Responses of Four Grasses at Different Stages Of Growth to Various Temperature Regimes[1]

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Grass seedling establishment has been a perennial problem on arid and semi-arid lands. Certain combinations of some of the factors that affect it result in success one year and failure the next. Temperature, which appears to be one of the primary factors influencing seedling establishment, was selected for this study.

Environmental factors such as temperature, in their extremes, restrict or kill living organisms. Within the limits of biological activity, however, the effects of gradations in temperature on the different plant processes are not well known. As with most plant-regulating factors, temperature effects are modified by and sometimes masked by other factors of the environment. The effects of specific factors vary with different species and even considerably within species (Haskell and Singleton, 1949).

Ludwig and Harper (1958), studying maize, concluded that soil temperature at planting time was an important factor in the time lapse from planting to emergence and the percentage of grains which became established as seedling. Working with fescue seed, Kern and Toole (1939), found a general decline in maximum germination with an increase in temperature from 10° to 30°C. Germination tests of seeds immediately after harvest showed a maximum germination at 10°C. As seed became progressively older, it appeared to germinate better at higher temperatures. Well-aged seed germinated best at constant temperatures as high as 20° to 25°C.

Crocker and Barton (1953) concluded that temperature affects the rate of water absorption and that both physical and chemical changes are involved. They stated that among the conditions necessary for seed germination, which have no relation to a need for pre-treatment, temperature is one of the most important. They also noted that the use of daily alternations of temperature brought about germination of many flower, grass, and vegetable seeds, which give poor seedling production under other conditions. The day and night temperatures most frequently used were 15° and 30° or 20° and 30°C.

Fayemi (1957) indicated that the rate of swelling of legume seeds was greatly influenced by temperature. The time from exposure to the initial absorption of water by the seeds became shorter as the temperature increased. At the end of 24 hours, except for seeds of crimson clover, from 90 to 100 per cent of the seeds at 25°C had absorbed water whereas only 5 to 50 per cent at the lower temperature (6.7°C.) had become swollen. The seeds kept at the low temperature did not germinate during this period but germinated readily when the temperature was raised. Water retention of swollen seeds at the low temperature did not reduce viability of any of the species except crimson clover.

Laude (1956) studied the relation of seedling emergence of perennial grasses and high soil temperature. When germinating grasses were subjected to various heat treatments, he found the nearer the heat exposure approached the time of expected emergence the fewer seedlings obtained.

The effect of temperature on water absorption, germination, and growth appears to be complex and is not altogether understood at present. As shown by Shull (1920), it is not the temperature alone which determines the rate of water uptake, germination and growth, but a complex of physiological processes. Effects of temperature treatments may often be masked by pathogens which attack plants. Once water has been absorbed, temperature becomes a most important factor in germination and growth of the plant. The effect of temperature on plants varies greatly among species, and in some cases, within species.

Methods and Materials

In September 1959, an experiment was initiated to determine the responses of four grass species to various temperature regimes at different stages of growth. Grass species used were all adapted for range or pasture seedings in the Pacific Northwest. The four species used in the study were beardless bluebunch wheatgrass (*Agropyron inerme* (Scribn. and Smith) Rydb.), hard fescue (*Festuca ovina* L. Var. *duriuscula* (L). Koch), big bluegrass (*Poa ampla* Merr.), and orchardgrass (*Dactylis glomerata* L.). The study was conducted in a controlled-environment growth chamber and in the greenhouse. A 13-hour day and an 11-hour night were maintained during the entire study. Greenhouse

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temperature was maintained at 70°F. Grasses were systematically rotated on the greenhouse benches every other day.

Five temperature regimes at 15 Fahrenheit degree intervals were selected for the growth-chamber phase of the study. These temperatures were (1) day 55°, night 40°; (2) day 70°, night 55°; (3) day 85°, night 70°; (4) day 100°, night 85°; and (5) day 115°, night 100°. All temperatures in this paper refer to degrees Fahrenheit. This study was set up as a randomized block design with five replications. Each pot was considered a plot. Grasses were grown in sterilized Palouse silt-loam soil in six-inch clay pots. Ten seeds of a species were planted per pot. Grasses were planted at six-day intervals for a total of five planting dates of 20 pots each. At the fifth and final planting date there were five replications of each species which were of the following ages: just planted, 6, 12, 18, and 24 days old. During the course of the study this entire procedure was repeated five times, once for each temperature regime.

Germination counts were made on all grasses and the maximum height of each seedling was recorded before placing pots in the growth chamber. At the same time, grasses which had been planted 18 and 24 days were thinned to three seedlings per pot to reduce root competition. The entire series was then moved from the greenhouse to the growth chamber and subjected to one of the five temperature regimes for 18 days. Upon removal from the growth chamber, germination counts were again made and plant heights were recorded for all species in all replications. In an attempt to ascertain immediate effects of each temperature regime, two of the five replications were randomly selected for intensive immediate study. Grasses from these replications were clipped at soil level, oven-dried, and weighed. The roots were carefully washed out and measured, and lengths were recorded.

The three remaining replications were returned to the greenhouse for six weeks to determine the carry-over effects of the growth chamber temperature regimes and recovery potential of the various grasses. However, because of a logistical error grasses subjected to the 55° temperature regime had a 10-week recovery period. Seedlings not thinned prior to introduction into the growth chamber were thinned to three per pot when about 30 mm. high. At the conclusion of the recovery period in the greenhouse, tops were harvested, oven-dried and weighed. Roots were also washed out, oven-dried and weighed.

During all phases of the experiment, plants were watered frequently and uniformly in an attempt to prevent soil moisture from becoming limiting.

Results And Discussion

Germination in Growth Chamber

A separate analysis of variance (Table 1) was run on each measured plant characteristic. Analysis of variance for germination (Table 1) indicated that effects of differences in temperature and differences among species were both significant at the 0.01 level. Effects on stage of growth, while shown to be significantly different, actually have little meaning because the seeds were planted at different times. The mean values (Table 2) for the five temperatures (average of the four species and their five planting dates) indicate that extreme temperature regimes of 55° and 115° were unsatisfactory for germination with values of 11.0 and 14.3 per cent, respectively. Mean values of 43.0 per cent for the 100° temperature regime and 47.6 per cent for the 70° regime were significantly higher than the means for the other temperature regimes but were not significantly different from each other (Table 2).

Seeds planted and immediately subjected to temperature treatment, germinated well at the three middle temperature regimes. All species when planted and immediately sub-

Table 1. Analysis of variance for six characteristics of four grasses subjected to various temperature regimes.

Source of Variation	Measurements While in Growth Chamber								Recovery Measurements			
	Germination		Top Elongation		Top Weight		Root Elongation		Final Top Weight		Final Root Weight	
	D.F.	Mean Square	D.F.	Mean Square	D.F.	Mean Square	D.F.	Mean Square	D.F.	Mean Square	D.F.	Mean Square
Temperature (T)	4	454.9**	4	113872**	4	0.0609**	4	39347**	3	0.0318**	3	0.1555**
Stage of Growth (S)	2	163.0**	4	5236**	4	0.1551**	4	72772**	4	0.0761**	4	0.3257**
T x S	8	42.1**	16	2804**	16	0.0095**	16	2743**	12	0.0044	12	0.0093
Grass Species (G)	3	58.3**	3	53525**	3	0.8883**	3	18696**	3	0.1213**	3	0.4496**
T x G	12	11.9	12	5403**	12	0.0058**	12	737	9	0.0094**	9	0.0192**
S x G	6	21.1**	12	5740**	12	0.0168**	12	842	12	0.0071**	12	0.0191**
T x S x G	24	8.0	48	699	48	0.0018	48	863	36	0.0023	36	0.0043

**Indicates significance at the 0.01 level jected to temperature treatments failed to germinate while in the growth chamber at the 55°F. regime. However some limited germination did occur after the pots were returned to the greenhouse. Differences between species for all temperatures and stages of growth were highly significant (Table 1). Highest over-all germination percentage (39.8) was exhibited by hard fescue. Beardless bluebunch wheatgrass, big bluegrass, and orchardgrass followed with 33.1, 24.5, and 20.1 per cent, respectively. Seeds of hard fescue germinated best at 100° with an average of 92 per cent. Beardless wheatgrass and big bluegrass both exhibited maximum germination at 85° with 70 and 68 per cent, respectively. Seeds of hard fescue germinated best at 100° with an average of 92 per cent. Beardless wheatgrass and big bluegrass both exhibited maximum germination at 85° with 70 and 68 per cent, respectively. An increase of 15 degrees caused a considerably greater decrease in germination than did a decrease of 15 degrees for these grasses. Orchardgrass exhibited fair germination for the three middle temperature regimes. A maximum of 56 per cent germination was obtained at 70° with complete inhibition of germination at 55° and 115°.

Extreme temperatures had a less pronounced effect on seeds which had been planted six days before introduction into the growth chamber. Differences were especially evident for beardless bluebunch wheatgrass and hard fescue at the 55° temperature regime and beardless wheatgrass, big bluegrass and orchardgrass at the 115° regime. Seed of the grasses under study were more affected by extreme temperatures during the first six days after planting. Seeds which had been planted 12 days before introduction into the growth chamber had, in most cases, completed germination. Orchardgrass, however, did increase in germination at 70°, even after the 12 days in the greenhouse. The 15° day and night temperature variation apparently results in germination of some seeds which would not have germinated at the nearly constant temperature of the greenhouse. Extreme temperatures while in the growth chamber appeared temporarily to inhibit germination of all species. Seeds of all species, however, continued to germinate upon being returned to the greenhouse.

Top Elongation

Analysis of variance for top elongation indicates that all species were greatly affected by the various temperature regimes (Table 1). Stage of growth, species, and their interactions all varied enough to be highly significant. Mean values for top elongation and least significant ranges over all stages of growth and all species are shown in Table 2. A marked increase in top elongation was indicated as temperature was increased from the 55° to the 85° temperature regime with 8.5 mm., 62.7 mm., and 79.4 mm. for the 55°, 70°, and 85° temperatures, respectively. The 100° temperature exhibited a slight but insignificant decrease from the 85° temperature. A further increase in temperature to 115° resulted in a highly significant decrease in top elongation (Table 2).

Seeds planted at the beginning of the temperature treatment germinated and initiated growth during the 18-day period in the growth chamber, appeared to benefit most from the 100° temperature, and did well at the 70° and 85° temperature, but were greatly inhibited at 55° and 115°. Grasses which had been planted six days before temperature treatment made maximum top elongation at the 70° temperature regime. Top elongation de-

Table 2. Mean effects of temperature on growth responses of four grass species and their least significant ranges.[1]

Characteristics					
GERMINATION (100)[2]					
Temperature F°	55	115	85	100	70
Mean (Percent)	11.0	14.3	31.0	43.0	47.6
TOP ELONGATION (100)					
Temperature F°	55	115	70	100	85
Mean (mm.)	8.5	14.7	62.7	74.2	79.4
TOP WEIGHT (40)					
Temperature F°	55	115	70	100	85
Mean (mg.)	1.84	3.66	9.38	9.39	10.44
ROOT ELONGATION (40)					
Temperature F°	55	115	70	85	100
Mean (cm.)	5.9	10.6	12.3	12.6	13.9
FINAL ROOT WEIGHT (60)					
Temperature F°	100	115	70	85	55
Mean (mg.)	4.72	4.99	6.23	9.16	9.60[3]
FINAL TOP WEIGHT (60)					
Temperature F°	115	100	70	55	85
Mean (mg.)	8.7	10.1	14.7	18.3[3]	20.6

[1]Any two means not underscored by a broken line or a solid line are significantly different at the 0.05 level. Any two means not underscored by a solid line are significantly different at the 0.01 level.

[2]Numbers in parentheses indicate number of observations.

[3]These means not directly comparable as plants at the 55° temperature regime were allowed a 10 rather than 6 weeks recovery period.

creased slightly as the temperature was increased to 100° and decreased rapidly with further increase in temperature. Grasses planted 12 and 24 days before temperature treatment made greatest top elongation at the 85° temperature regime.

Beardless wheatgrass, hard fescue, and orchardgrass exhibited maximum top elongation at the 85° regime. Big bluegrass exhibited maximum elongation at 70° but growth decreased as the temperature increased to 100°. The highest and lowest temperatures greatly inhibited elongation of all species.

These data indicate rapid top elongation between 70° and 100°. Also, there appeared to be a stimulation of top growth from the relatively high temperature of 100° when the grass was emerging. These data indicate the crucial range for top elongation to be between 55° and 70°. Between these two temperatures there was an average seven-fold increase in top elongation. All species studied exhibited further growth increases from the 70° to the 85° regimes at the oldest stage of growth.

Top Weight While in Growth Chamber

Analysis of variance for top weight while in the growth chamber indicates that temperature, stage of growth, species, and their interactions are all highly significant (Table 1). The 85° temperature regime resulted in the greatest average top production over all stages of growth (Table 2). When the temperature was increased or decreased by 15° increments from the 85° temperature regime, top weight was reduced significantly. Mean top production values of 10.44, 9.39, 9.38, 3.66, and 1.84 mg. were found for 85°, 100°, 70°, 115°, and 55° respectively. Top production was significantly reduced between 55° and 70° and between 100° and 115°.

Grasses planted 0 and 18 days before introduction into the growth chamber made their greatest growth at 100°. Grasses just emerging at the time of introduction into the growth chamber made maximum growth at 70°. Grasses planted 12 and 24 days before temperature treatment made their maximum growth at 85°. Top production appears to be significantly influenced by temperature, the magnitude of the effect depending on how far the temperature diverges from the optimum. Of the temperatures studied, 70° resulted in greatest top production for big bluegrass and 85° for the remaining species.

Root Elongation While in Growth Chamber

Analysis of variance for root elongation indicates a highly significant variation between temperature, stage of growth, and species (Table 1). The most pronounced increase in root elongation due to temperature was a two-fold increase of 5.0 cm. to 12.3 cm. from the 55° to the 70° regime. Mean root elongation of 12.6 cm. for the 85° regime was not significantly different from the root elongation of the 70° regime (Table 2); however, the mean values for both 85° and 70° were significantly less than the 13.9 cm. mean growth at 100° which appeared to be optimum for root elongation. The 115° regime resulted in a highly significant decrease in elongation as compared with the 100°, with a mean value of 10.6 cm.

Grasses planted 0, 6, and 18 days before being placed in the growth chamber exhibited maximum elongation at 100°. Grasses planted 12 days prior to being placed in the growth chamber made maximum root growth at the 85° regime. Of the grasses planted 24 days before being placed in the growth chamber, beardless wheatgrass and orchardgrass showed a pronounced stimulation at the 115° regime. Hard fescue and big bluegrass, however, exhibited maximum elongation at the 85° regime.

Final Top Weight

Mean values showing residual effect of temperature on top weights indicate a definite residual effect of the various temperature regimes (Table 2). The effect of the inhibition of normal growth as a result of the 115° treatment was especially pronounced, even after the six-week time lapse since treatment. Grasses at 55° would be expected to have the most top growth, since their recovery period was four weeks longer than that of grasses receiving other treatments. This was true in less than 50 per cent of the observations. These data suggest that 18 days at 55° put the grasses tested about four weeks behind in top production as compared with those at the 85° regime. Temperature, stage of growth, grass species, the interaction of temperature and growth, and the interaction of stage of growth and species were all highly significant (Table 1). Means for final top weight indicate that even after a six-week recovery period, production at the 85° regime was significantly higher than any of the others (Table 2). Presumably, if recovery periods were equal, the mean values for the 55° regime would have been significantly below the mean values of 14.7 mg. and 20.6 mg. for the 70° and 85° regimes, respectively. The values of 10.1 mg. for the 100° regime and 8.7 for the 115° regime were not significantly different from each other but were significantly lower than the value for the 70° regime (Table 2).

These data suggest that the two high temperature regimes, 100° and 115°, had a prolonged deleterious effect on the grass seedlings. Following the six-weeks recovery period in the greenhouse, top weights of plants subjected to the two high temperatures were still significantly lower than top weights of plants subjected to the 70° and 85° temperatures. As stated before, final top weights of seedlings subjected to the 55° temperatures cannot be directly compared as they were allowed a ten-week recovery period.

Final Root Weight

Final root weights follow a similar pattern as final top weights. Analysis of variance for final root weight shows temperature, stage of growth, species, and the interactions of these variables to be significant at the 0.01 level (Table 1). Final root weight was greatest at the 85° regime and this value was highly significantly different from all other values for root weight. This apparently was a reversal of the trend immediately following temperature treatment where root growth exhibited an optimum growth at 100°. Six weeks after treatment, root growth for the 85° regime was 9.16 mg., about double that for the 100° regime (4.72) (Table 2). Mean values for the 100°, 115°, and the 70° regimes were not significantly different. The final root weight for the 55° regime should not be compared because of the difference in recovery period.

Six weeks after temperature treatment, there appeared to be complete masking of the immediate root stimulation at the higher temperature regimes; plants subjected to the 85° regime produced maximum root production. In some instances, as with beardless wheatgrass at the oldest stage of growth, the effects of the temperature stimulation in the growth chamber were still evident six weeks after removal.

Summary And Conclusions

Results of germination analysis on beardless bluebunch wheatgrass, hard fescue, big bluegrass, and orchardgrass indicated that germination is inhibited or greatly reduced at temperatures above 100° or below 70°. Germination was fair between 70° and 100°. Orchardgrass germinated best at the lower temperature and beardless wheatgrass, hard fescue, and big bluegrass at the higher temperatures. No apparent detrimental carry-over effects from extreme temperatures were observed after returning seeds to greenhouse conditions.

A pronounced increase in top production was exhibited as the temperature was increased from 55° to 85°. The 85° regime resulted in the greatest top growth over all stages of growth. Little growth occurred at 55°. A sharp decline in top production took place at 115°.

In contrast to the decline in top growth from 85° to 100°, root growth as measured by elongation was greatest at 100°. The stimulation of root elongation at 100° was followed by an over-all decrease in both top and root production during the six-week recovery period.

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