# Annual Brome Seed Germination in the Northern Great Plains: An Update

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**Abstract**: Japanese brome (*Bromus japonicus* Thunb) and downy brome (*B. tectorum* L.), alien weedy cool-season annual grasses, have invaded thousands of hectares of grass and shrub communities in the Northern Great Plains, Great Basin, and Columbia Basin. Abundance of brome is dependent upon availability of seed, amount and distribution of rainfall, temperature, and availability of soil nitrogen. More than 10,000 annual brome seeds can be present in a square meter in the mixed-grass prairie of the Northern Great Plains. A large portion of ripe seeds will generally germinate over a wide range of temperatures and osmotic potentials that often occur in late summer and autumn, but soils usually must be moist for 3 to 5 days for seeds to germinate. However, a percentage of seeds that do not germinate by late September can become dormant when water is taken up at or below 0 °C. This dormant state can last through the next winter, spring, and summer. These characteristics aid annual brome's persistence on rangelands.

## Introduction

Japanese brome (*Bromus japonicus* Thunb) and downy brome (*B. tectorum* L.), alien weedy cool-season annual grasses, have invaded thousands of hectares of grass and shrub communities in the Northern Great Plains (Haferkamp and others 1993; Hewlett and others 1981; Whisenant 1990), Great Basin (Mack 1981; Young and Evans 1972), and Columbia Basin (Daubenmire 1970; Hulbert 1955). Although annual bromes can produce large quantities of nutritious spring forage, they can have a negative impact on associated perennial forage species and performance of grazers (Haferkamp and others 1994b, 1997, 1998, 2001a,b; Rummell 1946). Forage production is erratic from year to year (Gartner and others 1986; Haferkamp and others 1993, 2001a), and due to early maturation of the annual bromes (Vallentine and Stevens 1994) compared to perennial grasses, their presence can alter seasonal patterns of forage production and cause relatively rapid declines in forage quality on infested rangelands (Haferkamp and others 1994b, 2001b).

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Abundance of brome is dependent upon the seedbank (Karl and others 1999), temperature, and amount and distribution of rainfall (Haferkamp and others 1993; Mack and Pyke 1983; Whisenant 1990). Karl and others (1999) reported that more than 10,000 germinable annual brome seeds can be present in a square meter in the mixed-grass prairie of the Northern Great Plains. Thus, the potential for dense populations of annual brome seedlings is great. We have developed a better understanding of the dynamics of seed germination for Japanese brome through a series of studies conducted at the Fort Keogh Livestock and Range Research Laboratory, Miles City, MT (Haferkamp and others 1994a, 1995a,b).

## Temperature

The influence of temperature on germination was investigated on Japanese brome seed collected on native rangeland in eastern Montana (Haferkamp and others 1995b). The objective was to determine temperature profiles for germination of Japanese brome seeds, representative of those disseminated from seed heads during the period spanning late summer to early autumn.

### Methods

Seeds were collected on eight dates during July and August 1990 and 1991. Seeds were stored in paper sacks in the laboratory at about 21 °C until germination trials were run in Reno, NV, 3 to 9 months after collection.

Four replications of 25 seeds from each collection date were incubated for 4 weeks in closed petri dishes on 1-mm-thick filter paper moistened with distilled water. Dishes were arranged in a randomized complete-block design, in 10 dark incubators. Constant incubator temperatures included 0, 2, 5, and all 5 °C increments through 40 °C. Alternating temperature regimes were attained by moving dishes between incubators using 16 hours at each constant temperature plus 8 hours at all possible higher temperatures. For example, 35 °C was alternated with 40 °C, while 0 °C was alternated with 2, 5, 10, 15, 20, 25, 30, 35, and 40 °C. Germination counts were taken weekly, and seeds were considered germinated when the radicle was at least 5 mm long.

Data from each base temperature and its alternating temperature regime were used to develop regression equations of quadratic response surfaces with estimated germination means and confidence intervals at the 5-percent level of probability. A number of germination parameters were

synthesized from these quadratic response surfaces to assist in interpretation of germination temperature profiles.

## Results and Discussion

Mean germination of Japanese brome seed from the 55 temperature profiles averaged across the eight collection dates represented in figure 1 was 71 ± 4.0 percent. Some germination occurred in 96 ± 1.4 percent of the temperature regimes, and the mean germination for regimes where some germination occurred was 74 ± 4.0 percent. Optimum temperatures for germination of Japanese brome seed were constant 20 °C and several alternating (16 hours of minimum with 18 hours of maximum) temperatures. The optimum alternating regimes were 2 through 10 °C minimums with 15 °C maximum, 0 through 15 °C minimums with 20 °C maximum, 5 through 20 °C minimums with 25 °C maximum, and 15 °C minimum with 30 °C maximum. Over 75 percent of the collections produced optimum germination (defined as germination not lower than the maximum observed minus one-half of its confidence interval at 0.05 level of probability) in these regimes. Maximum germination of Japanese brome seed occurred at moderate and cold seedbed conditions with germination being somewhat depressed in very cold and warmer than moderate temperatures. Young and Evans (1985) report that at least some germination of downy brome seed is possible with temperatures as low as 0 °C and as high as 40 °C.

A wide range of temperature conditions occur in autumn on seedbeds in the Northern Great Plains region. Findings of this study suggest that while Japanese brome seeds collected in Montana are sensitive to temperature, germination in excess of 50 percent occurs over a wide range of temperature regimes. Thus, there is an excellent potential for continued invasion of this species on these Northern Great Plains rangelands. The high level of germination exhibited by afterripened Japanese brome seeds suggest that a large portion of the disseminated seeds will germinate completely with available water during late summer and early autumn.

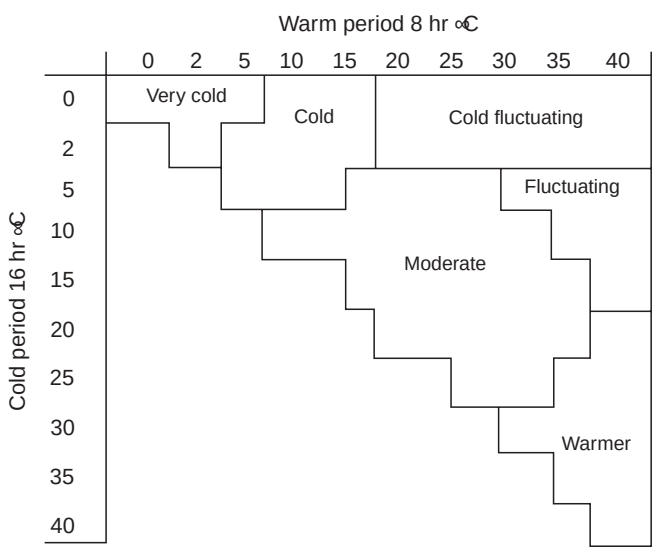


**Figure 1**—Temperature regimes reflecting seedbed environments occurring across a wide array of geographic locations. Regimes are based on monitoring studies.

# Secondary Dormancy

We previously collected data that suggested up to 72 percent of Japanese brome seeds disseminated after mid-September in eastern Montana may enter a secondary dormancy state when they imbibe water at or near 0 °C (Haferkamp and others 1994a). These findings agree with Baskin and Baskin (1981) for Japanese brome in north-central Kentucky and with Hull and Hansen (1974) for downy brome in Utah and Idaho. We further investigated the potential for onset of secondary dormancy in Japanese brome (Haferkamp and others 1995a) by designing a study to determine which Japanese brome seed collections obtained from mid-June to late January were receptive to induction of secondary dormancy when imbibed at 0 °C.

## Methods

Japanese brome seeds, collected on 17 dates from June 18, 1992, to January 28, 1993, were hand threshed and stored in near ambient outside conditions in a warehouse. In early February 1993, eight replications of 100 seeds of each collection were incubated in 9-cm petri dishes. Each dish contained two pieces of a thick medium speed filter paper with high water retention supported on a polyurethane foam disc. Distilled water was supplied to the paper (Haferkamp and others 1994a). Seeds were incubated initially for 10 days in alternating 12-hour periods of 0 and 10 °C and then transferred and incubated for an additional 18 days in alternating 12-hour periods of 8 and 23 °C. Light was supplied with cool-white fluorescent bulbs (PAR = 30 µmoles $m^{-2}$ $sec^{-1}$) during each 12-hour 10 or 23 °C period. One set of seeds, the wet regime, was moistened on day 1, and another set, the dry regime, was not moistened until day 11, when seeds were transferred to the 8 and 23 °C temperature regime. Germinated seeds were counted on days 11, 14, 21, and 28, and removed from the dishes when the radicle and coleoptile were at least 5-mm long. Dishes were arranged in a randomized block design. Analysis of variance was used to detect differences in total germination data resulting from varying seed collection dates and moisture regimes. Separate analyses were conducted for each count date. Means were separated by Least Significant Difference ($P \geq 0.05$).

## Results and Discussion

No seeds had germinated by day 11 (table 1). By day 14 less than 5 percent of the seeds germinated in the dry regime, but up to 69 percent germinated in the wet regime. Seed collected from June to January germinated readily in the dry regime by day 21 (92 percent) and day 28 (97 percent), and seed collected from June through mid-September germinated 94 percent by day 21 and 96 percent by day 28 in the wet regime. Germination, however, declined in the wet regime beginning with the late September collection to

**Table 1**—Total germination of Japanese brome seeds (includes all but moldy seeds) collected from June 1992 to January 1993 near Miles City, MT, U.S.A., and incubated for 10 days at 0 and 10 °C and 18 days at 8 and 23 °C. Dry seeds were moistened on day 11 and wet seeds were moistened on day 1.

| Collection date | Count days[a] 14 Dry | 14 Wet | 21 Dry | 21 Wet | 28 Dry | 28 Wet |
|---|---|---|---|---|---|---|
| | percent | | | | | |
| **Brown seed** | | | | | | |
| 6/18/92 | $0.0^{A}_{a}$ | $39.7^{B}_{c}$ | $98.4^{A}_{a}$ | $97.7^{A}_{b}$ | $99.2^{A}_{a}$ | $98.5^{A}_{a}$ |
| **Green seed** | | | | | | |
| 6/19/92 | $.0^{A}_{a}$ | $19.3^{B}_{efg}$ | $90.1^{A}_{ab}$ | $84.8^{A}_{b}$ | $94.5^{A}_{ab}$ | $87.9^{A}_{b}$ |
| 7/02/92 | $.0^{A}_{a}$ | $68.3^{B}_{a}$ | $97.5^{A}_{ab}$ | $98.0^{A}_{a}$ | $98.0^{A}_{ab}$ | $98.8^{A}_{a}$ |
| 7/15/92 | $1.0^{A}_{a}$ | $69.4^{B}_{a}$ | $99.4^{A}_{ab}$ | $98.3^{A}_{a}$ | $97.6^{A}_{ab}$ | $99.2^{A}_{a}$ |
| 7/30/92 | $.0^{A}_{a}$ | $57.6^{B}_{b}$ | $96.7^{A}_{ab}$ | $95.8^{A}_{a}$ | $98.9^{A}_{a}$ | $96.1^{A}_{a}$ |
| 8/13/92 | $.8^{A}_{a}$ | $63.2^{B}_{ab}$ | $97.7^{A}_{ab}$ | $93.9^{A}_{a}$ | $99.0^{A}_{a}$ | $95.0^{A}_{ab}$ |
| 8/27/92 | $4.0^{A}_{a}$ | $56.4^{B}_{b}$ | $98.8^{A}_{a}$ | $96.8^{A}_{a}$ | $98.8^{A}_{a}$ | $97.4^{A}_{a}$ |
| 9/10/92 | $2.5^{A}_{a}$ | $27.5^{B}_{cde}$ | $98.8^{A}_{a}$ | $89.9^{B}_{ab}$ | $98.8^{A}_{a}$ | $92.8^{A}_{ab}$ |
| 9/24/92 | $.5^{A}_{a}$ | $19.5^{B}_{defg}$ | $97.9^{A}_{a}$ | $72.1^{B}_{c}$ | $98.1^{A}_{ab}$ | $74.4^{B}_{c}$ |
| 10/08/92 | $.8^{A}_{a}$ | $12.8^{B}_{efgh}$ | $98.2^{A}_{a}$ | $50.4^{B}_{e}$ | $99.2^{A}_{a}$ | $56.1^{B}_{d}$ |
| 10/22/92 | $.0^{A}_{a}$ | $6.0^{A}_{fgh}$ | $95.9^{A}_{ab}$ | $59.0^{B}_{d}$ | $97.8^{A}_{ab}$ | $73.8^{B}_{c}$ |
| 11/05/92 | $.0^{A}_{a}$ | $12.3^{A}_{efgh}$ | $90.3^{A}_{ab}$ | $46.9^{B}_{e}$ | $95.0^{A}_{ab}$ | $53.6^{B}_{d}$ |
| 11/19/92 | $.0^{A}_{a}$ | $.6^{A}_{h}$ | $69.4^{A}_{c}$ | $32.4^{B}_{g}$ | $93.1^{A}_{ab}$ | $54.2^{B}_{d}$ |
| 12/02/92 | $.0^{A}_{a}$ | $4.6^{A}_{fgh}$ | $75.3^{A}_{c}$ | $32.5^{B}_{fg}$ | $90.8^{A}_{b}$ | $42.3^{B}_{e}$ |
| 12/17/92 | $.0^{A}_{a}$ | $6.5^{A}_{fgh}$ | $88.0^{A}_{b}$ | $46.0^{B}_{ef}$ | $96.9^{A}_{ab}$ | $53.9^{B}_{d}$ |
| 12/31/92 | $.0^{A}_{a}$ | $3.5^{A}_{gh}$ | $89.2^{A}_{b}$ | $46.8^{B}_{e}$ | $95.9^{A}_{ab}$ | $60.0^{B}_{d}$ |
| 1/28/93 | $.0^{A}_{a}$ | $4.1^{A}_{fgh}$ | $81.8^{A}_{bc}$ | $19.0^{B}_{h}$ | $95.5^{A}_{ab}$ | $28.2^{B}_{f}$ |

[a]Paired moisture treatment means within collection date and count day followed by the same superscript do not differ significantly (P > 0.05). Collection date means within a moisture treatment and count day followed by a similar subscript do not differ significantly (P > 0.05).

an average of 45 percent by day 21 and 55 percent by day 28 for seed collected from late September to January.

Timing of seed dissemination is determined by seed maturation and factors such as wind, rain, and disturbance by birds, insects, and mammals. These results suggest that 26 to 72 percent of the seeds that were not disseminated until after mid-September may enter secondary dormancy. These seeds that enter secondary dormancy may enter the seed bank and germinate the following autumn or later. Allowing this large percentage of seeds to overwinter will potentially enhance proliferation and perpetuation of Japanese brome on Northern Great Plains rangelands.

## Water Stress

Seed germination is controlled by the availability of soil water at an adequate temperature. Pyke and Novak (1994) found that germination of downy brome occurred over a normal range of soil water contents, and germination was not inhibited by soil water potentials of –1.5 MPa. Downy brome seed tend to respond to intermittent moisture with minimal delay in germination rate (Allen and others 1994). Time to germination of downy brome seed may increase as soil water potential becomes more negative (Evans 1961; Evans and Young 1972). Our objective was to determine the impact of water stress on seed germination of Japanese and downy brome. Alternately, were differences between species in germination pattern sufficient to explain the dominance of downy brome on drier sites in years following relative dry autumns?

## Methods

Japanese and downy brome seed were collected in July 1992 from native rangeland near Miles City, MT. Seeds were initially stored in paper sacks in an unheated warehouse until July 1993 when they were brought into the laboratory and stored at about 21 °C. Seeds were germinated in 9-cm petri dishes containing 30 ml of the appropriate solution. Osmotic solutions were prepared with 20,000 MW polyethylene glycol and distilled water. In Trial 1 osmotic potentials ranged from –0.05 to –1.3 MPa, and in Trial 2 osmotic potentials ranged from –0.03 to –0.99 MPa. Solution osmotic potentials were measured at the beginning and end of the study with a vapor pressure osmometer. Each dish contained one piece of a thick medium-speed filter paper with high retention supported on a polyurethane foam disc (Haferkamp and others 1994a). The filter paper was continually moistened via a cotton wick inserted through the center of the foam disc. Once filter paper was saturated, 100 seeds of each collection were placed on the filter paper, and covered dishes were placed individually into a polyethylene bag. Seeds were germinated for 28 days at alternating 8/23 °C with illumination during the 12 hours at 23 °C. Dishes were arranged in a randomized complete-block design with eight replications. Replications were run over time, with two replications placed in the

germinator at 2-day intervals in Trial 1 and 7-day intervals in Trial 2, until all eight replications were being incubated. Germination was counted every 2 days in Trial 1 and every 7 days in Trial 2. Seeds were considered germinated when coleoptiles and radicals were 5 mm long.

In Trial 1, a sigmoidal time-dependent response function was fit to data from each dish. Resulting parameters were subject to analysis of variance to determine osmotic potential effects on germination patterns. In Trial 2, the sampling interval precluded fitting a sigmoid-shaped curve to the data. Thus, the counts of seeds germinated at each sampling point were subject to analysis of variance directly.

## Results and Discussion

In Trial 1 no Japanese brome seed germinated in osmotic potentials ranging from –0.9 to –1.3 MPa (fig. 2). Maximum seed germination was >95 percent in –0.05 to –0.23 MPa. Seed germination declined to <35 percent in –0.63 MPa. Days to 50 percent of maximum germination ranged from 5 to 9 days for –0.05 to –0.23 MPa to 22 days for –0.63 MPa (fig. 3). In Trial 2 Japanese brome seed germination was <15 percent in –0.99 MPa (fig. 4), >90 percent in –0.03 to –0.29 MPa, and <90 percent but >75 percent in –0.5 MPa and >35 percent in –0.71 MPa. Japanese and downy brome seed germinated similarly in –0.03 to –0.16 MPa (figs. 4 and 5). Maximum germination of downy brome seed was, however, up to 5.5 fold greater than germination of Japanese brome seed in –0.29 to –0.99 MPa.

Water stress can both reduce amount and rate of germination of Japanese brome seed. In addition we have observed years when seedlings that emerged from germinating seeds during late August perished due to lack of soil water in September. It appears that soils must be wet for 3 to 5 days for seeds to germinate. Mack and Pyke (1984) report that a series of successive days of >1 mm of precipitation during autumn appears adequate for germination of downy brome. Thill and others (1979) report that reductions in soil matric potential from –0.2 to –1.6 MPa markedly reduced the percentage and rate of germination of downy brome. They

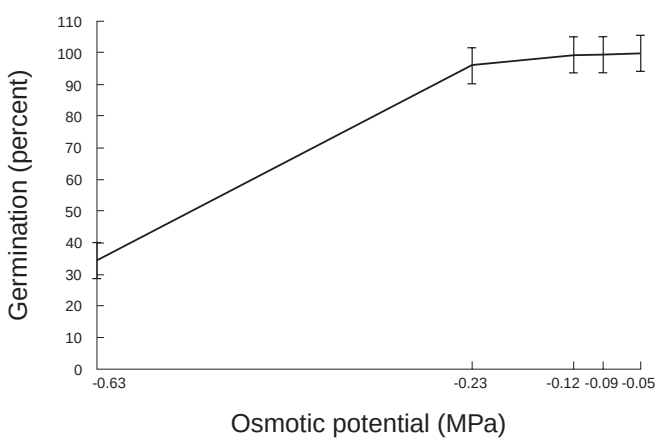


**Figure 2**—Effect of osmotic potential on maximum percentage germination of Japanese brome seed. Least square means ± standard error at P = 0.05 are presented.

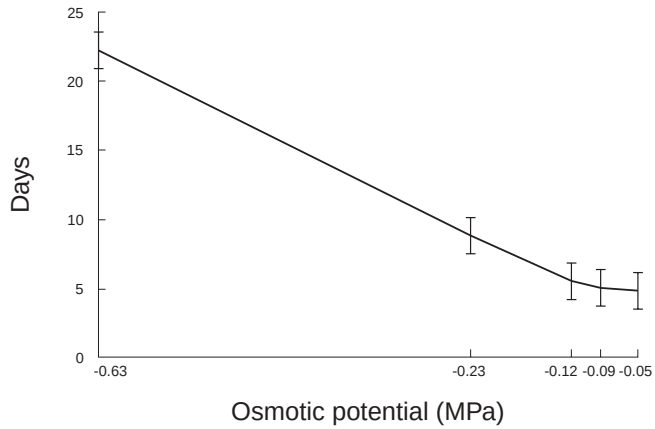


**Figure 3**—Effect of osmotic potential on days to 50-percent germination of Japanese brome seed. Least square means ± standard error at P = 0.05 are presented.

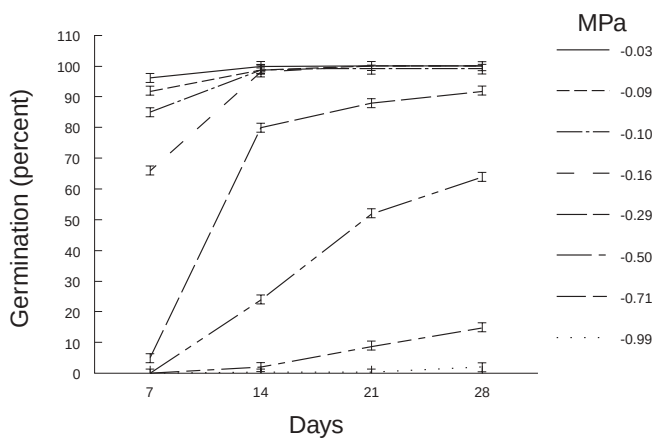


**Figure 4**—Effect of osmotic potential on percent germination of Japanese brome seed. Least square means ± standard error at P = 0.05 are presented.

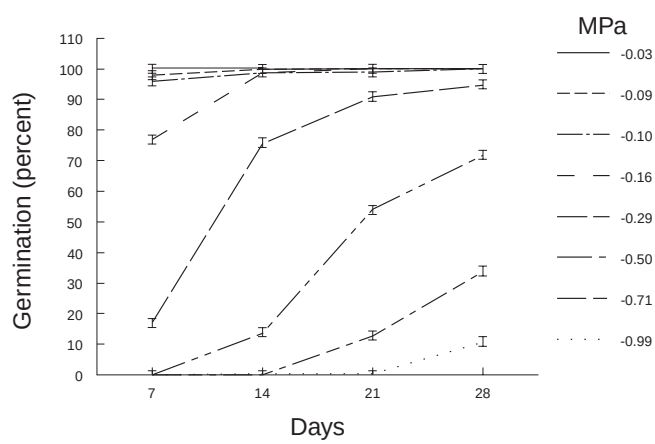


**Figure 5**—Effect of osmotic potential on percent germination of downy brome seed. Least square means ± standard error at P = 0.05 are presented.

found that downy brome is adapted to a wide range of temperatures and soil water conditions, and is limited mostly by cold soil or warm dry soil. Although seeds of both annual bromes germinated over a wide range of osmotic potentials in our study, the fact that downy brome seeds appeared to germinate with greater stress than Japanese brome seed helps explain why downy brome dominates on drier sites and in years preceded by dry autumns in the Northern Great Plains.

## Conclusions

Annual bromes are clearly adapted to the Northern Great Plains. The high level of germination exhibited by after-ripened seeds suggests a large portion of the disseminated seeds will germinate with available water during late summer and early autumn. The secondary dormancy state attained by some seeds will also enhance the species persistence on rangelands, because seedlings emerging in August and September in any year likely come from two seed crops, the current and previous years.

Fluctuations in environmental conditions will continue to cause erratic fluctuations in annual brome populations on Northern Great Plains rangelands. However, due to the large seed banks and ability of seeds to germinate in variable environmental conditions, we think annual bromes will persist on these rangelands for many years in the future.

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