50	22	30.6
6	(1101)	52	20	27.8
7	(1301)	45	27	36.5
8	(1306)	43	29	40.3
9	(1407*)	52	20	27.8
10	(1516) No. 1*	50	22	30.6
11	(1402x)	45	27	37.5
12	(1306) 2nd year**	49	23	32.0
13	(1004) 2nd year**	55	17	23.6
14	(1306)*** Iso.	21	12	36.4
15	(S7°)	52	20	27.8
S16	(I-8) Nos. 7,9,13*	55	17	23.6
P16	(I-8) Nos. 2,4,8*	46	26	36.1
S17	(SA5) Nos. 4,5,6*	42	30	41.7
S18	(SB1) Nos. 6,19*	53	19	26.4
P18	(SB1) Nos. 1,3*	57	15	20.8
S19	(SC2) Nos. 7,13,17*	59	13	18.1
P19	(SC2) Nos. 1,2*	61	11	15.3
S20	(SC3) Nos. 17,18,20*	61	11	15.3
P20	(SC3) Nos. 1,2*	56	16	22.2
S21	(G4*) Nos. 3,7*	49	23	32.0
S22	(HS12) Nos. 3,18*	44	28	38.9

* Plant number within the row.

** One additional year of selection.

*** Only eleven pots of this selection were tested.

Table 5. Resistance of Bromegrass Seedlings to High Temperatures.
Composited results of all three series of tests.

Selection No.	Nursery No.	No. of plants: Alive	No. of plants: Dead	Chi square (16)[1]
1	(1004)	116	211	22.70**
2	(1003)	136	191	9.82**
3	(G4)	152	175	3.52
4	(G4*)	172	155	0.10
6	(1101)	176	151	Check
7	(1301)	160	167	1.56
8	(1306)	77	250	63.18**
9	(1407)	153	174	3.22
11	(1402x)	148	179	4.80*

[1] Chi square when statistical analysis is made between the check selection and each of the other selections.

* Significant difference in statistical analysis (5 percent level).

** Highly significant difference in statistical analysis (1 percent level).

Table 6. Date of treatment, time of day, temperature and relative humidity to which the plants were subjected.

Treat-ment No.	Date	Time in	Time out	Total hours	Average temperature	Relative humidity
		Series 1. 12-14 to 12-22-'40				
1	12-14-40	8:00 A.M.	7:00 P.M.	11	126	55-60
2	12-16-40	7:30 A.M.	5:15 P.M.	9 3/4	127	55-60
3	12-17-40	8:00 A.M.	5:00 P.M.	9	127	55-60
4	12-18-40	8:00 A.M.	5:00 P.M.	9	129	55-60
5	12-19-40	8:00 A.M.	5:00 P.M.	9	128	55-60
6	12-20-40	9:30 A.M.	4:30 P.M.	7	125	55-60
7	12-21-40	11:45 A.M.	9:15 P.M.	9 1/2	132	55-60
8	12-22-40	8:15 A.M.	5:15 P.M.	9	134	55-60
				9.16	128	
		Series 2. 1-30 to 2-2-'41				
1	1-30-41	8:00 A.M.	2:15 P.M.	6 1/4	130	55-60
2	1-30-41	3:00 A.M.	8:30 P.M.	5 1/2	130	55-60
3	1-31-41	11:15 A.M.	4:30 P.M.	5 1/4	129	55-60
4	2- 1-41	8:00 A.M.	1:45 P.M.	5 3/4	130	55-60
5	2- 1-41	2:00 A.M.	8:15 P.M.	6 1/4	130	55-60
6	2- 2-41	9:00 A.M.	3:00 P.M.	6	130	55-60
				5.83	129.8	
		Series 3. 11-8 to 11-14-'41				
1	11- 8-41	10:35 A.M.	6:20 P.M.	7 3/4	126	55-60
2	11- 9-41	7:55 A.M.	3:40 P.M.	7 3/4	126	55-60
3	11-10-41	8:15 A.M.	4:30 P.M.	8 1/4	128	55-60
4	11-10-41	5:00 A.M.	1:15 P.M.	8 1/4	126	55-60
5	11-11-41	7:45 A.M.	3:00 P.M.	7 1/4	129	55-60
6	11-12-41	8:00 A.M.	3:45 P.M.	7 3/4	129	55-60
7	11-13-41	8:00 A.M.	3:00 P.M.	7	130	55-60
8	11-14-41	1:00 A.M.	8:00 P.M.	7	131	55-60
				7.62	128.1	

Table 7. Place of origin of the strains of bromegrass tested and time of their introduction into the Manhattan Nursery.

Strain	Year planted	Source	Outstanding characteristics of original plants
Achenbach	1935	Washington County, Kansas	Various: leafiness, stemminess glume color, and time of maturity
Roadside	1935	Manhattan, Kansas	Wide leaves, bunch type
Pullman	1936	Pullman, Washington	Vigor and forage production
Neodesha	1937	Wilson County, Kansas	Southern adaptation
Walter	1939	Manhattan, Kansas (seed originally from Achenbach)	Local adaptation and high seed production

Table 8. Sources of bromegrass lines tested and number of generations of selection.

Selection No.	Nursery No.	Original source	Generations selected
1	(1004)	Southeast Kansas	3
2	(1003)	Southeast Kansas	3
3	(G4) Nos. 3,6	Local roadside	3
4	(G4*) Nos. 3,6	Local roadside	3
5	(1006)	Achenbach Bros.	3
6	(1101)	Achenbach Bros.	3
7	(1301)	Achenbach Bros.	3
8	(1306	Pullman, Washington	3
9	(Iso.7)	Achenbach Bros.	2
10	(1516)	Southeast Kansas	3
11	(1402x)	Achenbach Bros.	3
12	(S8)	Pullman, Washington	4
13	(S1)	Southeast Kansas	4
14	(Iso.8)	Pullman, Washington	2
15	(1407)	Achenbach Bros.	3
S16	(I-8) Nos. 7,9,13	Pullman, Washington	3
P16	(I-8) Nos. 2,4,8	Pullman, Washington	3
S17	(SA5) Nos. 4,5,6	Southeast Kansas	3
S18	(SB1) Nos. 6,19	Neodesha	2
P18	(SB1) Nos. 1,3	Neodesha	2
S19	(SC2) Nos. 7,13,17	Local roadside	3
P19	(SC2) Nos. 1,2	Local roadside	3
S20	(SC3) Nos. 17,18,20	Local roadside	3
P20	(SC3) Nos. 1,2	Local roadside	3
S21	(G4*) Nos. 3,7	Local roadside	3
S22	(HS12) Nos. 3,18	Lee Walters (Achenbach)	1

Plant numbers refer to the order of the plants in the row.

Generations of selection refer to the number of times seed has been selected from plants and new plants established from this seed.

DISCUSSION

These series of high temperature studies were made to obtain information on the tolerance of bromegrass progeny groups (plants having the same or very similar ancestry) to high temperatures and to discover, if possible, any relationships that might exist between heat tolerance and plant type, source of seed, method of pollination and hybridization. Many such relationships were found to exist and some other correlations are suggested by the experiments. One of the first questions to present itself before further time and effort could be given to these high temperature tests was to discover whether or not bromegrass plants differed in their response to heat in the seedling stage. The first series of temperature tests indicated differences and subsequent experiments substantiated that result. In this series three of the selections proved to differ from a check selection to a highly significant degree (1940). A larger percent of the seedling bromegrass plants were killed in this series than in the two which followed due to the severity of treatment. It is also noteworthy that the differences, when a statistical analysis was applied, were more apparent and striking.

The second and third series of tests did not produce results so clearly defined, but in both tests, selection No. 8 proved least heat tolerant and selection No. 6 most heat tolerant. These results substantiated the evidence found in the first series. Selection No. 1 was highly susceptible to heat in the first and second tests but gave somewhat more promising results in the third. Nevertheless, the important fact to be considered is that these selections did exhibit highly significant differences in their responses to heat. Since there were differences in survival of seedling plants secured from plants and progeny groups when subjected to high temperature, it seems practical to search for those that may have heat tolerance and to eliminate those progeny groups showing susceptibility to heat. There were two methods by which this might be accomplished. All progeny rows could be tested or only those progeny rows which were derived from sources found to give a high percentage of tolerant individuals.

Some of the relationships between original sources and method of pollination could be observed from the data even though the evidences of such relationships were inconclusive. Selections from the strain of bromegrass developed by the Achenbach Bros. of Washington County, Kansas, showed much heat tolerance. Selections No. 6 and 7 are examples of this resistance. They rated first and third, respectively, in the tables showing the combined results of all three series of the heat tests. Selection No. 8, a third generation selection from a Pullman, Washington strain proved to be highly susceptible in the seedling stage. Progeny groups which traced to seed collected in southeastern Kansas, namely selections No. 1 and 2, did not show evidence of being above average in heat tolerance and thus their use in building the desired heat resistant strain would be questionable unless they contained other desirable characters. Plants originating from seed gathered along the roadside and in fields near Manhattan, Kansas, progeny rows SC2 and SC3, exhibited high heat tolerance in the third test. If this is substantiated by further tests, these two progeny groups could be used to considerable advantage in building the desired strain of bromegrass.

Evidence of hybrid vigor can be observed in a comparison of selections No. 3 and 4. These came from progeny rows of the same grandparent. The row from which selection No. 3 was secured was from the open-pollinated seed of this plant. Selection No. 4 was gathered from a plant in the progeny row grown from self-pollinated seed of this same grandparent. The differences in survival of the two selections were not great enough to be significant when tested statistically but trends can be observed by studying the tables in which the latter selection produced a higher number of surviving seedlings in the first two tests and equalled the former selection in the third test.

Selections No. 12 and 13 are related to selections No.

8 and No. 1 in a similar manner. Plants that survived the heat tests in the winter of 1940-1941 were placed in isolation on the agronomy farm. Seedlings of selection No. 8 produced seed used as selection No. 12 and seedlings of selection No. 1 produced seed used as selection No. 13. Table 4 (third series of tests) shows that progeny of plants which had survived one heat test produced seedlings that were more tolerant to high temperatures than seedlings of the original source. If later experiments give similar results this will open a method of selection for the desired heat resistant strain. Grasshopper injury prevented similar tests of other selections whose surviving seedlings were grown in isolated groups but produced insufficient seed for testing in the fall of 1941. However, these will be available for testing in the summer of 1942.

Another relationship observed was that of the heat susceptibility of seedlings whose sources came from vigorous desirable plants in a progeny row and those coming from weak, undesirable plants in the same progeny row. Selections from progeny rows I-8, SB-1, SC2, and SC3 illustrate this type of relationship. Lines or selections designated by S as S16, S18, etc. represent selections secured from the desirable plants and those designated by P, as P16, P18, etc. represent those selections gathered from the undesirable plants in the progeny row. The results indicate that plants from the same progeny row contain similar inherent germ plasm as to heat tolerance since in two of the four examples, the selections from the desirable plants gave higher seedling survivals while in the other two lines the undesirable plants proved more tolerant to high temperatures.

SUMMARY

1. This series of tests was initiated to study differences in resistance to high temperatures of nursery strains or progeny groups of Bromus inermis Leyss. with a view of producing a heat and drought resistant strain.

2. Highly significant differences in resistance to high temperatures were found between progeny groups growing in the nursery.

3. Lines No. 6, 4, and 7 ranked in that order in resistance to high temperatures.

4. Lines No. 19, 18, and 20 appear high in resistance from preliminary testing.

5. No relationship was found between agronomic characters of vigor and forage production and resistance to high temperatures.

6. Elimination of individuals susceptible to high temperatures by means of the temperature control chamber appears possible, and the resistant plants are being isolated in the nursery as a source of germ plasm for a heat and drought resistant strain.

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