Wyoming Big Sagebrush Density: Effects of Seeding Rates and Grass Competition

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Abstract

The mining industry commonly seeds shrubs and grasses concurrently on coal-mined lands of northeastern Wyoming, but ecological interactions between seeded shrubs and grasses are not well documented. *Artemisia tridentata* Nutt. ssp. *wyomingensis* (Beetle and Young) (Wyoming big sagebrush) is the dominant pre-mining shrub on many Wyoming mine sites. Despite past failures to establish Wyoming big sagebrush, the Wyoming Department of Environmental Quality, Land Quality Division's rules and regulations require establishment of 1 shrub per m^2 on 20% of post-mined land in Wyoming. A study was established at the Belle Ayr Coal Mine south of Gillette, Wyoming to evaluate the effects of sagebrush seeding rates and grass competition on Wyoming big sagebrush seedling density. Three sagebrush seeding rates (1, 2, and 4 kg pure live seed [pls]/ha; 350, 700, and 1,400 pls/m^2, respectively) and seven cool-season perennial grass mixture seeding rates (0, 2, 4, 6, 8, 10, and 14 kg pls/ha; 0, 187, 374, 561, 750, 935, and 1,309 pls/m^2, respectively) were applied during winter 1998–1999. *Pascopyrum smithii* (Rydb.) A. Love (western wheatgrass), *Elymus lanceolatus* (Scribner & J.G. Smith) Gould (thickspike wheatgrass), and *Elymus trachycaulus* (Link) Gould ex Shinners (slender wheatgrass) comprised the grass seed mix (equal seed numbers of each species). Sagebrush seedling density differed among sagebrush seeding rates but not among grass seeding rates. On all sampling dates in 1999 and 2000, sagebrush seedling density differed among sagebrush rates and was greatest at the 4 kg pls/ha sagebrush seeding rate. All sagebrush seeding rates provided densities of at least 1 shrub per m^2 after two growing seasons. Grass density and production in 2000 suggest that adequate grass production ($\geqslant$75 g/m^2) was achieved by seeding at 6 to 8 kg pls/ha. Within these grass seeding rates, four or more sagebrush seedlings per m^2 were attained when sagebrush was seeded at 2 to 4 kg pls/ha. Use of these seeding rate combinations in mine reclamation can achieve Wyoming big sagebrush standards and reduce reseeding costs.

Key words: ***Artemisia tridentata*** **ssp.** ***wyomingensis*****, coal mine reclamation, competition, seeding rates.**

Introduction

The goal of mine land reclamation in the western United States is to develop a plant community that provides soil stability, wildlife habitat, and/or livestock grazing. Although concurrent planting of grasses, forbs, and shrubs is a common reclamation practice, this approach often results in inadequate shrub establishment due to competition from herbaceous species (Blaisdell 1949; Shaw & Monsen 1988; Schuman et al. 1998). In general, high seeding rates create dense stands with low vigor (DePuit et al. 1980) and can limit seedling emergence due to inter- and intraspecies competition (Bergelson & Perry 1989). Recent studies showed that grass can limit *Artemisia tridentata* Nutt. ssp. *wyomingensis* (Beetle & Young) (Wyoming big sagebrush) (Eissenstat & Caldwell 1988; Schuman et al. 1998) and *Artemisia tridentata* ssp. *vaseyana* (mountain big sagebrush) seedling establishment (Richardson et al. 1986).

Shrub standards for reclaimed mine lands in Wyoming require a minimum of 1 shrub per m^2 on lands where the post-mine land use includes wildlife habitat (Wyoming Department of Environmental Quality 1996). Even though research has shown that competition with herbaceous species influences Wyoming big sagebrush establishment, the regulations require topsoil stabilization using a permanent vegetation cover that is as productive as pre-mine conditions. These two mine land reclamation requirements result in a potential limitation that must be understood to successfully establish a

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diverse plant community. Recent studies (e.g., Schuman et al. 1998; Stahl et al. 1998) have provided improved cultural techniques for sagebrush reestablishment on coal mined lands. In general, minimizing grass seeding rates may reduce losses from competition when seeding Wyoming big sagebrush (Kleinman 1996). However, definitive guidelines do not exist for combined sagebrush and grass seeding rates.

This study was conducted to evaluate the establishment of Wyoming big sagebrush when sown with a mixture of cool-season perennial grasses on reclaimed land at the Belle Ayr Coal Mine near Gillette, Wyoming, U.S.A. Three seeding rates of Wyoming big sagebrush and seven grass seeding rates were used to evaluate the influence of sagebrush seeding rate and grass competition on establishment of Wyoming big sagebrush seedlings during the 1999 and 2000 growing seasons. We addressed three questions: (1) Does grass seeding density influence Wyoming big sagebrush emergence and establishment? (2) Do Wyoming big sagebrush seeding rates determine subsequent Wyoming big sagebrush seedling densities? (3) Does the establishment of Wyoming big sagebrush seedlings depend on the interaction of these two factors?

Materials and Methods

Site Description

The study site was located within a 36-ha area at RAG Coal West, Inc., Belle Ayr Coal Mine, 29 km southeast of Gillette, Wyoming. The Belle Ayr Mine is situated in the Powder River Basin between the Black Hills and Big Horn Mountains (44° 17′N, 105° 30′W; elevation 1,460 m; Espenshade et al. 1995) and has a continental climate. Mean air temperature is 6.7°C and average annual precipitation is 376 mm (Belle Ayr Coal Mine 2000). Rolling plains, terraces, and sloping alluvial fans along streams characterize the landscape. Pre-mining vegetation of the Powder River Basin included localized concentrations of shrubs in a matrix of cool- and warm-season perennial grasses typical of northern mixed-grass prairie (Glassey et al. 1955). Wyoming big sagebrush is common on shallow soils, whereas *Artemisia cana* (silver sagebrush) is commonly found within drainages. Local soils formed from both Tertiary and Upper Cretaceous shale, sandstone, and limestone. These soils often have a carbonate horizon 40- to 76-cm deep in the profile (Glassey et al. 1955).

Plot Layout and Seeding Treatments

Topsoil was spread 56-cm deep from a 7-year-old stockpile over 70 m of graded spoil from December 1997 through January 1998. In spring 1998, the site was seeded to *Hordeum vulgare* var. "Steptoe" (barley). The barley was mowed in late summer and again in early fall 1998 to provide a standing stubble mulch.

In December 1998 seven grass seeding rate treatments of 0, 2, 4, 6, 8, 10, and 14 kg pure live seed (pls)/ha (0, 187, 374, 561, 750, 935, and 1,309 pls/m^2) were randomly assigned to 6.5 × 27-m main plots within each of four, 27 × 45.5 m replicate blocks. Previous research found no grass competition effects at grass seeding rates greater than 16 kg pls/ha (Schuman et al. 1998). They only observed significant differences in sagebrush establishment between 0 and 16 kg pls/ha seeding rates. Grasses were drill seeded into the stubble mulch at 1.5- to 2.0-cm depth, using a 153-cm wide double disk drill. Three cool-season perennial grass species, *Pascopyrum smithii* (Rydb.) A. Love, "Barton" (western wheatgrass), *Elymus lanceolatus* (Scribner & J. G. Smith) Gould, "Critana" (thickspike wheatgrass), and *Elymus trachycaulus* (Link) Gould ex Shinners, "Pryor" (slender wheatgrass), comprised the grass mixture (equal seed numbers of each species). These three grass species are commonly used in mine reclamation and are dominant species on premine lands in northeastern Wyoming.

Each grass treatment plot was divided into three, 6 × 9 m subplots, which were randomly seeded to one of three Wyoming big sagebrush seeding rates (1, 2, and 4 kg pls/ha; 350, 700, and 1,400 pls/m^2) in March 1999. Sagebrush seeding rates between 2.2 and 3.9 kg pls/ha have proven successful for establishing Wyoming big sagebrush (Gores 1995; Quinney et al. 1996). A local Wyoming big sagebrush seed source (88% viability and 23% pls) collected in December 1997 was seeded using a precision broadcast seeder (Hege 33 Fertilizer Distributor System, Wintersteiger USA, Salt Lake City, UT, U.S.A.). Cracked corn was mixed with the sagebrush seed to accomplish uniform seed distribution and flow through the seeder.

Environmental Measurements

Air temperature was collected weekly using a minimum/maximum thermometer. Soil temperatures were recorded weekly using a remote thermograph (Qualimetrix Inc/Weathertronics, Sacramento, CA, U.S.A.) with sensors buried at 5- and 15-cm depths. Precipitation was recorded weekly adjacent to the site from May to October 1999 and from May to September 2000 using a Belfort weighing bucket gauge (Belfort Instrument Company, Baltimore, MD). Annual precipitation records were obtained from the Belle Ayr Mine meteorological site located about 4 km from the study site.

Gravimetric soil moisture (dry weight basis) was determined biweekly in 1999 and 2000 at 0- to 5-cm and 5- to 15-cm depths from each grass main plot within two randomly selected replicate blocks. Samples were taken with a 3.8-cm diameter core sampler on six sampling dates in 1999 and five sampling dates in 2000 and oven dried at 105°C for 24 hr.

Soil samples taken with a core sampler at three depths (0–15, 15–30, and 30–45 cm) in seven random locations across the study plot were analyzed separately and used to characterize the soil physiochemical properties within the plot area (Table 1). Percent total nitrogen and organic carbon were determined using a Carlo-Erba® C/N analyzer. Electrical conductivity (EC), pH, and soluble cations were determined on a 1:1 soil-to-water extract (United States Salinity Laboratory Staff 1954). Soluble cations were determined by atomic absorption spectrophotometry (United States Salinity Laboratory Staff 1954). Bicarbonate extractable phosphorus was determined by the sodium bicarbonate extraction method (Olsen et al. 1954). Soil particle size was assessed using standard hydrometer methods (United States Salinity Laboratory Staff 1954).

Vegetation Measurements

Before seedling emergence in 1999, six 1-m^2 quadrats were permanently marked within each treatment subplot. Sagebrush seedlings in each 1-m^2 quadrat were counted on 30 June, 3 August, 31 August, and 25 October 1999 and on 5 June and 18 September 2000. In June 2000, planted grass culm density in six 0.18-m^2 quadrats located adjacent to the sagebrush sampling quadrats were counted. Each culm density quadrat covered three grass drill rows.

In 1999, a high density of exotic colonizing forb species were present on the study site, particularly *Kochia scoparia* (kochia), *Melilotus officinalis* (yellow sweet clover), and *Salsola kali* var. *tenuifolia* (Russian thistle). Twenty-eight 0.5-m^2 quadrats (seven grass seeding rates × four blocks) were clipped in June 1999 to estimate biomass of forbs, planted grasses, and barley. The plant material was dried at 60ºC and weighed. To mimic reclamation procedures on adjacent lands at Belle Ayr Mine and to improve sagebrush density sampling accuracy, the study area was mowed and the mowed plant litter was removed from the plots (after the first sagebrush seedling count, 30 June 1999). Plots were mowed at 15- to 18-cm heights to prevent damage to sagebrush seedlings.

In July 2000, biomass at peak standing crop of all species except Wyoming big sagebrush was determined by clipping four 0.18-m^2 quadrats within each of the 84 sagebrush-by-grass subplots. Aboveground biomass was separated into planted grasses (western, thickspike, and slender wheatgrasses); exotic grasses, including annuals such as *Bromus japonicus* (Japanese brome) and *B. tectorum* (cheatgrass); and forbs, including kochia, Russian thistle, and *Chenopodium album* (lambs quarter). Although barley was seeded as a stubble mulch, clipped volunteer barley plants were included with other grasses, because barley comprised a very small part of the total aboveground biomass.

Table 1. Topsoil physiochemical properties at the Belle Ayr Mine study site, Gillette, Wyoming.

	Depth (cm)		
	0–15	*15–30*	*30–45*
Total N (%)	0.07 ± 0.006	0.07 ± 0.01	0.07 ± 0.008
Total C (%)	0.96 ± 0.11	0.93 ± 0.21	1.02 ± 0.29
Bicarb P (ppm)	5.07 ± 0.73	5.37 ± 2.68	4.41 ± 1.18
pH	7.61 ± 0.05	7.62 ± 0.09	7.63 ± 0.06
EC (ds/m)	1.77 ± 0.51	1.94 ± 0.59	2.24 ± 0.45
Soluble cations			
Ca^{2+} (mg/kg)	284.9 ± 75.3	266.9 ± 75.2	295.7 ± 51.6
Mg^{2+} (mg/kg)	111.8 ± 32.9	124.5 ± 41.5	137.8 ± 28.2
Na^{+} (mg/kg)	51.8 ± 19.6	111.1 ± 31.2	136.4 ± 41.4
K^{+} (mg/kg)	21.2 ± 4.2	19.6 ± 3.4	23.3 ± 3.9
Sand (%)	43.6 ± 5.5	46.6 ± 5.8	46.2 ± 6.0
Clay (%)	34.2 ± 4.1	30.8 ± 4.8	30.5 ± 4.1
Silt (%)	22.3 ± 1.8	22.6 ± 2.5	23.4 ± 4.0

Values are means ± SD, $n = 7$ for each soil depth.

Experimental Design and Data Analysis

Analysis of variance was conducted on biomass, sagebrush, and grass density data using a split-plot randomized block design (Proc GLM, SAS Institute 1999). Grass seeding rate treatments were main plots and Wyoming big sagebrush seeding rate was the split-plot. Soil moisture content was analyzed by depth for the 1999 and 2000 growing seasons using repeated-measures analysis of variance. Where F-test probabilities were significant ($\alpha = 0.05$), least significant difference mean separations were used to indicate differences among treatments. Data were assessed for conformance to assumptions of analysis of variance, including parametric data distribution.

Results

Environmental Conditions

Mean air temperatures in 2000 were higher (18.8°C) than in 1999 (17.6°C). Soil temperature was more variable at 5 cm (4.4–33.8°C, 1999; 2.8–31.4°C, 2000) than at 15 cm (7.7–28.2°C, 1999; 4.7–24.5°C, 2000) and was highest in mid-to late summer. Spring and summer precipitation was above long-term averages in 1999 (Fig. 1). Rainfall amounts in 1999 were 81, 64, and 39% above the 68-year average for April, June, and July, respectively. Precipitation amounts were below normal in 2000 except in April and July.

In 1999, soil moisture differed among sample dates at both the 0- to 5-cm ($F_{4,28} = 85.1$, $p = 0.0001$) and 5- to 15-cm ($F_{4,28} = 42.2$, $p = 0.0001$) depths (Fig. 2). Soil mois-

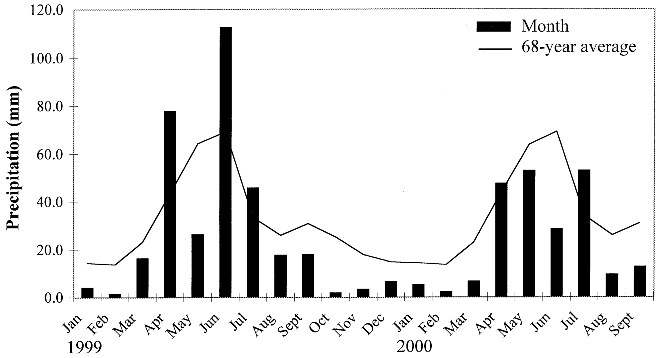

Figure 1. Monthly precipitation (mm) from January 1999 through September 2000 and long term (68-year) average at Belle Ayr Coal Mine, Gillette, Wyoming.

ture was greatest in June and August at both soil depths and was reflective of the June and late July 1999 precipitation. Soil moisture in 2000 also differed over the summer at both soil depths and ranged between 3 and 15% at the 0- to 5-cm depth ($F_{3,21} = 145.5$, $p = 0.0001$), whereas moisture at 5- to 15-cm depth averaged 8% over the growing season ($F_{3,21} = 7.1$, $p = 0.0017$). Moisture declined at both soil depths at the end of each growing season and was generally less in 2000 than in 1999, as would be expected based on precipitation (Fig. 1). In general, soil moisture was more consistent at the 5- to 15-cm depth throughout the study period and above the permanent wilting point (−1.5 MPa) for the soil represented in the study (Stahl et al. 1998).

Aboveground Production and Composition

Total biomass did not differ among grass seeding rates in 1999 ($F_{6,18} = 1.3$, $p = 0.3095$) or 2000 ($F_{6,18} = 0.8$, $p = 0.5718$). Total biomass in 1999, averaged across grass seeding rates, was 4,084 kg/ha (3,228 kg/ha forb, 193 kg/ha planted grass, and 663 kg/ha barley) and in 2000 was 974 kg/ha (289 kg/ha forb, 677 kg/ha planted grass, and 7.7 kg/ha other grass). Production of planted grasses, other grasses, and forbs all differed in 2000 among the seven grass seeding rates (Fig. 3). Planted grass biomass was greater in grass seeding rates at least 4 kg pls/ha than in the 0- and 2-kg pls/ha rates ($F_{6,18} = 23.2$, $p \leq 0.0001$). No differences were observed in planted grass production among the 4- to 14-kg pls/ha rates. Production of other grasses ($F_{6,18} = 5.9$, $p = 0.0015$) and forbs ($F_{6,18} = 4.0$, $p = 0.0096$) was greater in the 0-kg pls/ha rates than in all other rates, likely because of the absence of competition from planted grasses. Other grass and forb biomass declined with increasing grass seeding rate, which can be attributed to competition from seeded grasses.

Grass culm density in 2000 was greater in the 14-kg pls/ha grass seeding rate (107.2 culms per m^2) than in the lower rates ($F_{6,18} = 29.5$, $p = 0.0001$). No difference in grass culm density was observed among the 6-, 8-, and 10-kg pls/ha rates (69, 83, and 84 culms per m^2, respectively), which may account for the lack of differences in planted grass production for seeding rates of 4- to 14-kg pls/ha for this specific grass mix.

Sagebrush Seedling Density

Sagebrush seedling densities after two growing seasons (September 2000) exceeded the 1 shrub per m^2 standard for all three sagebrush seeding rates. Sagebrush density

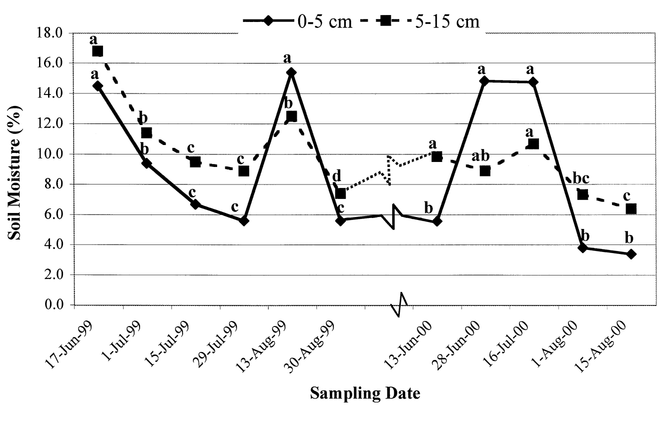

Figure 2. Soil moisture at 0- to 5-cm and 5- to 15-cm depths during the 1999 and 2000 growing seasons at Belle Ayr Coal Mine ($n = 14$). Means with the same letter within a depth and year are not different ($LSD_{0.05} = 1.2$ for 0- to 5-cm depth, 1999; $LSD_{0.05} = 1.3$ for 5- to 15-cm depth, 1999; $LSD_{0.05} = 1.6$ for 0- to 5-cm depth, 2000; $LSD_{0.05} = 2.0$ for 5- to 15-cm depth, 2000).

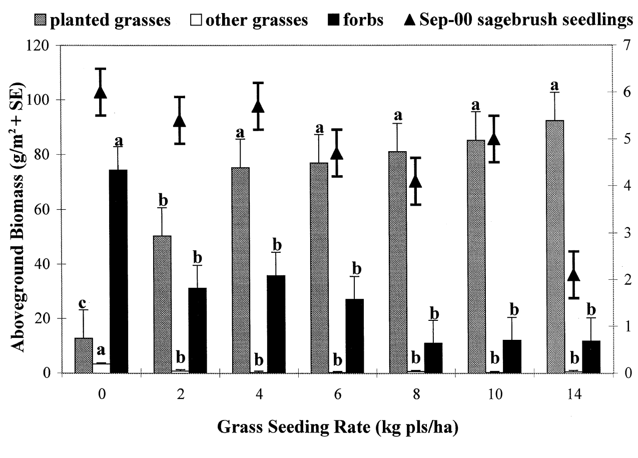

Figure 3. Aboveground biomass production (columns) and sagebrush seedling density in September 2000 (triangles) across seven grass seeding rates. Means within a class (planted grass, other grass, and forb biomass) with the same lowercase letter are not different ($LSD_{0.05} = 3.1$ within planted grass biomass, $LSD_{0.05} = 0.2$ within other grass biomass, $LSD_{0.05} = 6.0$ within forb biomass; $n = 12$). Bars represent standard errors.

exhibited a sagebrush seeding rate by sample date interaction ($F_{10,315} = 91.4$, $p < 0.0001$). Sagebrush seedling emergence and density was greatest in June 1999 and generally declined over the 1999 growing season (Fig. 4). Across all sampling dates, sagebrush seedling densities were greater at 4-kg pls/ha sagebrush seeding rate than at the 1- or 2-kg pls/ha rate. Seedling densities increased between the 25 October 1999 and 5 June 2000 sampling dates, indicating that new seedling establishment in the early spring 2000 exceeded winter mortality. No changes occurred in sagebrush seedling densities from June to September 2000. Sagebrush seedling density did not differ among grass seeding rates and did not reflect interactions of grass seeding rates with sagebrush seeding rate treatment or sampling date.

Discussion

Favorable precipitation in 1999 and the lack of a moisture deficiency in 2000 resulted in soil moisture levels throughout the study period that were conducive to initial establishment and survival of big sagebrush seedlings. Declines in sagebrush seedling numbers (particularly from 30 June to 3 August) in the 1999 growing season parallel declining soil moisture in the surface 0- to 5-cm soil depth and unusually high aboveground production of volunteer species. Lack of seedling mortality in 2000 from 5 June to 18 September indicates that water and space competition was not great enough to cause seedling mortality.

Precipitation in April and May 2000 promoted germination of new seedlings. Sampling before germination of new seedlings or marking of each new seedling would have allowed us to estimate mortality of sagebrush seedlings over the winter. New sagebrush seedlings can establish in subsequent (3–4) years after the initial seeding (Schuman et al. 1998) due to sustained seed viability (Monsen & Richardson 1986; Schuman 1999).

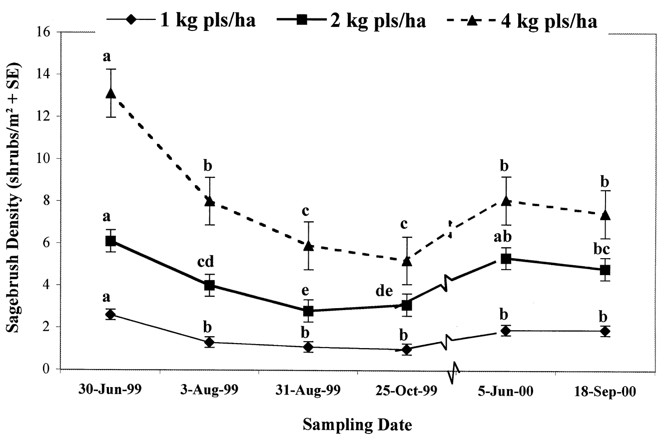

Figure 4. Sagebrush densities differed significantly among seeding rates for each date ($LSD_{0.05} = 1.2$). Density means for dates within seeding rates with the same lowercase letter are not different ($LSD_{0.05} = 1.2$; $n = 28$). Bars represent standard errors.

Increased shrub density from high shrub seeding rates is documented in the literature (Richardson et al. 1986; Gores 1995; Quinney et al. 1996; Booth et al. 1999). However, increasing seeding rates beyond a reasonable amount may not be fruitful because increased intraspecific competition may limit seedling establishment (Begon et al. 1996; Whisenant 1999). Seeding at moderate to high sagebrush seeding rates (2–4 kg pls/ha) may increase Wyoming big sagebrush establishment by increasing initial emergence and by providing seed that will remain viable and germinate 3 to 4 years after seeding, when climatic conditions become more conducive (Schuman & Booth 1998; Schuman 1999).

The minimal influence of grasses on sagebrush seedling densities follows trends reported by Johnson and Payne (1968), Gores (1995), and Quinney et al. (1996). Our grass seeding rates were intended to represent rates that had minimal competitive effects on sagebrush establishment. Even though the 14-kg pls/ha grass seeding rate exhibited 30 to 50% less sagebrush seedling density, there were no differences in sagebrush seedling density a mong grass seeding rates. The presence of volunteer forbs in the lower grass seeding rates may have produced similar competitive effects as the grass and perhaps masked the effects of grass seeding rates (Fig. 3).

Growth of volunteer species during both growing seasons may have influenced establishment of sagebrush seedlings. Within seeded plots of *Bromus tectorum* (cheatgrass), emergence of *Purshia tridentata* (antelope bitterbrush) seedlings was low compared with emergence within seeded perennial grass plots (Hall et al. 1999). Allen (1988) observed limited success of big sagebrush establishment in secondary successional plots with high cover of Russian thistle. The native grasses that were able to colonize research plots with Russian thistle expanded vegetatively after the successional decline of Russian thistle after 3 to 4 years, and sagebrush was still not able to colonize. However, sagebrush was able to colonize research plots where Russian thistle was absent initially, as the initial native forb and grass cover was sparse (Allen & Knight 1984, Allen 1988). Available open space around sagebrush seedlings can influence their survival over time, where greater open spaces are linked to high seedling survival (Owens & Norton 1989). The exotic forbs present in our 0-, 2-, and 4-kg pls/ha grass seeding rates may have created a level of competition similar to the higher grass seeding rates, resulting in a similar sagebrush seedling density across all grass treatments.

Concurrent planting of grass and shrub species can suppress shrub establishment (Eissenstat & Caldwell

1988). At 16- and 32-kg pls/ha grass seeding rates, grasses limited Wyoming big sagebrush seedlings to densities less than when sagebrush was seeded alone (Schuman et al. 1998). Richardson et al. (1986) found that grasses and forbs seeded above 13-kg pls/ha prevented mountain big sagebrush establishment. However, they also found that elimination of grass and forbs from the seed mix provided good sagebrush establishment, regardless of sagebrush seeding rates (Richardson et al. 1986). Chambers et al. (1994) reported that concurrent planting of introduced and native grasses and forbs at high rates provided production and cover comparable with adjacent unmined areas. However, establishment of natives included in the mix was reduced because of competition with the more aggressive introduced forage species. In contrast, low seeding rates of grasses and forbs can produce similar cover and production as high seeding rates over time and may enable establishment of the lesser competitive native species (Stevenson et al. 1995; Fortier 2000).

Management Considerations

Using the sagebrush seedling densities found in our study and long-term survival rates for seeded big sagebrush documented in other studies, we assessed the potential of achieving the Wyoming shrub density standard. Eight years after seeding sagebrush in the Powder River Basin, Wyoming big sagebrush survival was 59% (Schuman & Belden 2002). On a coal mine site in northwestern Colorado, Kiger et al. (1987) reported that 28 to 32% of sagebrush seedlings established the first year survived after 11 years. Applying these survival rates to our data suggests that grass seeding rates of 6- or 8-kg pls/ha and sagebrush seeding rates of 2- or 4-kg pls/ha should satisfy the Wyoming shrub density standard. Using the average sagebrush density (7.8 shrubs per m^2) obtained for the 6- and 8-kg pls/ha grass seeding rate and 4-kg pls/ha sagebrush seeding rate, we can estimate that the density at bond release would be 2.2 or 4.6 shrubs per m^2 using the reported long-term survival of 28 and 59%, respectively. Estimated sagebrush densities for the 2-kg pls/ha sagebrush seeding rate at these grass seeding rates, based on a sagebrush density of 4.1 shrubs per m^2, would be 1.1 and 2.5 shrubs per m^2, respectively, using the reported survival rates.

We must evaluate the interaction of grass seeding rates on Wyoming big sagebrush establishment and soil resource stability to thoroughly understand the effects of reduced grass seeding rate on soil stability (erosion protection) and to follow long-term effects of grass competition during years of resource (moisture, space, nutrient) limitations. However, our data show that grass seeding rates from 4- to 14-kg pls/ha resulted in similar forage production and hence probably adequate erosion protection. To achieve a better understanding of the effects of grass competition on sagebrush establishment and to strengthen our seeding recommendations, we will assess these research plots in subsequent years.

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