Temperature requirements for mountain rye, Hycrest crested wheatgrass, and downy brome germination

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Abstract

In this study we determined that mountain rye *(Secale montanum)*, crested wheatgrass *(Agropyron cristatum × desertorum* 'Hycrest'), and downy brome *(Bromus tectorum)* have similar germination temperature requirements and thus have the potential to germinate under similar soil temperature regimes, a feature which could be advantageous for subsequent seedling competition of mountain rye or crested wheatgrass against downy brome. Germination temperature profiles were compared using a thermogradient germination plate. Fifty-six different day/night temperature regimes were utilized for the comparisons. The bivariate spline model was found to be the best model for predicting germination-temperature response of the 3 species. Mountain rye and downy brome produced high germination under widely fluctuating (20–30° C, 16 hr day/5–10° C, 8 hr night) temperature regimes with crested wheatgrass demonstrating an optimum germination temperature over a 10–20° C day/25° C night regime. One of the 2 downy brome sources evaluated exhibited a much broader optimum germination temperature range. However, the differences in germination temperature profiles obtained were not of a magnitude likely to be biologically or ecologically significant due to the relatively high germination obtained over a wide range of fluctuating day/night temperatures for all 3 species.

Key Words: bivariate spline, biological weed control, thermogradient germination plate, *Secale montanum* Guss., *Bromus tectorum* L., *Agropyron cristatum* × *desertorum*.

Downy brome *(Bromus tectorum)* is an annual grass that occupies more than 41 million ha of land in the Intermountain West as the dominant species (Mack 1981). While the species provides early spring grazing (Klemmedson and Smith 1964), it is generally considered a weed species because of its short grazing season and competitive suppression of more desirable perennials. Several methods of downy brome control on rangelands have been utilized with variable success. Mechanical control by disking followed by seeding of perennial grasses was not very effective (Eckert et al. 1974). The soil seed reserves of downy brome may be reduced by burning allowing seeding of perennials, but fire also enhances annual grass dominance of sites in subsequent years (Young et al. 1976). Chemical control methods have been used successfully (Eckert et al. 1974, Evans et al. 1967), but have not gained widespread acceptance for economic and environmental reasons. Another approach in which we are interested is biological control of downy brome by seeding grasses that are able to competitively suppress downy brome without additional control measures. This concept was one of 2 approaches proposed by Evans et al. (1970), i.e., (1) utilize a perennial species that can effectively overcome the competition imposed by downy brome or, (2) alter the seedbed microenvironment to favor germination and growth of seeded perennials. In attempting the first approach, mountain rye *(Secale montanum)* and crested wheatgrass *(Agropyron cristatum × desertorum* 'Hycrest') and (Asay et al. 1985) are 2 species under consideration.

The objective of this study was to determine the germination temperature requirements of these 2 species relative to that of downy brome. Late fall and early spring germination is characteristic of downy brome, i.e., under conditions of cool and diurnally widely fluctuating temperatures (Evans et al. 1970, Thill et al. 1984). The capacity in these 2 species for high, rapid germination under similar conditions would be advantageous for the competitive suppression of downy brome. A companion study compared early seedling growth of the 3 species (Buman et al. 1987).

Materials and Methods

Mountain rye seed of the Elk Creek accession was collected from a planting site near Boise, Idaho, in August 1984. Hycrest crested wheatgrass seed (1984 harvest) was obtained from field plantings of the USDA-ARS (Logan, Utah) in August 1984. Downy brome seed was collected in June 1984 from 2 sites, a rangeland site south of Juniper Lake in Oregon (downy brome OR) and a cropland site south of Pullman, Wash. (downy brome WA).

The mountain rye seedlot was mechanically threshed and screened before use. Downy brome seed was deawned using a spike-tooth cereal head thresher, while Hycrest crested wheatgrass required no seed conditioning. A sample of each seedlot was evaluated for post-harvest dormancy by a germination test in September 1984. Four replications of 100 seeds from each seedlot were placed on moist blotter paper in 11 by 11-cm germination boxes and maintained at a 12 hour 20° C day (56 $\mu E/m^2/sec$) and a 12 hour 15° C night for a period of 21 days. Germination was assessed by radicles 3 mm or longer counted at 1-day intervals.

Temperature profiles for germination of mountain rye, Hycrest crested wheatgrass and downy brome were determined during the period Octobr 1984 through March 1985 using a two-way thermogradient germination plate (Larsen 1971). The temperature profile had a range of −5.0 to 27.8° C ± 1° C during the light period (16 hours, 56 $\mu E/m^2/sec$), and a range of −6.4 to 27.8° C during the dark period (8 hr). Irradiance was provided by 4 soft-white fluorescent bulbs.

An experimental unit consisted of 100 seeds placed on 2 pieces of moist filter paper in a covered glass petri dish (9 cm diameter). Fifty-six of these petri dishes were placed directly on the thermogradient plate which maintained each at a unique day-night temperature combination. The moisture content and germination of each dish was checked every 24 hr for a 21-day period. Seeds with radicles 3 mm long were counted as germinated and removed daily from each dish. Any seeds that had visual sign of fungal infection were removed from the dish. A repeat run for each seedlot was initiated immediately after the completion of the original runs. One method to analyze the effect of different day-night temperature regimes on percent germination is to use a three-dimensional plane. To test for differences between seedlots, a three-dimensional regression model was needed. Evans et al. (1982) suggested the use of a quadratic regression equation. This model was compared with log transformation models, arcsin transformation models, and the bivariate spline model. After comparison of lowest mean square error, plots of normal probability, plots of residuals vs. fitted

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values, plots of studentized residuals vs. fitted values, and raw data vs. fitted data, the bivariate spline model was selected as the best model for the data obtained in this study. A model temperature profile for seed germination was constructed from the 2 replicate runs for each seedlot by using the bivariate spline (Montgomery and Peck 1982):

$$
\begin{aligned}
Y = {} & B_0 + B_1\,(\text{DAY TEMP}) + B_2(\text{NIGHT TEMP}) + B_3(\text{DAY TEMP}^2) + \\
& B_4(\text{NIGHT TEMP}^2) + B_5(\text{DAY TEMP} \times \text{NIGHT TEMP}) + \\
& B_6(\text{DAY TEMP} - t)_+^2 + B_7(\text{NIGHT TEMP} - t)_+^2 + \\
& B_8[(\text{DAY TEMP} - t)_+^1(\text{NIGHT TEMP} - t)_+^1]
\end{aligned}
$$

where, Y equals estimated percent germination and t represents the day or night temperature at which a significant change in slope occurred. This model was adjusted when more than 1 significant change in slope occurred for day and/or night temperature to provide the most adequate model.

All combinations of the 4 bivariate spline models (1 for each seedlot) were compared to determine if the three-dimensional response surfaces were significantly different from one another (alpha = 0.05) by use of indicator variables (Montgomery and Peck 1982). The bivariate spline equations were then used to calculate percent germination values for every 5° C interval over the entire day-night temperature range of -5° C to 30° C. These fitted percent germination values were used to determine germination parameters similar to those described by Young and Evans (1982) to characterize and compare germination temperature requirements of different species. The parameters used included: mean germination, mean germination of temperature regimes with some germination, percent of regimes with some germination, percent of regimes with optimum germination, mean of optimum germination regimes, and maximum germination. The equation used to calculate optimum temperature used a full confidence interval instead of one-half of a confidence interval.

Results and Discussion

Post-harvest dormancy has been reported for downy brome (Steinbauer and Gigsby 1957). For example, over a 5-month period of after-ripening the total percent germination increased from 0 to 80% (Laude 1956). However, Thill et al. (1984) reported 92% germination after only 8 weeks of storage at room temperature. Downy brome (OR), downy brome (WA), and Hycrest crested wheatgrass seedlots used in this study had germination percentages of 71, 81, and 85, respectively, when tested after 3 months of post-harvest storage. Mountain rye germinated at 83% when tested at a temperature of 20° C after one month of post-harvest storage. Thus, both seedlots of downy brome and the seedlot of Hycrest crested wheatgrass contained a high percentage of viable, nondormant seeds after 3 months of storage, and mountain rye seeds were readily germinable after 1 month of storage. This suggested that mountain rye and Hycrest crested wheatgrass could germinate in the fall and overwinter as a seedling similar to the germination/establishment pattern which has been reported for downy brome (Thill et al. 1984, Young and Evans 1982). However, concurrent fall germination could occur only if the germination temperature requirements of these 2 species were similar to those of downy brome.

The raw data of all 4 seedlots showed a rapid decrease in total germination when the day or night temperature was below 5° C and a plateau at temperatures above 5° C as shown by the representative data for downy brome (OR) (Fig. 1A). The quadratic equation did not respond to rapid changes in slope but, rather, produced smooth and more gradual changes in slope (Fig. 1B). This resulted in three-dimensional graphs of the data which had small, rounded peaks and smooth, rounded sides, thus producing models which were not as statistically accurate as the bivariate spline model (Fig. 1C).

The bivariate spline allows creation of a three-dimensional surface with lines at places where there are significant changes in slope. If a single line in each direction is used on the three-dimensional surface then 4 separate regression equations are produced. These 4 equations are then combined into 1 equation which produces a single three-dimensional surface.

The derived model for each seedlot (Table 1) was compared by indicator variables to determine if response surfaces were signifi-

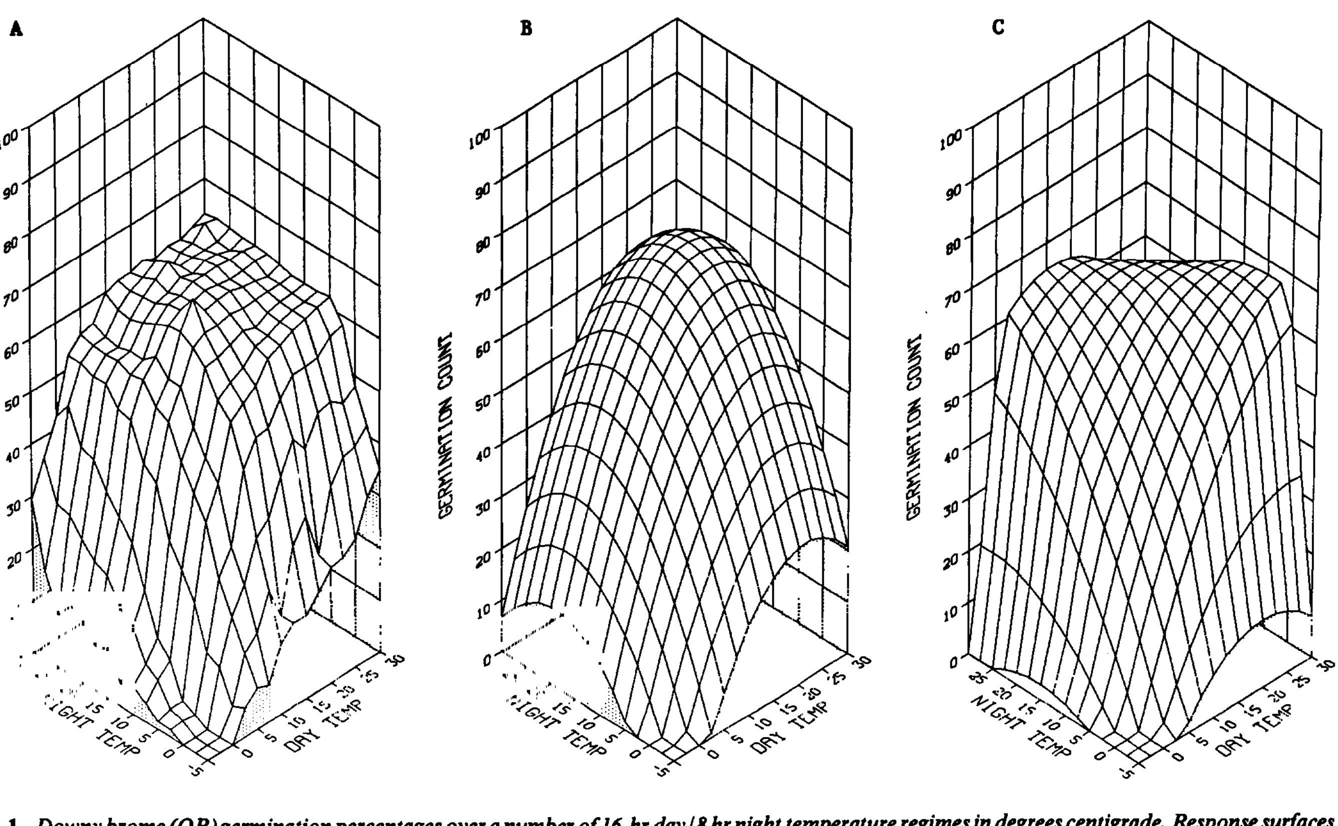

Fig. 1. *Downy brome (OR) germination percentages over a number of 16 hr day/8 hr night temperature regimes in degrees centigrade. Response surfaces were generated from raw data (A), from a quadratic regression model (B), and from a bivariate spline model (C).*

Table 1. Bivariate spline models for the total percent germination of mountain rye, downy brome, and Hycrest crested wheatgrass germinated on a thermogradient plate. The seed was germinated using a 16 hour day and an 8 hour night period.

Mountain Rye — adjusted R^2 = 92.1%

$$Y=16.03+3.75(\text{Day Temp.})+2.15(\text{Night Temp.})+0.231(\text{Day Temp.}^2)-0.106(\text{Night Temp.}^2)+0.226(\text{Day Temp.}\times\text{Night Temp.})-0.287(\text{Day Temp.}-1.0C)_+^2+0.081(\text{Night Temp.}-0.0C)_+^2-0.315[(\text{Day Temp.}-1.0C)_+^1(\text{Night Temp.}-0.5C)_+^1]$$

Downy Brome (OR) — adjusted R^2 = 87.7%

$$Y=0.10+2.70(\text{Day Temp.})+2.26(\text{Night Temp.})+0.370(\text{Day Temp.}^2)+0.195(\text{Night Temp.}^2)+0.310(\text{Day Temp.}\times\text{Night Temp.})-0.420(\text{Day Temp.}-1.0C)_+^2+0.226(\text{Night Temp.}-0.5C)^2+0.396[(\text{Day Temp.}-1.0C)_+^1(\text{Night Temp.}-0.5C)_+^1]$$

Downy Brome (WA) — adjusted R^2 = 94.5%

$$Y=9.50+3.60(\text{Day Temp.})+1.61(\text{Night Temp.})+0.291(\text{Day Temp.}^2)-0.030(\text{Night Temp.}^2)+0.327(\text{Day Temp.}\times\text{Night Temp.})-0.341(\text{Day Temp.}-1.0C)_+^2+0.041(\text{Night Temp.}-0.0C)^2+0.438[(\text{Day Temp.}-1.0C)_+^1(\text{Night Temp.}-0.0C)_+^1]$$

Hycrest Crested Wheatgrass — adjusted R^2 = 94.2%

$$Y=1.72+4.66(\text{Day Temp.})+3.83(\text{Night Temp.})+0.465(\text{Day Temp.}^2)+0.0531(\text{Night Temp.}^2)+0.505(\text{Day Temp.}\times\text{Night Temp.})-0.539(\text{Day Temp.}-0.0C)^2-0.258(\text{Night Temp.}-21.2C)_+^2-0.539[\text{Day Temp.}-0.0C_+^2(\text{Night Temp.}-0.5C)_+^2 0.163[(\text{Day Temp.}-0.0C)_+^1(\text{Night Temp.}-21.2C)_+^1]-0.644[(\text{Day Temp.}-0.0C)_+^1\ \text{Night Temp.}-0.5_+^1]$$

cantly different and if further analysis was required. The models for each individual species were found to be significantly different at an alpha of 0.05. The models were then used to calculate estimated total percent germination values for 5° C temperature intervals from –5° C to 30° C (Tables 3 to 6), and parameters to describe the germination characteristics of each seedlot (Young and Evans, 1982) were determined (Table 2).

Table 2. Germination parameters for mountain rye (Semo), downy brome (Brte), and Hycrest crested wheatgrass (Agdecr) germinated at fifty-six distinct day-night temperature regimes. The seed was germinated using a 16 hour day and an 8 hour night.

Germination parameter	Semo	Brte(OR)	Brte(WA)	Agdecr
	%			
Mean germination	57	40	53	54
Maximum germination	90	67	93	89
Regimes with some germination	98	89	94	89
Mean of regimes with some germination	57	45	56	61
Regimes with optimum germination[1]	11	34	3	5
Mean optima	86	64	89	88

[1]Optimum germination is defined as the germination percentage within one 95% confidence interval of the maximum germination.

Mountain rye had the greatest number of regimes with some germination (Table 2) and the highest mean percent germination values (Table 3) for the widely fluctuating and cold temperatures (below 0° C) of the 4 seedlots. Downy brome (OR) (Table 4) and Hycrest crested wheatgrass (Table 6) had the poorest response to widely fluctuating and cold temperatures. The difference in immediate germination response of the 4 seedlots to constant low temperatures of 1° C or less, and, to widely fluctuating temperatures with a day or night temperature of less than 0° C are not likely to be biologically significant. Prolonged periods at these temperatures during the fall are not likely. These temperatures would more likely be expected to have an effect on germination after prolonged exposure, i.e., spring, in a field environment. Of greater importance was the finding that mountain rye and Hycrest crested wheatgrass seedlots had little post-harvest dormancy by fall and exhibited germination at cool and widely fluctuating temperatures generally similar to that of downy brome. This would indicate that both species could germinate in the fall under the same conditions as downy brome.

Results also showed that downy brome (WA) (Fig. 5) had slightly higher germination in those temperature regimes in which there was a wide temperature fluctuation than in those with a constant day-night temperature. This increase in germination with widely fluctuating temperatures was not observed in downy brome

Table 3. The estimated percent germination values with 95% confidence intervals for mountain rye germinated on a thermogradient plate. The starred values indicate the optimum germination temperature range. Optimum germination ranged from 82.9% to 90.3% for this seedlot.

	Germination Percentage (± .95 CI)							
Day temperature - 16 Hr (C)	Night Temperatures – 8 Hr –5	0	5	10	15	20	25	30
	%							
–5	0 (±0)	4 (±6)	8 (±4)	12 (±4)	14 (±4)	15 (±5)	14 (±6)	12 (±8)
0	3 (±6)	16 (±6)	26 (±5)	35 (±5)	43 (±5)	49 (±5)	54 (±5)	58 (±7)
5	16 (±5)	35 (±5)	44 (±3)	53 (±3)	60 (±3)	66 (±3)	70 (±4)	73 (±6)
10	27 (±4)	52 (±4)	59 (±3)	65 (±3)	70 (±3)	73 (±3)	75 (±3)	77 (±6)
15	35 (±4)	65 (±4)	70 (±3)	74 (±3)	77 (±3)	78 (±3)	78 (±3)	77 (±5)
20	40 (±4)	76 (±4)	79 (±3)	81 (±3)	81 (±2)	80 (±2)	78 (±3)	74 (±5)
25	43 (±5)	85* (±5)	85* (±4)	84* (±5)	83* (±3)	79 (±3)	75 (±4)	69 (±6)
30	43 (±8)	90* (±7)	88* (±6)	86* (±5)	81 (±5)	76 (±5)	69 (±6)	61 (±8)

Table 4. The estimated percent germination values with 95% confidence intervals for downy brome (OR) germinated on a thermogradient plate. The starred values indicate the optimum germination temperature range. Optimum germination ranged from 60.1% to 67.3% for this seedlot.

Day temperature - 16 Hr (C)	Germination Percentage (± .95 CI) Night Temperatures – 8 Hr -5	0	5	10	15	20	25	30
	%							
-5	0 (±0)	0 (±0)	0 (±0)	2 (±5)	3 (±5)	2 (±6)	0 (±7)	0 (±0)
0	0 (±0)	0 (±7)	12 (±6)	22 (±6)	30 (±5)	37 (±5)	43 (±6)	47 (±7)
5	2 (±6)	16 (±6)	28 (±4)	38 (±4)	47 (±4)	54 (±4)	59 (±5)	63* (±8)
10	8 (±5)	30 (±5)	41 (±3)	49 (±3)	55 (±3)	60 (±3)	63* (±4)	65* (±7)
15	12 (±5)	42 (±5)	51 (±3)	57 (±3)	61* (±3)	64* (±3)	65* (±4)	64* (±7)
20	13 (±6)	50 (±4)	59 (±3)	63* (±3)	65* (±3)	65* (±3)	64* (±4)	61* (±7)
25	12 (±7)	57 (±6)	64* (±4)	66* (±4)	66* (±4)	64* (±4)	60* (±5)	56 (±7)
30	8 (±9)	61* (±9)	67* (±7)	66* (±6)	64* (±6)	60* (±6)	55 (±7)	48 (±10)

Table 5. The estimated percent germination values with 95% confidence intervals for downy brome (WA) germinated on a thermogradient plate. The starred values indicate the optimum germination temperature range. Optimum germination ranged from 86.1% to 92.6% for this seedlot.

Day temperature - 16 Hr (C)	Germination Percentage (± .95 CI) Night Temperatures – 8 Hr -5	0	5	10	15	20	25	30
	%							
-5	0 (±0)	0 (±0)	0 (±0)	0 (±0)	1 (±4)	3 (±4)	5 (±5)	8 (±7)
0	1 (±5)	10 (±6)	18 (±4)	27 (±4)	36 (±4)	46 (±4)	57 (±4)	68 (±6)
5	12 (±4)	29 (±4)	37 (±3)	45 (±3)	54 (±3)	63 (±3)	73 (±3)	84 (±6)
10	22 (±4)	47 (±4)	52 (±2)	57 (±2)	63 (±2)	70 (±2)	77 (±3)	85 (±5)
15	29 (±4)	62 (±3)	64 (±2)	67 (±2)	70 (±2)	74 (±2)	78 (±3)	83 (±5)
20	33 (±4)	75 (±4)	74 (±2)	74 (±2)	74 (±2)	76 (±2)	77 (±3)	79 (±5)
25	35 (±5)	85 (±5)	82 (±3)	79 (±3)	76 (±3)	74 (±3)	73 (±3)	72 (±5)
30	35 (±7)	93* (±6)	86* (±5)	81 (±5)	76 (±5)	71 (±5)	67 (±5)	63 (±7)

(OR) or the other 2 species. Another finding was that downy brome (OR) had the highest percentage of regimes in which optimum germination occurred. These 2 responses probably would not increase competitive ability of this species over the others during fall or early spring field germination, because the germination percentage of mountain rye and Hycrest crested wheatgrass was also relatively high at these temperatures.

The differences in mean germination, maximum germination, and mean optimum values in Table 2 for mountain rye, downy brome (WA), and Hycrest crested wheatgrass are probably not great enough to provide 1 of these species with a competitive advantage over the others, i.e., not biologically significant. The downy brome (OR) seedlot would have a slightly lower potential for establishment than the other seedlots due to its 22–25% lower maximum germination. Other than the lower total germination percent for downy brome (OR), there was little difference between the 4 seedlots.

Conclusions

The bivariate spline was found to be the best model for statistically predicting germination response of the 3 species compared in this study. A bivariate spline allows an accurate model to be constructed which can be used for analysis and to determine predicted total germination values for selected temperatures within the temperature ranges.

Although statistical differences in germination temperature responses of the 3 species were obtained, biological-ecological significance of these responses was unlikely. The results of this

Table 6. The estimated percent germination values with 95% confidence intervals for Hycrest crested wheatgrass germinated on a thermogradient plate. The starred values indicate the optimum germination temperature range. Optimum germination ranged from 86.0% to 94.4% for this seedlot.

Day temperature - 16 Hr (C)	Germination Percentage (± .95 CI) Night Temperatures – 8 Hr							
	-5	0	5	10	15	20	25	30
	%							
-5	0 (±0)	0 (±0)	0 (±0)	3 (±5)	6 (±5)	6 (±5)	0 (±0)	0 (±0)
0	0 (±0)	2 (±7)	22 (±6)	40 (±5)	56 (±5)	68 (±6)	74 (±6)	65 (±17)
5	5 (±5)	23 (±5)	42 (±4)	56 (±4)	68 (±3)	77 (±4)	83 (±4)	74 (±15)
10	10 (±5)	41 (±4)	58 (±3)	69 (±3)	77 (±3)	83 (±3)	88* (±4)	80 (±26)
15	11 (±5)	55 (±4)	70 (±4)	78 (±3)	82 (±3)	84 (±3)	89* (±4)	82 (±13)
20	9 (±5)	66 (±5)	79 (±3)	87 (±3)	84 (±3)	83 (±3)	87* (±4)	80 (±12)
25	3 (±6)	72 (±6)	83 (±4)	84 (±4)	82 (±4)	77 (±1)	81 (±5)	75 (±12)
30	0 (±0)	75 (±8)	85 (±6)	82 (±6)	76 (±6)	68 (±7)	72 (±7)	66 (±14)

study suggested that if mountain rye or Hycrest crested wheatgrass were interseeded into downy brome dominated areas in the fall, all 3 species could potentially germinate and establish that fall. The first requirements for the use of either mountain rye or Hycrest crested wheatgrass in biologically controlling downy brome, that of potential germination, would be satisfied. Other studies (Buman[1], Buman et al. 1987) of growth responses of seedlings of the 3 species in competition have shown that mountain rye may be a superior competitor.

[1]Buman, R.A. 1986. Seed germination and seedling interspecific competition of mountain rye (*Secale montanum* Guss.), 'Hycrest' crested wheatgrass (*Agropyron cristatum* L. × *A. desertorum* Fisch.) and downy brome (*Bromus tectorum* L.). M.S. Thesis. Univ. of Wyoming.

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