Effect of *Pseudoroegneria spicata* (bluebunch wheatgrass) Seeding Date on Establishment and Resistance to Invasion by *Bromus tectorum* (cheatgrass)

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ABSTRACT

Rangelands degraded by non-native annual grasses are commonly restored by integrating herbicide with fall seeding of native perennial grasses. Seeds are expected to remain dormant throughout winter and emerge in spring. However, restoration often fails due to annual grass seedlings out-competing seeded grasses because they emerge sooner and grow faster. At two sites in Montana, we tested eight seeding dates of *Pseudoroegneria spicata* to determine the effect on resistance to invasion by the annual grass *Bromus tectorum*. After one growing season, fall (November) and early spring (April) seeding resulted in larger *P. spicata* than later spring seeding (May) (829–1,180 tillers per m² versus 349–561 tillers per m²) at one site, while seeding date had no effect on *P. spicata* at the second site. In the second season and after *B. tectorum* introduction, fall and early spring seeded *P. spicata* was more resistant to *B. tectorum* compared to late spring seeded. For example, *B. tectorum* was less dense (480 ± 101 tillers per m²) in *P. spicata* stands seeded 7 April than 12 May (943 ± 188 tillers per m²), and *B. tectorum* biomass was lower in fall-seeded stands (227 ± 81 g per m²) than stands seeded 12 May (533 ± 206 g per m²). Our results demonstrate that establishment and subsequent invasion resistance is enhanced by seeding native grasses from fall to early spring, presenting a wider timeframe for seeding than commonly practiced.

Keywords: invasive grass, seasonal priority effect, seeding timing

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ꙮ Restoration Recap ꙮ

- We seeded the native perennial grass *Pseudoroegneria spicata* in November 2015 and weekly from April to early May 2016 to determine which seeding date resulted in the best stand establishment and greatest potential to resist invasion by the invasive annual grass *Bromus tectorum*.
- *Pseudoroegneria spicata* stands seeded in fall (November) and early spring (April) had higher plant density and biomass than those seeded later in spring (late April through May).
- *Bromus tectorum* was less abundant in *P. spicata* stands seeded in fall and early spring than in stands seeded in late spring, suggesting larger perennial grasses can limit invasion of annual grasses.
- Seeding *P. spicata* after 206 growing degree days (GDD, first week of May) is not advised as there was a trend of decreasing *P. spicata* and increasing *B. tectorum* abundance after this date.
- Land managers may have a wide window of opportunity for seeding native grasses, ranging from a fall dormant seeding through early spring, but care should be taken to not seed too late in spring.

Degraded range and wildlands are difficult to revegetate due to the persistence of non-native, annual grasses

or secondary invasions following control of the target annual grass (Pearson et al. 2016, Schantz et al. 2016). In habitats dominated by non-native, invasive annual grasses, their seedlings can outcompete native perennial grass seedlings due to early emergence of the annual grasses (Wainwright et al. 2012). Earlier emergence by these invasive winter annual grasses compared to native plants allows

for primary access to water and nutrients (Mangla et al. 2011a, Dickson et al. 2012). These benefits are amplified after germination and emergence because ruderal invasive annual grasses grow faster than native perennial grasses, compounding preemptive use of essential resources (Grotkopp and Rejmánek 2007, James and Drenovsky 2007, James 2008). Being the first to fill a vacant ecological niche is known as a priority effect (Wainwright et al. 2012). Seed banks of lands infested by invasive annual grasses are often dominated by those same species, limiting the recruitment of native plants.

Strategically modifying the seeding date of native plants to mitigate seasonal priority effects of invasive annual grasses during revegetation can be an ecologically-based management approach for improving native species recruitment and establishment (James et al. 2011, Farrell and Fehmi 2018). For example, the native grass *Pseudoroegneria spicata* (bluebunch wheatgrass) suppressed the non-native, invasive annual grass *Bromus tectorum* (cheatgrass) in a greenhouse setting when seeded four weeks prior to seeding of *B. tectorum* (Orloff et al. 2013, Larson et al. 2018). Similar studies also support the effectiveness of seeding early to improve native grass establishment over invasive annual plants (Grman and Suding 2010, Boyd and James 2013). In the field, Boyd and Lemos (2015) attributed higher seedling survival of fall versus spring seeding to more established root systems from additional growing degree days (GDD). However, the success of direct seeding from fall versus spring seeding is still largely unknown in relation to its potential for resisting subsequent weed invasion.

During revegetation of invasive annual grass-infested areas in the semi-arid western United States, seeding of native perennial grasses like *P. spicata* often occurs in the fall, following a summer or fall herbicide application aimed at controlling annual grasses. Seeds are expected to remain dormant throughout winter and emerge in the spring at the earliest opportune time (Boyd and James 2013). However, fall dormant seeding has its limitations. First, fall dormant seedings expose seeds to predators and pathogens for several months before the seeds are expected to germinate, and some research suggests that seeds of native species may be more susceptible to predation than those of non-native species (Lucero and Callaway 2018). Furthermore, unanticipated germination prior to spring can put seedlings at risk of failure during winter freeze-thaw cycles (James et al. 2012). Revegetation failure can also result from the slow-growing nature of native perennial grasses, which do not typically reach reproductive maturity in the first growing season in contrast to quickly-growing annual grasses that complete their life cycle in less than a year (Schantz et al. 2016). Finally, though fall dormant seedings are common practice (Monsen and Stevens 2004), they eliminate the option of a spring herbicide application to control spring-emerging invasive grasses because such an application would also injure seedlings of the seeded species.

Delaying seeding until spring, as an alternative to seeding in the fall, has had varied success in terms of density and biomass of seeded perennial grasses (Schantz et al. 2015, 2016). Density of surviving seedlings from spring seeding can be similar or greater than that of fall seeding (Boyd and Lemos 2015). Spring seeding on a site where annual grass propagule pressure was low (between 150–1,500 seeds per m²) and irrigation was available during the first growing season, resulted in satisfactory perennial grass establishment (Schantz et al. 2016). However, in semi-arid climates where irrigation is not available, delaying seeding until spring can be risky. Seedlings emerge, but may not grow enough, particularly in terms of root length, to survive seasonal drought (Schantz et al. 2016). Late spring-seeded perennial grasses also experience fewer GDD and accumulated precipitation than fall or early spring seedings (Boyd and Lemos 2015). Addressing how late in the spring seeding can occur while still resulting in satisfactory native perennial grass establishment is necessary to improve revegetation of invasive annual grass-infested range and wildlands.

The first objective of this study was to examine whether fall or early to late spring seeding resulted in higher establishment of the native perennial grass *P. spicata* over two growing seasons. Consistent with previous studies (Boyd and James 2013, Boyd and Lemos 2015), we hypothesized perennial grass density and biomass to be highest for fall and early spring-seeded cohorts when compared to late spring-seeded cohorts. We used *P. spicata* for this study because it is a large-statured, native bunchgrass that is common across mountain and foothill rangelands, is valued as a forage species for livestock and wildlife (Stubbendieck et al. 1997), and in Montana it is often one of the last native perennial grasses to persist in areas invaded by non-native species (J. Mangold, Montana State University, pers. comm.). Several cultivars of *P. spicata* have demonstrated successful establishment in other studies (Sheley et al. 2001, Sheley et al. 2006, Jacobs et al. 2006, Rinella et al. 2012, Mangold et al. 2015).

The second objective addressed whether *P. spicata* seeding date affected suppression of the invasive annual grass *B. tectorum* when it was introduced to the plots at the end of *P. spicata*'s first growing season. We hypothesized *B. tectorum* biomass and density would be lowest where *P. spicata* was seeded in fall and early spring when compared to late spring seeding, due to the predicted increase in density and biomass of *P. spicata* plants during the first growing season.

Methods

This study occurred at two field sites which were located at the Arthur H. Post Research Farm (45°40′38.01″ N 111° 9′19.49″ W) and Fort Ellis Research Farm (45°40′13.19″ N 110°58′48.13″ W), hereafter referred to as Post Farm and Fort Ellis, respectively, near Bozeman, Montana. Elevation at Post Farm and Fort Ellis are 1,450 m and 1,484 m, respectively. In 2016 and 2017, the total annual precipitation at Post Farm was 32.5 cm and 37.7 cm, and annual minimum/maximum temperatures were 1.21°C/14.8°C and 0.23°C/13.8°C, respectively (Table 1, NOAA 2018). In 2016 and 2017, the total annual precipitation at Fort Ellis was 46.7 cm and 60.7 cm, and minimum/maximum temperatures were 1.06°C/13.8°C and –0.1°C/13.0°C, respectively (Table 1, Weather Underground 2018).

Prior to setting up the study, existing vegetation was manually removed, and the fallow fields were tilled. A completely randomized split-plot design was used to test eight seeding dates of *P. spicata* (whole plots, 1 m × 2 m with additional 0.5 m buffer) and two levels (absent and present) of *B. tectorum* competition (split-plots, 1 m × 1 m). Seeding treatments were replicated four times at each site for a total of 32 main plots and 64 split-plots per site.

The eight seeding date treatments were 8 November 2015 (fall) and seven weekly spring seeding dates from 1 April 2016 to 12 May 2016 (early to late spring, Table 2). Seeds of *P. spicata* (Goldar cultivar) were hand broadcasted evenly on the soil surface at 667 seeds per m² (following Orloff et al. 2013) for each treatment at each site. Seeds

were produced and obtained from Bruce Seed Farm near Townsend, Montana, approximately 100 km from the study sites. June of the first growing season was drier than the 30-year mean precipitation (Western Regional Climate Center 2019) at the Post Farm: we applied the equivalent of 1.27 cm of precipitation in June 2016 to address this deficit. All vegetation other than *P. spicata* was removed by hand throughout the first growing season. In September 2016, after the first growing season and when plants were in a reproductive state, *P. spicata* density (tillers per m²) was measured across whole plots (1 m × 2 m).

After the first growing season, *B. tectorum* seeds were sown into competition split-plots on 1 September 2016 at 1,112 seeds per m² (following Orloff et al. 2013), using seeds collected from several sites near Bozeman, Montana. In both years, only target species, *P. spicata* and *B. tectorum*, were grown and all other species were removed by hand until data were collected from 23 June 2017–10 July 2017. Three randomly-placed 50 cm × 20 cm frames (Daubenmire 1959) per split-plot were used to sample density (tillers per m²) and aboveground biomass of *P. spicata* and *B. tectorum*. Biomass was clipped to 2 cm above ground level, dried at 37°C for 48 hours, and weighed to the nearest 0.1 gram.

An analysis of variance (ANOVA) was used on a general linear model with a Quasi-Poisson distribution to detect differences in *P. spicata* density (tillers per m²) by seeding date for each site for objective one. One replication of the Spring 5 seeding data at Post Farm was removed from analysis because the plots received run-off irrigation from

Table 1. Average spring (March–May), summer (June–August), fall (September–November), and total precipitation (cm) and average minimum and maximum temperatures (°C) for spring, summer, fall and annual at Post Farm and Fort Ellis across a 30-year period and years 2016 and 2017. *30-year averages (1981–2010) were based on the Western Regional Climate Center (WRCC) monthly data for this region and were only available at the Post Farm site

Site	Year	Precipitation (cm)				Temperature (°C, min/max)			
		Spring	Summer	Fall	Total	Spring	Summer	Fall	Annual
Post Farm	30 year*	4.76	4.57	3.00	41.1	–0.8/13.6	5.09/26.3	–0.5/14.3	–0.7/14.1
	2016	3.76	2.06	4.09	32.5	1.24/14.7	9.47/28.0	2.89/15.0	1.21/14.8
	2017	4.67	2.18	3.68	37.7	1.44/14.5	10.3/27.8	0.16/13.0	0.23/13.8
Fort Ellis	2016	5.35	2.57	6.30	46.7	1.25/13.1	9.45/26.4	2.66/14.3	1.06/13.8
	2017	8.08	5.02	5.13	60.7	0.85/13.3	10.2/26.5	–0.3/12.3	–0.1/13.0

Table 2. Seeding dates and cumulative growing degree days (GDD = sum of average daily temperature °C — temperature base 4.4°C between 1 March 2016 to 12 May 2016) for *Pseudoroegneria spicata* at Post Farm (PF) and Fort Ellis (FE) sites.

Treatment	Seeding Date	PF GDD	FE GDD	Average GDD
Fall	8 November 2015	—	—	—
Spring 1 (S1)	1 April 2016	39.5	34.4	37.0
Spring 2 (S2)	7 April 2016	70.1	58.1	64.1
Spring 3 (S3)	13 April 2016	114	93.7	104
Spring 4 (S4)	21 April 2016	142	126	134
Spring 5 (S5)	29 April 2016	172	150	161
Spring 6 (S6)	5 May 2016	217	195	206
Spring 7 (S7)	12 May 2016	261	231	246

an adjacent field and produced abnormally high *P. spicata* densities. In both years, *P. spicata* density across main plots was used to determine establishment for all seeding cohorts, whereas in the second year *P. spicata* density in the no competition plots were evaluated. Tukey pairwise comparisons were used to determine differences across seeding date treatments for each site.

For objective two, the effect of seeding date on *P. spicata* and *B. tectorum* was analyzed using ANOVA models. Specifically, an ANOVA on a linear mixed effects model was used to determine differences in *P. spicata* density and biomass, where fixed effects were seeding and competition treatments and site, and random effects accounted for plot-to-plot variation. When analyzing *B. tectorum* density, an ANOVA was used on a general linear model to determine seeding date treatment effects across sites. Data were over-dispersed, so a Quasi-Poisson distribution was used. When analyzing *B. tectorum* biomass, an ANOVA was used on a linear model to determine seeding date treatment effects across sites. Tukey pairwise comparisons were used to determine differences between seeding groups and competition levels.

For all analyses, all models were explored for normality, independence, and constant variance assumptions and median values are shared. Graphical interpretations and analyses were conducted using R Software 3.5.1 (R Core Team 2018), specifically dplyr, lme4, emmeans, and ggplot2 packages (Bates et al. 2015, Lenth et al. 2018, Wickham 2016, Wickham et al. 2018).

Results

Pseudoroegneria spicata *Density and Biomass*

Seeding treatments affected *P. spicata* density after one growing season, but the effect depended on site ($F_{7,110}$ = 2.759, p = 0.011). At Fort Ellis, Spring 2 resulted in 1,180 ± 169 tillers per m² (estimate ± standard error), which was similar to Fall (1,009 ± 176 tillers per m²), Spring 1 (1,038 ± 122 tillers per m²), Spring 3 (856 ± 180 tillers per m²), and Spring 5 (829 ± 223 tillers per m²) (Figure 1). Spring 4, Spring 6, and Spring 7 had similarly low densities at 472 ± 72 tillers per m², 561 ± 134 tillers per m², and 349 ± 63 tillers per m², respectively. At Post Farm, there was no
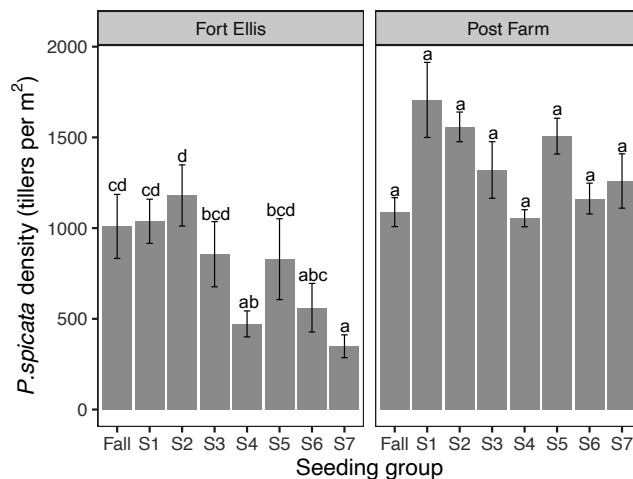
Figure 1. *Pseudoroegneria spicata* **density (tillers per m² ± SE) after one growing season (2016) at two sites in southwestern Montana. Seeding dates are Fall (11 November 2015), S1 (1 April 2016), S2 (7 April 2016), S3 (13 April 2016), S4 (21 April 2016), S5 (29 April 2016), S6 (5 May 2016), S7 (12 May 2016). Similar letters indicate no difference in density across treatments within a site (α = 0.05).**

effect of seeding treatment on *P. spicata* density. Densities ranged from 1,054 ± 47 tillers per m² in Spring 4 to 1,706 ± 207 tillers per m² in Spring 1 (Figure 1).
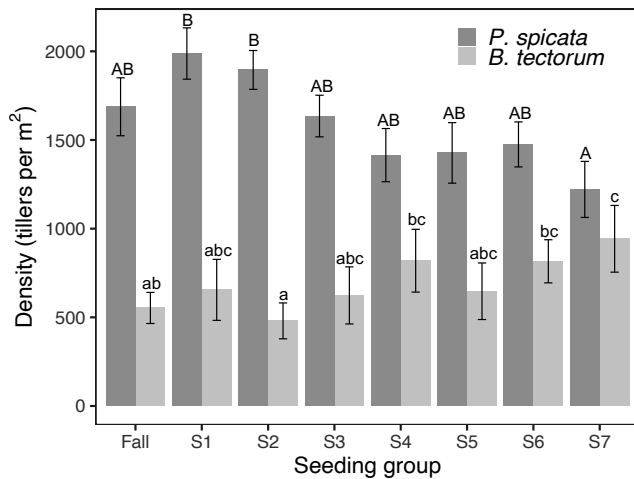
After two growing seasons, seeding treatment affected density of *P. spicata* ($F_{7,47}$ = 3.344, p = 0.005) (Table 3). Spring 7, which resulted in 1,221 ± 158 tillers per m², was lower than Spring 1 and Spring 2 (1,988 ± 145 and 1,895 ± 110 tillers per m², respectively) (Figure 2). Density of *P. spicata* was otherwise similar across seeding treatments and ranged from 1,221 to 1,988 tillers per m².

Density of *P. spicata* was also affected by competition from *B. tectorum*, where the effect varied by site ($F_{1,54}$ = 23.63, p < 0.001) (Table 3). At Fort Ellis, the no competition treatment (control) yielded higher density of *P. spicata* (1,735 ± 122 tillers per m²) than the *B. tectorum* competition treatment (1,161 ± 107 tillers per m²), while *B. tectorum* competition had no effect on *P. spicata* density at Post Farm (mean = 1,748 ± 55 per m²).
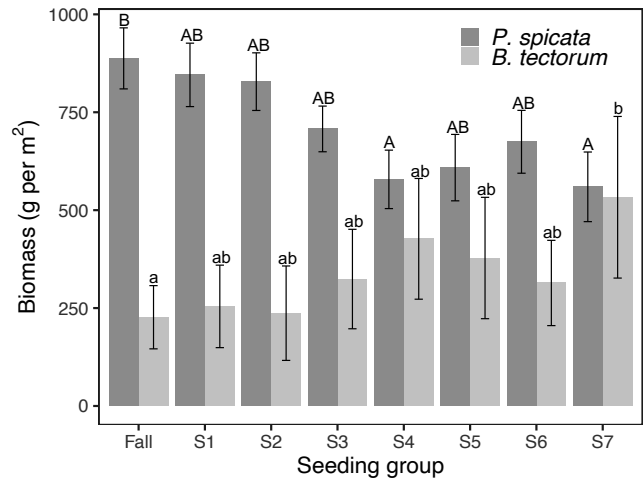
After two growing seasons, biomass of *P. spicata* was affected by seeding treatment ($F_{7,47}$ = 3.423, p = 0.005) (Table 3). Biomass was lower in seeding treatments Spring

Table 3. Analysis of variance (ANOVA) table for *Pseudoroegneria spicata* density (tillers per m²) and biomass (g per m²) after two growing seasons (2017). Competition indicates presence or absence of *Bromus tectorum*.

Main Effects and Interactions	df	Density		Biomass	
		F-value	*p*-value	F-value	*p*-value
Seeding	7, 47	3.344	0.005	3.423	0.005
Competition	1, 54	8.706	0.005	5.139	0.027
Site	1, 47	8.944	0.004	35.31	< 0.001
Seeding*Competition	7, 54	1.416	0.218	1.234	0.301
Seeding*Site	7, 47	1.959	0.081	1.361	0.244
Competition*Site	1, 54	23.63	< 0.001	9.731	0.003

Figure 2. *Pseudoroegneria spicata* and *Bromus tectorum* density (tillers per m² ± SE) across seeding treatments after two growing seasons (2017) at two sites in southwestern Montana. Seeding dates are Fall (11 November 2015), S1 (1 April 2016), S2 (7 April 2016), S3 (13 April 2016), S4 (21 April 2016), S5 (29 April 2016), S6 (5 May 2016), S7 (12 May 2016). Similar letters indicate no difference in a species' density across treatments (α = 0.05).

Figure 3. *Pseudoroegneria spicata* and *Bromus tectorum* biomass (g per m² ± SE) across seeding treatments after two growing seasons (2017) at two sites in southwestern Montana. Seeding dates are Fall (11 November 2015), S1 (1 April 2016), S2 (7 April 2016), S3 (13 April 2016), S4 (21 April 2016), S5 (29 April 2016), S6 (5 May 2016), S7 (12 May 2016). Similar letters indicate no difference in a species' biomass across treatments (α = 0.05).

7 and Spring 4 (560 ± 88.9 g per m² and 578 ± 74.6 g per m², respectively) compared to Fall (888 ± 77.9 g per m²) (Figure 3). Otherwise, biomass was similar across most seeding treatments (Figure 3).

Biomass of *P. spicata* was affected by competition treatment, and the effect varied by site ($F_{1,54}$ = 9.731, p = 0.003) (Table 3). At Fort Ellis, the no competition treatment yielded higher *P. spicata* biomass (687 ± 57.2 g per m²) than the *B. tectorum* competition treatment (455 ± 51.8 g per m²). Competition from *B. tectorum* had no effect on *P. spicata* biomass at Post Farm (mean = 859 ± 31.2 g per m²).

Bromus tectorum *Density and Biomass*

There was a difference in *B. tectorum* density due to the main effects of site ($F_{1,54}$ = 173.2, p < 0.001) and seeding treatment ($F_{7,55}$ = 4.500, p < 0.001; Table 4). Fort Ellis had higher density of *B. tectorum* (1,019 ± 59 tillers per m²) than Post Farm (356 ± 29 tillers per m²). Averaged across sites, *B. tectorum* density was higher in Spring 7 (943 ± 188 tillers per m²) than Fall (553 ± 88 tillers per m²) and Spring 2 (480 ± 101 tillers per m²) (Figure 2). All other seeding treatments were similar to each other.

Biomass showed a similar pattern to density: there was a difference in *B. tectorum* biomass across the main effects of site ($F_{1,47}$ = 158.0, p < 0.001) and seeding treatment ($F_{7,47}$ = 2.397, p = 0.035; Table 4). Fort Ellis had higher *B. tectorum* biomass (636 ± 53.4 g per m²) than Post Farm (26.3 ± 6.0 g per m²). Averaged across sites, *B. tectorum* biomass was higher in Spring 7 (533 ± 206 g per m²) than Fall (227 ± 80.7 g per m²) (Figure 3). All other seeding treatments were similar to each other.

Discussion

Fall (*i.e.,* November) and early spring (*i.e.,* April) seeding generally resulted in greater establishment of *P. spicata* after one and two growing seasons than late spring seeding, as has been observed in other studies (Boyd and Davies 2012, Boyd and James 2013, Rinella and James 2017). The effect of seeding date was more pronouced in the first year at Fort Ellis, with the exception of Spring 5 at both sites. We believe the Spring 5 seeding cohort benefted from 2.2 cm of snow that fell from 23 April to 28 April 2016 (NOAA 2018) across both sites. The legacy of seeding date was less pronounced in the second year, as would be expected, though greater establishment of *P. spicata* in the fall (*i.e.,* biomass) and early spring (*i.e.,* density) than late spring was evident across the two sites. Our results generally support the first hypothesis and previous studies, indicating fall and early spring seeding produce larger perennial grasses than late spring seeding dates (James et al. 2012, Boyd and Lemos 2015). We recognize that other native grasses may differ in optimal seeding time, but given that *P. spicata* is arguably one of the most important native grasses on western rangeland, our study provides important information on best practices for its establishment.

The second hypothesis that *B. tectorum* density and biomass was expected to be lowest where *P. spicata* was highest in fall and early spring seeding was also generally supported. In particular, the high density of *P. spicata* in the Spring 2 treatment (*i.e.,* seeded 7 April) had the greatest competitive effect on *B. tectorum* density. *Pseudoroegneria spicata* biomass also was greatest in the Fall as compared

to late spring (i.e., seeded 21 April and 12 May) seeding which subsequently led to lower *B. tectorum* biomass. This study also indicates that seeding after the first week of May (above 206 GDD; Table 2) is not ideal as there was a trend of decreasing *P. spicata* abundance and subsequent increase in *B. tectorum* abundance at the latest spring seeding date. This trend was consistent across both sites, suggesting results found here may hold true across locations that have similar climatic conditions as southwestern Montana.

Across both sites there was no competition by seeding date interaction which suggests once *P. spicata* is established, the effect of competition from *B. tectorum* is lessened. We did not measure resource availability (e.g., soil moisture or nutrient concentrations), and we acknowledge that competition in fallow and tilled fields used in this study is not like that in impacted rangelands. Furthermore, establishment of *P. spicata* was higher than that seen in studies that occurred in range or wildlands infested with *B. tectorum* or other invasive plants (Whitson and Koch 1998, Sheley et al. 2001, Mangold et al. 2015). However, our results support that *P. spicata*, once established, can be highly competitive against secondary invasion (Rinella et al. 2012, USDA-NRCS 2012). Providing seeded species with a seasonal priority effect can shift competitive dynamics in a positive direction (Orloff et al. 2013), and along with other research suggests large and robust perennial grasses can limit invasion by annual grasses (Whitson and Koch 1998, Humphrey and Schupp 2004, James et al. 2008, Davies and Johnson 2017, Young et al. 2005).

Despite evidence suggesting precipitation is a key factor influencing revegetation success in semi-arid regions (Hardegree et al. 2013, Hardegree et al. 2016), wetter conditions at Fort Ellis compared to Post Farm did not have a substantial impact on *P. spicata* establishment and competitive dynamics with *B. tectorum*. In fact, abundance of *P. spicata* was lower at Fort Ellis than Post Farm; and, perhaps accordingly, abundance of *B. tectorum* was higher at Fort Ellis. Other revegetation studies have failed to find a beneficial effect of additional moisture on seedling success. For example, experimental observations in Oregon found no effect of additional watering on final density and biomass of *P. spicata* that was seeded fall (Boyd and James 2013) or spring (James and Svejcar 2010). However, it should be noted that in our study there was more variability at Fort Ellis in the response of *P. spicata* density to seeding date during the first year of the study, and there was an effect of the competition treatment during the second year of the study. Of further note, annual precipitation at Fort Ellis during our study was higher than the 30-year average precipitation and within the recommended precipitation zone (at least 30.5 cm) for the cultivar of *P. spicata* used in this study (USDA-NRCS 2012). Of the recommended USDA cultivars of *P. spicata*, "Goldar," which was used in this study, is well adapted for rapid growth under dry

conditions at or above 30.5 cm of annual rainfall above 1,000 m elevation (USDA-NRCS 2012).

One of the foremost risks to seeding a degraded site with native species is competition from invasive seedlings (Ray-Mukherjee et al. 2011). Decreasing seeds of undesirable species in the seed bank to a level that allows native species to establish (less than 1,500 seeds per m²; Schantz et al. 2016) can prove difficult when natural seed rain of *B. tectorum* can be as high as 12,000 seeds per m² (Humphrey and Schupp 2001). Applying management tactics that eliminate or reduce seed production, like herbicides or targeted grazing, over multiple years or using herbicides with multiple years of annual grass control (Sebastian et al. 2016, Sebastian et al. 2017a, Sebastian et al. 2017b) can reduce the seed bank of invasive annual grasses and minimize competition with seeded species. Continued practice of fall dormant seeding at the recommended rate (approximately 17 pounds per acre for *P. spicata*) (Sheley et al. 2008) is supported by this study, but practitioners should consider early spring seeding as an option as well. Our findings suggest that land managers can delay seeding until early spring without compromising native grass establishment. Spring seeding offers the option of applying a non-selective, non-persistent herbicide like glyphosate to control *B. tectorum* seedlings that emerged over the winter and into early spring (Kyser et al. 2012, Kyser et al. 2013), eliminating competition for at least one growing season. If seeding is delayed until spring, though, seeding after the first week of May (or GDD greater than 206) is not recommended as it could result in decreased establishment.

Our results show that providing native perennial grasses with a seasonal priority effect can improve their resistance to invasion by weedy annual grasses. The success of varied seeding dates indicates a wide range of opportunity available to land managers when seeding native grasses with fall (November) and early spring (April) seeding producing favorable results. However, we also found a trend of decreasing *P. spicata*, as well as increasing *B. tectorum*, when cohorts were seeded after 206 GDD. Further studies could help consolidate the optimum range of *P. spicata* seeding dates for different regions across the West. In addition, testing the effect of seeding date for other important native grass species of mountain and foothill rangelands in the West is also encouraged.

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