Temperature Profiles for Germination of Bluebunch and Beardless Wheatgrasses

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Abstract

The germination of seeds of beardless and bluebunch wheatgrasses was investigated over a wide range of constant and alternating temperatures. Seeds of 'Whitmar' beardless wheatgrass, a collection from Nevada, and numbered accessions of bluebunch wheatgrass were used. Seeds of 'Whitmar' beardless wheatgrass germinated at 87% of the 55 temperature regimes tested with a mean germination of 52%. Germination at 42% of the temperature regimes was optimum [defined as not significantly ($P = 0.01$) different from maximum], with a mean of 84%. Freshly harvested seeds of the Nevada source of bluebunch wheatgrass germinated at 78% of the temperature regimes with a mean of 40%. Comparable figures for fully ripened seeds 5 months after harvest were 84% with a mean of 62%. The germination response of 1-month old bluebunch wheatgrass seeds indicated that germination could occur at the high seedbed temperatures encountered in a late summer moisture event. The temperature-germination profiles for the numbered accessions of bluebunch wheatgrass had the same general pattern as the Nevada source. Generally, seeds were highly germinable at a number of temperatures. Optimum germination of all the sources of seed occurred at 37 temperature regimes at least once and always occurred at 15 temperatures ranging from an alternating 5/15° C through a constant 25° C. This range of germination temperatures is much wider than that exhibited by squirreltail and Sandberg bluebunch. The bluebunch wheatgrass material has the inherent potential to germinate and to be highly germinable at a wide range of temperatures.

Bluebunch wheatgrass (*Agropyron spicatum*) is one of the most widespread and important native forage grasses on rangelands of the western United States (Hitchcock 1951). Bluebunch wheatgrass is the dominant or codominant perennial grass of sagebrush (*Artemisia*)/bunchgrass communities in eastern Washington, Idaho, eastern Oregon, northern Nevada, and Utah (Stoddard 1941, Daubenmire 1970).

Considering its wide distribution and the characteristics of other species of *Agropyron*, bluebunch wheatgrass is not a highly variable species (Hitchcock et al. 1969). Generally, awned and awnless forms are recognized. The awnless phase has been generally recognized in the commercial seed trade and range literature as beardless wheatgrass (*Agropyron inerme*). Cytogenetic evidence shows the two phases to be completely interfertile with normal pairing in meiosis (Cronquist et al. 1977). Understanding the germination ecology of bluebunch and beardless wheatgrasses is vitally important for cultivar selection, management of native stands, and artificial revegetation of degraded stands. One aspect of the germination of these wheatgrass species is their response to temperature. Our purpose was to evaluate the germination of a broad spectrum of wheatgrass collections in response to constant and alternating incubation temperatures.

Materials and Methods

We used seeds of beardless wheatgrass, cultivar 'Whitmar' obtained from the Soil Conservation Service (SCS) U.S. Department of Agriculture (Table 1). A total of 10 sources of bluebunch wheatgrass were tested, nine from the SCS, and one from Nevada. The material obtained from the SCS represents the accessions in their collections under evaluation for selection of a cultivar. Accession P-285272 is considered a hybrid of beardless and bluebunch wheatgrass. The source from Nevada was collected from a native stand on the Goldbanks allotment south of Winnemucca, Humboldt County, Nevada.

The accessions obtained from the SCS differed in the location at which they were grown, Pullman, Washington, or Bridger, Montana; and the year grown, 1968 to 1976 (Table 1). All SCS accessions were tested in 1978.

The Nevada material was grown in a space planted common garden at Reno, Nevada. The garden was given weed control and supplemental irrigation. It was established with seedlings transplanted from the greenhouse in 1977. A limited number of seeds were collected from the plants in 1977 but seed production was excellent in 1978.

All germination experiments involved four replications of 25 seeds each and tests were repeated at least once. Seeds were placed on a single thickness of germination paper in petri dishes and kept moist with tap water. Tests were conducted in the dark. Seeds were incubated for 4 weeks with germination counts made weekly. Seeds from all sources were initially tested at constant incubation temperatures of 2, 5, 10, 15, 20, 25, and 30° C. Based on the results of these initial experiments, we selected 'Whitmar', the Nevada material, P-6409, P-737, P-739, P-285272, and M-883 for additional testing to develop complete germination profiles.

For development of germination profiles, seeds of the selected sources were incubated at constant temperatures of 0, 2, 5, 10, 15, 20, 25, 30, 35, and 40° C. Alternating temperature regimes consisted of 16 hours at each lower constant temperature and 8 hours at all possible higher temperatures in each 24-hour period. For example, 0° C was alternated with 2, 5, 10, 15, 20, 25, 30, 35, and 40° C whereas 35° C was alternated with 40° C only. In all, 55 constant and alternating temperature regimes were tested.

In 1978 we tested the Nevada source seed 1 month after harvest and again 5 months after harvest to test for afterripening requirements.

After germination data were obtained for all 55 temperature regimes, the percentage of temperature regimes and mean germination for those temperatures that produced some germination were obtained. We define optimum germination percentages as those not significantly different ($P = 0.01$) from the maximum. The number and mean of the optimums were calculated for each profile. The percent of temperature regimes having germination in the percentiles <10, 10 to 25 (not including 25), 25 to 50, 50 to 75, 75 to 90 and >90% was calculated for each germination profile.

We compared the temperature-germination profiles of the selections tested under a discriminant classification of seedbed temper-

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Table 1. Species, accession, cultivar, or collection and origin of seeds of wheatgrasses used in germination experiments.¹

Species or forma	Accession, cultivar, or collection	Origin	Year grown	Location grown	Tag germination (%)	Germination profiles developed
<i>Agropyron inerme</i>	'Whitmar'	Union County, Oreg.	76	Union, Oreg.	81	X
<i>Agropyron spicatum</i>	P-6409	Lewiston, Idaho	76	Pullman, Wash.	81	X
<i>Agropyron spicatum</i>	P-737	Joel, Idaho	75	Pullman, Wash.	80	X
<i>Agropyron spicatum</i>	P-739	Asotin, Wash.	75	Pullman, Wash.	86	X
<i>Agropyron spicatum</i>	P-15623	Granite County, Mont.	68	Bridger, Mont.	67	
<i>Agropyron spicatum</i>	P-15634	Park County, Wyo.	68	Bridger, Mont.	42	
<i>Agropyron spicatum</i> X						
<i>A. inerme</i>	P-285272	Whitman County, Wash.	71	Bridger, Mont.	—	X
<i>Agropyron spicatum</i>	M-883	Wheatland County, Mont.	74	Bridger, Mont.	—	X
<i>Agropyron spicatum</i>	C-29	Grand County, Colo.	70	Bridger, Mont.	—	
<i>Agropyron spicatum</i>	Nevada	Humboldt County, Nev.	77-78	Reno, Nev.	—	X
<i>Agropyron spicatum</i>	P-15649	Lincoln County, Mont.	75	Bridger, Mont.	—	

¹Year grown and tag germination taken from seed tag. Not all lots had germination indicated.

atures. This classification system included 19 moderate temperature regimes, 5/15, (5° C for 16 hr and 15° C for 8 hr in each day) 5/20, 5/25, 10/10 through 10/30, 15/15 through 15/35, 20/20 through 20/35, 25/25/ and 25/30° C; 11 colder than moderate regimes, 0/0 through 0/15, 2/2 through 2/15, 5/5 and 5/10° C; 16 widely fluctuating regimes, 0/20 through 0/40, 2/20 through 2/40, 5/30 through 5/40, 10/35 and 10/40, and 15/40° C; and 9 warmer-than-moderate regimes 20/40, 25/35, 25/40, 30/30 through 30/40, 35/35, 35/40, and 40/40° C. This classification is based on the monitoring of field seedbeds in sagebrush grassland (Evans et al. 1970) and experience with the germination response of many grass species.

A frequency analysis was used to determine, for all sources of bluebunch wheatgrass, which temperature regimes supported germination most frequently in the optimum range.

Results

Screening of Seed from All Sources

Comparison of the germination at constant temperatures of bluebunch and beardless wheatgrass seeds from the various sources revealed three lots, P-15634, C-29, and P-15623, that were significantly less germinable than the rest (Table 2). These three accessions were the oldest seeds tested and apparently had largely lost their germinability; two accessions had previously much higher germination percentages, indicated by their lot tags (Table 1). These three accessions were dropped from further testing.

'Whitmar' Beardless Wheatgrass

Some germination occurred at 87% of the temperature regimes tested with a mean germination of 52% (Table 3). Germination at 42% of the 55 temperature regimes used was in the optimum range with a mean of optimums of 84%. Germination was completely inhibited only at the very cold temperatures of 0° C, 0/2 (0° C for 16 hr alternating with 2° C for 8 hr) and 0/5° C, the extremely

fluctuating temperature regimes of 0/40, 2/40, and 5/40° C, and the very warm incubation temperature of 40° C.

The inherent ability to germinate at low temperatures while soil moisture is still available is one of the most important germination characteristics influencing seedling establishment in the spring on sagebrush rangelands (Evans et al. 1970). Differences of a few days may mean the difference between successful establishment and seeding failure. 'Whitmar' seeds germinated after 4 weeks incubation at 0/20° C at a level significantly ($P = 0.01$) lower from the optimum. However, even this is a fairly high day temperature for field seedbeds in the early spring (Evans et al. 1970). A 0/15° C temperature regime probably better reflects field conditions. At this regime 'Whitmar' seed germination fell to 32% and at 0/10° C it was only 3% (Table 3). Raising the cold period temperature to 2° C did not significantly increase the germination with warm-period temperatures 15, 20, or 25° C.

With cold-period temperatures from 5 through 25° C and warm-period temperatures below 35° C, the germination was in the optimum range (Table 3). Germination at 15/25° C, the temperature regime used for official determinations of the germination of this cultivar (Anon. 1978), was 95%, the maximum obtained.

Bluebunch Wheatgrass

Afterripening

The seeds of many species require a period of time after they fall from the maternal plant for embryo maturation before they will germinate. This time period is the afterripening requirement (Mayer and Poljakoff-Mayher 1963).

When seeds of bluebunch wheatgrass from the Nevada 1978 source were tested 1 month after harvest, germination occurred at 78% of the 55 regimes tested, with a mean of 40% (Table 4). Optimum germination occurred at 18% of the temperature regimes with a mean of 83%. Two groups of temperature regimes supported optimum germination; one was at 10/35° C, 20/20° C and all

Table 2. Percent germination at constant temperatures for bluebunch and beardless wheatgrass seed from 12 sources.

Temperature (C°)	Germination (%) ¹										Nevada	
	P-737	M-883	P-6409	'Whitmar'	P-15634	C-29	P-285272	P-15649	P-15623	P-739	1977	1978
2	54 a-c	87 a-d	30 e	8 b	0	1 d	8 c	48 bc	0	12 e	0 d	10 b
5	50 a-d	72 b-d	50 de	88 a	2	1 d	22 c	25 c	0	26 de	58 b	96 a
10	65 a	90 a-c	76 a-c	96 a	15	1 d	92 a	80 a	8 d	70 ac	71 ab	88 a
15	57 a-c	91 a-c	67 a-d	89 a	16	12 cd	83 ab	73 ab	0	93 a	84 a	89 a
20	52 a-d	93 ab	72 a-d	85 a	15	30 a	90 a	81 a	0	78 a-c	62 b	85 a
25	43 ae	84 ad	70 a-d	82 a	19	7 cd	83 ab	77 ab	0	78 a-c	23 c	82 a
30	28 d-f	80 a-d	47 de	21 b	11	4 d	69 b	63 ab	10 cd	60 a-c	8 cd	19 b
Mean	50 b	85 a	59 b	67 ab	11 c	8 c	64 ab	64 ab	3 c	60 ab	44 b	67 ab

¹Means within sources compared vertically within sources, and overall means compared horizontally among sources. Means followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test. No letters indicates no significance.

Table 3. Germination profile for seeds of 'Whitmar' beardless wheatgrass.¹

Cool-period temperature (°C) (16 hr)	Germination (%)									
	Warm-period temperature °C 8-hr									
	0	2	5	10	15	20	25	30	35	40
0	0	0	0	3 j	32 f-j	45 d-g	<u>74 a-d</u>	22 f-j	1 j	0
2		3 j	3 j	12 hi-j	45 d-g	<u>71 a-d</u>	<u>68 a-d</u>	19 f-j	5 ij	0
5			90 ab	90 ab	89 ab	85 ab	95 a	89 ab	39 e-h	0
10				<u>72 a-d</u>	89 ab	93 a	83 ab	86 ab	45 d-g	3 i
15					87 ab	95 a	95 a	76 abc	47 c-f	14 hij
20						<u>81 ab</u>	95 a	87 ab	25 f-j	14 hij
25							<u>71 a-d</u>	<u>68 a-d</u>	23 f-j	16 g-j
30								61 b-e	35 e-i	18 f-j
35									22 f-j	3 j
40										0

Some germination = 87% $\bar{x}$ germination = 52%.

Optimums = 42% $\bar{x}$ of optimums = 84%.

Germination percentiles

< 10=25%, 10 to 25=16%, 25 to 50=15%, 50 to 75=13%, 76 to 90=18%, >90=13%

¹Means followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test. For the reader's convenience, means not significantly different from optimum are underlined.

temperatures alternating with 15° C as the cool-period temperature and the second at 0/15 and 0/20° C.

It is not unusual for freshly harvested seeds to have optimum germination at temperature regimes with 2 or 0° C cold periods. The cool period portion of the regime serves as a cool-moist stratification environment that satisfies afterripening requirements. The germination profile for the freshly harvested Nevada source seed is unusual in that germination is greatly restricted at temperature regimes with 2° C cold periods compared to 0 or 5° C (Table 4). Upon observing this unusual pattern we immediately repeated the germination test with 2-month-old seed. We obtained generally higher germination, but the depression with the 2° C cold periods and optimums with the 0/15 and 0/20° C regimes continued (data not shown).

Since bluebunch wheatgrass seeds germinate very well at some temperatures 1 month after harvest, germination with unusual moisture events during late August or early September is possible. A 15/40° C temperature regime is conceivable for this time period, and seeds could germinate if the moisture event was of sufficient duration and magnitude. Harris (1957) considered the establishment of spring germinated bluebunch wheatgrass to be conditioned by the occurrence of unusual moisture events during the usually dry summer periods characteristic of the far west.

Fully Ripened Germination

Five months after harvest there was no additional increase in germinability. The 5-month post-harvest profile had some germination at 84% of the temperature regimes tested, with a mean of

Table 4. Germination profile of bluebunch wheatgrass from Nevada source grown in a common garden at Reno in 1978. Germination test conducted 1 month after harvest.¹

Cool-period temperature (°C) (16 hr)	Germination (%)									
	Warm-period temperature °C 8-hr									
	0	2	5	10	15	20	25	30	35	40
0	0	0	3 np	57 c-g	<u>70 a-e</u>	<u>74 a-e</u>	55 d-h	11 k-p	1 p	0
2		0	0	0	7 m-p	2 op	1 p	0	0	0
5			32 g-m	40 f-j	41 f-j	28 i-o	36 g-k	34 g-l	12 k-p	17 j-p
10				32 g-m	41 f-j	40 f-j	50 e-i	36 g-k	<u>80 a-d</u>	66 b-f
15					82 abc	87 ab	87 ab	89 ab	86 ab	77 a-d
20						<u>94 a</u>	30 h-m	37 g-k	29 h-n	25 i-p
25							24 i-p	28 i-o	29 h-n	25 i-p
30								14 j-p	8 l-p	6 m-p
35									0	0
40										0

Some germination = 78% $\bar{x}$ germination = 40%.

Optimums = 18% $\bar{x}$ of optimums = 83%.

Germination percentiles

<10=35%, 10 to 25=11%, 25 to 50=29%, 50 to 75=11%, 75 to 90=13%, >90=1%.

¹Means followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test. For the reader's convenience, means not significantly different from maximum are underlined.

Table 5. Germination profile of seeds of bluebunch wheatgrass from the Nevada source, grown in a common garden. Germination test conducted 5 months after harvest.¹

Cool-period temperature (° C) (16 hr)	Germination (%)										
	Warm-period temperature ° C 8-hr										
	0	2	5	10	15	20	25	30	35	40	
0	0	0	0	4 i	10 ghi	9-ghi	47 d-f	14 ghi	14 ghi	0	
2		10 ghi	4 i	34 e-h	98 a	95 a	87 abc	77 ac	0	0	
5			96 a	95 a	94 ab	94 ab	97 a	58 c-e	77 ghi	0	
10				88 ab	81 abc	89 ab	93 ab	87 ab	73 a-d	65 b-d	
15					89 ab	94 ab	94 ab	94 ab	82 abc	72 a-d	
20						85 abc	93 ab	92 ab	89 ab	93 ab	
25							82 abc	85 abc	10 ghi	6 hi	
30								19 ghi	22 f-i	5 i	
35									4 i	0	
40										0	
Some germination = 84%					x germination = 62%.						
Optimums = 51%					x of optimums = 89%.						
Germination percentiles											
<10=27%, 10 to 25=13%, 25 to 50=5%, 50 to 75=7%, 75 to 90=22%, >90=26%											

¹Means followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test. For the reader's convenience, means not significantly different from maximum are underlined.

62% (Table 5). Optimum germination occurred at 51% of the temperature regimes, with a mean of 89%.

The depression in germination with 2° C cold periods was no longer apparent. However, germination at 0/10, 0/15, and 0/20° C was markedly lower for the fully matured seeds than for seeds tested 1-month post-harvest.

The seeds of the Nevada source of bluebunch wheatgrass must be classed as highly germinable, for 25% of the temperature regimes supported germination at or above 90%, and 47% supported germination at 75% or above (Table 5).

This germination profile is an indication of the potential of seeds of the species to germinate. Germination and seed production of many native grasses, including beardless wheatgrass, have been shown to increase under an optimum seed-production environment (Miltimore et al. 1962). Seeds of bluebunch wheatgrass produced from native stands under harsh environmental conditions probably would be much less germinable. Seeds of squirreltail (*Sitanion hystrix*) from native stands have been shown to be more highly germinable, with optimum germination at a greater number of temperatures, in favorable seasons for growth and seed production (Young and Evans 1977).

Comparison of Numbered Accessions

The numbered accessions represent the plant material from which a cultivar of bluebunch wheatgrass may be selected for release for use on rangelands. Over a longer time, plant breeders may recombine this and other plant material through hybridization and selection to develop additional cultivars. The numbered accessions were originally collected over a wide geographic area of the western United States and provide a broad representation of the species.

Accession M-883, originally collected in Wheatland County, Montana, had optimum germination in four categories: some germination, mean germination, optimums, and mean of optimums (Table 6). Both accessions P-6409 and P-739 were optimum in all categories except for the some germination category. The hybrid accession P-285272 had some germination at 90% of the 55 temperature regimes tested.

Germination Percentiles

Comparing germination by percentiles revealed accession P-6409 had less than 10% germination at only 4% of the temperature regimes tested (Table 6). In comparison, accession P-737 had less than 10% germination at 33% of the temperature regimes. Acces-

sion P-6409 had greater than 50% germination at 73% of the temperature regimes tested although 90% germination was attained at only 6% of the regimes tested. However, there was no significant ($P = 0.01$) difference among the accessions in the percentage of temperature regimes producing germination equal to or greater than 90%.

Optimum Germination

We found 15 temperature regimes that always supported optimum germination for the accessions tested (Table 7). These temperatures were in a block of 5/15 through 5/30° C, 10/15 through 15/30° C, and 20/20 through 20/30 and 25/25° C. Comparable figures on the temperature regimes that support optimum germination for squirreltail and Sandberg bluegrass (*Poa Sandbergii*) seeds collected from native stands reveal only three temperature regimes for each species that were always optimum (Evans et

Table 6. Selected characteristics of germination-temperature profiles for five numbered accessions of bluebunch wheatgrass seed tested under 55 temperature regimes.

Temperature profile characteristics ¹	Accessions				
	P-737	P-285272	P-6409	P-739	M-883
Some germination (%)	78 b	90 a	82 b	82 b	93 a
Mean germination (%)	35 c	49 bc	70 a	64 ab	59 ab
Optimum germination (%)	38 b	38 b	56 a	51 a	51 a
Mean of optimums (%)	55 b	66 ab	81 a	81 a	82 a
Percentiles					
<10%	33 a W	10 cY	4 d Z	25 b W	16 c XY
10 to 25%	13 ab Y	11 b Y	20 a Y	3 c Y	7 bc Z
25 to 50%	25 b X	32 a X	4 d Z	11 c X	15 c XY
50 to 75%	29 b WX	40 a W	27 b X	24 b W	22 b X
75 to 90%	0 c Z	7 c Y	40 a W	27 b W	29 b W
>90%	0 z	0 Z	6 Z	10 X	11 YZ

¹ Means of temperature-profile characteristics and percentiles are compared horizontally among accessions. Means followed by the same letter (a through d) are not significantly different at the 0.01 level of probability as determined by Dunan's multiple range test. No letters indicates no significance. Means of percentiles are compared vertically within accessions and percentile means followed by the same letter (w through z) are not significantly different at the 0.01 level of probability.

Table 7. Frequency (%) that optimum germination occurred at a given temperature regime in the germination profiles of five numbered accessions and the Nevada collection of bluebunch wheatgrass.¹

Cool-period temperature (°C)	Frequency of optimum germination (%)										
	Warm-period temperature °C 8-hr										
	(16 hr)	0	2	5	10	15	20	25	30	35	40
0											
2					17	85	85	85	68	17	
5				3	68	100	100	100	100	51	
10					85	<u>100</u>	85	<u>100</u>	<u>100</u>	68	
15						<u>100</u>	100	100	<u>100</u>	68	51
20							<u>100</u>	100	100	68	51
25								<u>100</u>	85	17	34
30									17	34	17
35											
40											

¹For emphasis, the 100% frequencies are underlined.

al. 1977; Young and Evans 1977). These temperatures were 10/15, 10/20, and 15/15° C for squirreltail and 5/20, 10/20, and 15/20° C for Sandberg bluegrass.

For the bluebunch wheatgrass complex, 37 temperature regimes supported optimum germination at least once (Table 7). In comparison, only 26 temperature regimes for squirreltail (Young and Evans 1977) and 17 for Sandberg bluegrass supported optimum germination at least once (Evans et al. 1977). However, the wheatgrass seeds were harvested from plants grown in gardens and the squirreltail and Sandberg bluegrass seeds were collected from native stands.

Constant vs. Alternating Temperatures

Germination in the field is almost always under alternating temperature regimes, but it is very convenient to do germination tests at one constant temperature. In the field the amount of diurnal fluctuation in seedbed temperature can be modified by the depth of planting or through the use of furrows (Evans and Young 1972). The germination of the seeds of some species is markedly enhanced by alternating temperatures. Mayer and Poljakoff-Mayher (1963) and Plummer (1943) reported that bluebunch wheatgrass seeds germinated better under alternating than under constant temperatures.

We found no readily apparent advantage to alternating versus constant temperature. For a more detailed comparison, we plotted the mean germination of all sources tested at constant temperature and the mean germination at alternating temperature with the base temperature with the highest mean germination (Fig. 1). In this comparison the alternating temperature regimes produced greater germination at low temperature, 0 through 10° C; roughly equal germination at moderate temperatures, 15 and 30° C; and lower germination at 35° C.

We compared the germination at constant temperatures with alternating temperature regimes that had the same number of

Fig. 1. Comparison of germination at constant incubation temperatures and at the alternating regimes with the base temperature that had the highest mean germination. Means of five numbered accessions, the Nevada collection of bluebunch wheatgrass, and 'Whitmar' beardless wheatgrass.

Table 8. Mean germination and percentages of temperature regimes with some germination at moderate and extreme (colder, widely fluctuating, and warmer) temperature regimes.¹

Wheatgrass	Mean germination (%) at indicated regime				Regimes with some germination (%)			
	Moderate	Colder	Widely fluctuating	Warmer	Moderate	Colder	Widely fluctuating	Warmer
'Whitmar' beardless	80 bc	25 jk	31 i	21 km	100 a	73 ef	81 c	89 b
Nevada bluebunch	90 a	32 i	40 h	18 mn	100 a	73 ef	75 de	78 cd
M-883 bluebunch	85 ab	23 km	48 fg	43 gh	100 a	64 h	100 a	100 a
P-737 bluebunch	52 ef	13 n	18 mn	18 mn	100 a	46 j	81 c	67 gh
P-6409 bluebunch	83 bc	30 ij	45 gh	56 e	100 a	75 de	69 fg	89 b
P-739 bluebunch	78 c	33 i	39 h	52 ef	100 a	46 j	81 c	89 b
P-285272 bluebunch	66 d	15 n	42 h	44 gh	100 a	55 i	100 a	100 a

¹Means followed by the same letter are not significantly different at the 0.01 level of significance as determined by Duncan's multiple range test. Mean germination and percent with some germination compared separately.

degree hours above 0° C in equivalent time periods (Fig. 2). In this comparison, there appears to be an advantage to constant temperature incubation at 5° C, probably because the equivalent alternating regimes alternate with 0° C.

Comparison with Seedbed Temperatures

At what we classify as moderate seedbed temperatures the Nevada source of bluebunch wheatgrass had the highest germination (Table 8), but was not significantly ($P = 0.01$) higher in germination than accession M-883. The Nevada collection and accessions P-6409 and P-739 of bluebunch wheatgrass had the highest germination at colder than moderate seedbed temperatures.

The range between highest and lowest mean germination drops dramatically with the colder than moderate temperature regimes, 38 versus 20 percent (Table 8). Accession P-285272 of bluebunch wheatgrass had the next to lowest mean germination at moderate and colder than moderate temperatures, but was among the highest germinators at widely fluctuating and warmer temperatures. There appears to be a correlation between germination at warmer than moderate temperatures and widely fluctuating temperatures. Such a relationship would indicate that the limiting factor in the widely fluctuating temperature regimes may be the warmer temperatures.

All of the sources tested generally had some germination at a high percentage of the temperature regimes tested with the exception of the colder than moderate classification. However, accessions M-883 and P-285272 were exceptional in germinating at all of the widely fluctuating and warmer regimes. No matter how limited, germination at extreme temperatures may be of practical importance. Wheatgrasses are normally seeded on sagebrush rangelands at the rate of 8 seeds per dm of row, and a fully stocked stand is one established plant per 3 dm of row. Theoretically, a fully stocked stand could be obtained with 4% germination. Obviously many more factors than germination enter into successful seedlings establishment, but a slight amount of germination at extra moderate temperatures might produce a successful stand.

Significance of Study

Many factors other than the germination response to temperature enter into the selection of a cultivar of bluebunch wheatgrass for use on rangelands. This study shows that most of the bluebunch wheatgrass accessions evaluated have the inherent potential for germination over a wide range of temperatures.

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Fig. 2. Comparison of germination at constant incubation temperatures and at alternating temperature regimes with equivalent amounts of degree hours above 0° C. Means of five numbered accessions, the Nevada collection of bluebunch wheatgrass, and 'Whitmar' beardless wheatgrass.

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