Enhancing Wyoming Big Sagebrush Establishment with Cultural Practices

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Abstract

Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) has proven difficult to re-establish by direct seeding on mined lands in the western U.S. This paper reviews research accomplishments over the last decade that address ecological and cultural practices to enhance big sagebrush establishment. Direct-placed topsoil, mulching and arbuscular mycorrhizae have been shown to positively influence seedling establishment of this species on mined land. Direct-placed topsoil possesses better biological, physical, and chemical characteristics that are conducive to plant establishment. Direct-placed topsoil has greater water storage capacity, better soil physical properties, and higher levels of mycorrhizal inoculum. However, direct-placed topsoil has not shown benefits as a source of sagebrush propagules. Mycorrhizae has in turn been shown to give the seedlings greater drought stress tolerance. Forty-five day old sagebrush seedlings that were mycorrhizal were able to survive in soils at -3.2 MPa of moisture stress compared to -2.8 MPa for those non-infected seedlings. Regardless of sagebrush seedling age, no non-mycorrhizal seedlings survived in soils with water potentials less than -3.3 MPa compared with mycorrhizal seedlings that survived in soils as dry as -3.7 MPa. Mulch is believed to produce micro-climate changes in the seedbed area that provide "safe-sites" that result in more optimum conditions for sagebrush germination and establishment. Grass seeded concurrently with sagebrush creates significant competition and has reduced sagebrush seedling establishment. The use of a more easily established shrub species (*Atriplex cansescens*) as a "pioneer" plant has not shown any beneficial or "exclusionary" effects on Wyoming big sagebrush establishment. Ten-year old reclaimed lands seeded with multiple shrub species had higher canopy cover, density, and diversity than sites where the seed mixture included only a single shrub species. These recent findings are being incorporated into direct seeding technology by the mining industry; however, some questions remain unanswered. These technology advances will not ensure seedling establishment but will greatly enhance the probability of success in arid and semiarid environments.

Introduction

Xerophytic shrubs are a significant component of rangelands throughout much of the arid/semiarid West and provide many benefits to the function and utility of rangeland ecosystems (McKell and Goodin 1973). Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) is one of the most widely distributed and adapted shrub species in Wyoming and the region (Beetle and Johnson 1982). However, its re-establishment on mined lands has generally proven difficult because

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of low seedling vigor, an inability to compete with herbaceous species and altered edaphic conditions (Harniss and McDonough 1976, Young and Evans 1989, Schuman et al. 1998).

Reduced levels of arbuscular mycorrhizae (AM) in disturbed soils have also been postulated as a factor limiting the success of re-establishment of big sagebrush on disturbed lands (Call and McKell 1982, Stahl et al. 1988). Arbuscular mycorrhizae can improve the host plant's ability to extract nutrients and water from soil (Stahl et al. 1988). Indirect evidence has indicated that water availability is one of the key factors involved in big sagebrush seedling establishment success (Jones 1991). Allen (1984) reported that sagebrush is particularly dependent upon AM symbiosis to reach full growth potential. Use of "pioneer" plants to improve soil conditions, including AM levels, of disturbed lands for later seral species has also been postulated as a means to enhance re-establishment of big sagebrush (Booth 1985, Meyer 1990). It is evident from this brief review of the literature that much additional information was needed to enhance our understanding of big sagebrush seedbed ecology and to develop a seeding technology that would result in successful re-establishment of this species.

Recent Findings

Schuman and Booth (1998), Stahl et al. (1998), Schuman et al. (1998), and Booth et al. (1999) reported on recent research evaluating the effects of historic reclamation practices, soil management, mulching, competition, and AM on big sagebrush establishment. Schuman and Booth (1998) and Schuman et al. (1998) in a study to evaluate the effect of topsoil management (5 yr old stockpiled vs direct placement), mulching (stubble, surface, stubble + surface, and no mulch), and competition (three grass seeding rates) found that all three variables affected big sagebrush seedling establishment in an interactive manner. Sagebrush seedling densities responded differently to the treatments during the first year (1992) after seeding and the following spring than they did in the fall of 1993 and 1994 (Table 1-3). The largest increase in sagebrush seedlings were observed between the spring 1993 and fall 1993 due to the wet and cool conditions during that period. Big sagebrush seedling densities observed in 1992 on the direct placed topsoil-no competition-mulched treatments (Table 1) exceeded the shrub density standard (1 shrub/m^2) adopted in Wyoming (Federal Register 1996). If we use Kriger et al. (1987) findings that 32% of the big sagebrush established the first year will survive after 11 years we still have adequate seedling densities for the stubble and surface mulch treatments to achieve this standard. This emphasizes the importance of good cultural practices in establishing big sagebrush since 1992 was a below average (87%) precipitation year. Direct-placed topsoil resulted in 40% more sagebrush seedlings than the stockpiled topsoil treatment after 3 years; however in 1992 and the spring of 1993, differences were 1-2 orders of magnitude greater for direct-placed topsoil. Soil moisture content of the surface 7.5 cm of direct-placed topsoil was always higher than that observed in the stockpiled topsoil treatment in 1992. This observed greater soil moisture undoubtedly improved sagebrush germination and establishment on direct-placed topsoil in 1992. The benefits of direct-placed topsoil were only observed in treatments where no grass was seeded. No differences in sagebrush seedling densities were evident between the 16 and 32 kg PLS/ha grass seeding rates. However, even the lowest grass seeding rate is slightly above the maximum used by the industry in their reclamation programs (further discussion of grass seeding rate will be covered later in the paper).

Table 1. Sagebrush seedling density as affected by topsoil management, mulch type, and grass seeding rate, 1992. (Schuman et al. 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kgPLS/ha)	0	16	32	0	16	32
Mulch Type	plants/m^2					
Spring 1992						
stubble	5.78	1.11	0.04	0.11	0	0
surface	7.37	0.07	0	0.04	0	0
stubble + surface	1.59	1.56	0.63	0.11	0	0.04
control	0	0	0.04	0	0	0

$LSD_{0.10}$=2.48, within a mulch type with a topsoil management;
$LSD_{0.10}$=2.51 within a topsoil management with a seeding rate;
$LSD_{0.10}$=2.71 within a mulch type within a seeding rate.

Fall 1992						
stubble	5.15	0.52	0.07	0	0	0.04
surface	6.07	0	0.15	0	0	0
stubble + surface	1.41	1.11	0.37	0.30	0.04	0
control	0	0	0	0	0	0

$LSD_{0.10}$=2.13 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.16 within a topsoil management within a seeding rate;
$LSD_{0.10}$=2.30 within a mulch type within a seeding rate.

Table 2. Sagebrush seedling density as affected by topsoil management, mulch type, and grass seeding rate, 1993. (Schuman et al. 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kgPLS/ha)	0	16	32	0	16	32
Mulch Type	plants/m^2					
Spring 1993						
stubble	6.30	2.04	1.81	1.63	0.04	0.15
surface	8.74	0.30	0.89	0.44	0.04	0.93
stubble + surface	4.07	2.48	1.52	1.56	0.33	0.11
control	1.26	0.56	0.22	0.37	0.14	0.04

$LSD_{0.10}$=2.01 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.07 within a topsoil management within a seeding rate;
$LSD_{0.10}$=2.73 within a mulch type within a seeding rate.

Fall 1993						
stubble	9.67	3.93	2.93	5.41	2.11	1.93
surface	13.48	1.00	1.22	2.74	1.81	2.18
stubble + surface	8.04	2.89	1.63	4.59	2.15	1.70
control	7.52	1.37	0.52	1.81	0.52	0.19

$LSD_{0.10}$=2.59 within a mulch type within a topsoil management;
$LSD_{0.10}$=2.89 within a topsoil management within a seeding rate;
$LSD_{0.10}$=3.91 within a mulch type within a seeding rate.

Table 3. Sagebrush seedling density as affected by topsoil management, mulch type, and grass competition, Fall 1994. (Schuman et al. 1998)

	Topsoil Management					
	Fresh			Stockpiled		
Competition (kgPLS/ha)	0	16	32	0	16	32
Mulch Type	---------- plants/m^2 ----------					
stubble	8.15	9.82	7.11	3.44	2.78	3.26
surface	12.11	4.63	5.33	2.40	3.52	5.07
stubble + surface	9.11	3.78	4.26	3.30	3.85	2.52
control	7.22	5.88	4.56	4.48	2.52	1.70

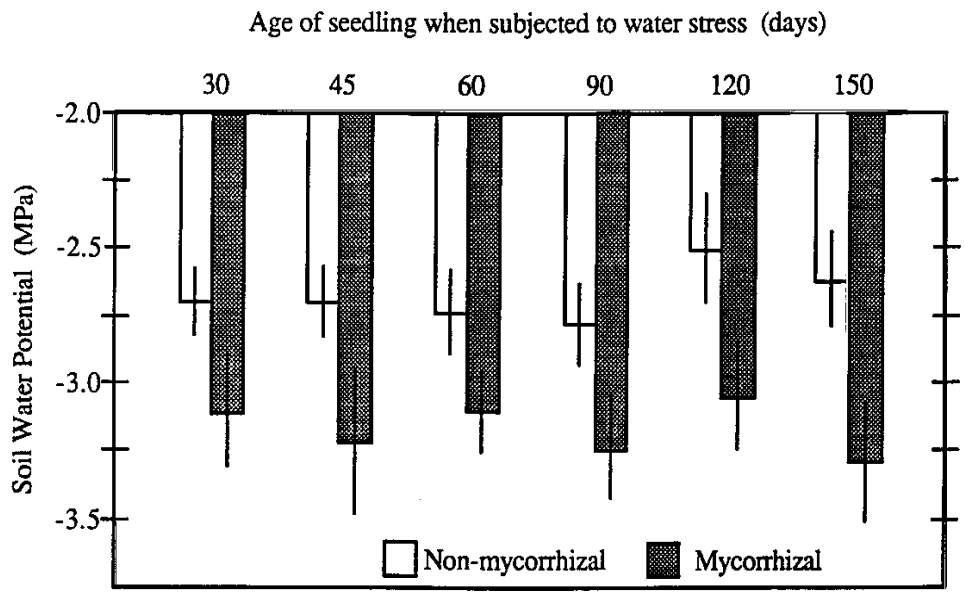
$LSD_{0.10}$=3.00 within a mulch type within a topsoil management;
$LSD_{0.10}$=3.79 within a topsoil management within a seeding rate;
$LSD_{0.10}$=3.99 within a mulch type within a seeding rate.

Benefits of topsoil management were evident in the initial year of establishment; however, this study did not clearly delineate some of the benefits expected. Unseeded control plots in an adjacent study did not have any sagebrush seedlings present after 4 yrs; therefore, direct-placed topsoil did not act as a seedbank for sagebrush nor was natural recruitment occurring (Schuman and Booth 1998),

Even though the AM fungal spore counts were significantly different between the two topsoil management treatments (3088/g stockpiled vs 4500/g direct-placed) no differences in sagebrush seedling infection was observed in the seedlings excavated in June 1993 (Schuman et al. 1998). Root segments examined from the study showed an infection rate of 66-76%. They believe that the time between topsoil placement (late summer 1990) and June 1993 was more than adequate for reinoculation of the stockpiled topsoil. Loree and Williams (1984) found that native grasses became infected with AM within a year of establishment on long-term stockpiled topsoil indicating inoculum is spread quite readily under natural conditions. However, this finding should not diminish the importance of topsoil management for AM concerns. Stahl et al. (1998), in a greenhouse study, found that the sagebrush seedling age groups of 30 to 150-days old that were mycorrhizal were able to tolerate greater drought stress (moisture tension) before dying than non-mycorrhizal seedlings. Non-mycorrhizal, 45-day-old sagebrush seedlings died when the moisture stress level was -2.8 MPa compared to the mycorrhizal seedlings which tolerated soil moisture tensions of -3.2 MPa before dying (Figure 1). Sagebrush seedling age and mycorrhizae treatment interacted, such that as sagebrush seedlings aged the beneficial influence of AM on soil moisture stress tolerance increased

(Figure 1). Those seedlings ≥120 days of age that were non-mycorrhizal were much less tolerant of soil moisture stress than younger non-mycorrhizal seedlings (Figure 1) indicating that sagebrush seedlings become more dependent upon the benefits of mycorrhizae as they age. They also showed

Figure 1. Average soil water potentials resulting in death of mycorrhizal and non-mycorrhizal sagebrush seedlings. Vertical bars on each column represent 1 standard deviation. Differences between mycorrhizal and non-mycorrhizal treatments were statistically significant at P≤0.01 for each age group. (Stahl et al. 1998)

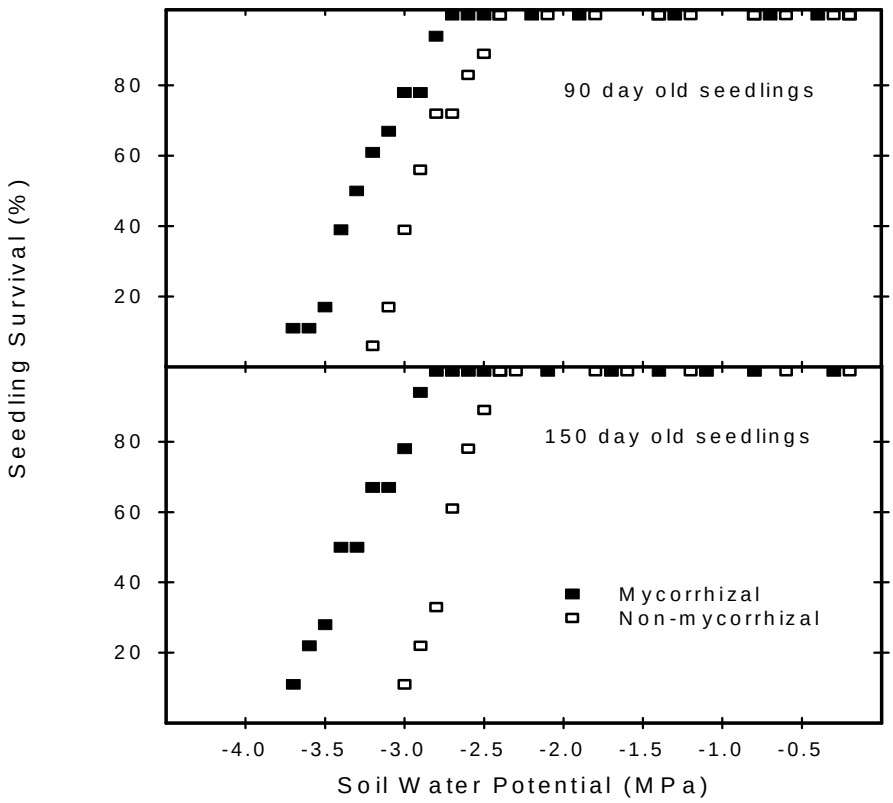


that sagebrush seedling survival across a range of soil water potentials was greater for mycorrhizal than non-mycorrhizal seedlings (Figure 2). These findings could partially explain the lack of infection differences observed by Schuman et al. (1998) in seedlings grown on direct-placed vs stockpiled topsoil. Those seedlings growing in stockpiled topsoil failing to form AM early in their development may have not tolerated repeated drying cycles experienced in a typical spring-summer period in a semiarid climate. Hence, seedlings sampled a year later may not have been representative of the seedling population that originally germinated and emerged because non-mycorrhizal seedlings may have died early in their development.

The presence of mulch also greatly affected sagebrush seedling establishment in 1992 (Schuman and Booth 1998, Schuman et al. 1998). No seedlings were evident in the first year where mulch was not applied (Table 1). Both stubble and surface mulch treatments had similar or greater seedling establishment than the stubble + surface mulch treatment. Soil moisture content of the surface 7.5 cm was greater under all mulch treatments compared to the no-mulch treatment. Schuman et al. (1980) found that stubble mulch enhanced grass seedling establishment through reduced diurnal temperature fluctuations and increased soil moisture.

Grass competition reduced sagebrush seedling densities throughout the duration of the study on direct-placed topsoil treatment where stubble or straw mulch was used (Schuman and Booth 1998, Schuman et al. 1998). They reported grass seedling densities of 0, 196, and 250 grass seedlings/m^2 for the 0, 16, and 32 kg PLS/ha grass seeding rates, respectively. No differences in grass seedling density among topsoil management treatments were observed. They concluded that successful establishment of big sagebrush on mined lands might require seeding in the absence of any grass or

Figure 2. Survival rates for 90 and 150 day old mycorrhizal and non-mycorrhizal sagebrush seedlings at different levels of soil dryness. (Stahl et al. 1998)



perhaps at very low grass seeding rates. These findings have led to further research by Fortier et al. (2000) evaluating effects of grass competition and big sagebrush seeding rates on sagebrush seedling establishment reported at this conference.

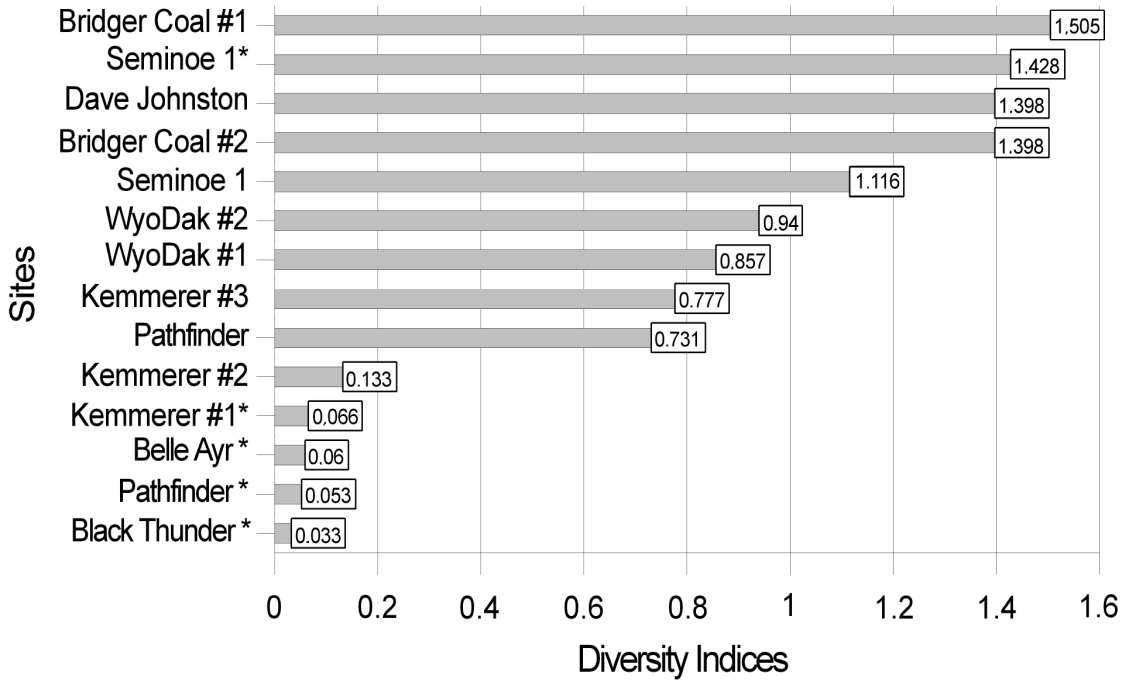
A research study aimed at assessing the role of fourwing saltbush (*Atriplex canescens* ssp. *aptera*) as a "pioneer" plant to enhance the later establishment of big sagebrush and to evaluate the role of this plant in excluding big sagebrush when seeded at rates in excess of 2.2 kg PLS/ha was reported by Schuman and Booth (1998). Grass competition was not evaluated in this study; hence, the only herbaceous plant competition that existed was from plants that became established naturally through the topsoil seedbank or other means of recruitment. The entire study area was stubble mulched. They found that fourwing saltbush neither improved nor restricted sagebrush

establishment; however, they did report greater total shrub densities where fourwing saltbush was over-seeded a year later with big sagebrush. Big sagebrush represented 42% of the shrub density and the seeding strategy produced about 10,000 more total shrub seedlings per hectare than other seeding strategies. Gores (1995), Booth et al. (1999), and Olson et al. (2000) also reported that shrub densities were greater when more than one shrub species is included in the reclamation seed mixture.

Schuman et al. (1998) and Schuman and Booth (1998) showed that big sagebrush seed maintains its viability for much longer than thought (Young and Evans 1989) because new seedlings were noted 3-5 years after the initial seeding of big sagebrush. Wyoming big sagebrush has been shown to have some seed dormancy (McDonough and Harniss 1974, Booth et al. 1997); therefore, Schuman et al. (1998) and Schuman and Booth (1998) believe that continued germination and establishment of big sagebrush for several years was related to seed dormancy, the continual development of "safe sites" for seed germination and establishment (Harper 1977) and improved climatic conditions (precipitation and temperature) in subsequent years.

Research has shown that seeding a mixture of shrub species also results in greater overall density, species diversity, and structural diversity than is achieved by a single shrub species (Gores 1995, Booth et al. 1999 and Olson et al. 2000). Gores (1995) and Olson et al. (2000) also reported that sites seeded to several shrub species resulted in higher diversity indices of reclaimed sites compared to those where only fourwing saltbush was seeded (Figure 3). Greater species and structural diversity greatly enhance wildlife habitat quality.

*Figure 3. Diversity indices for fourwing saltbush/grass (denoted by *) and fourwing saltbush/big sagebrush/grass sites. Refer to Booth et al. 1997 for a list of seeding mixture used at each site. (Olson et al. 2000)*



Conclusions/Summary

Research reviewed in this paper has answered many questions related to establishment of Wyoming big sagebrush on mined lands; however, not all issues/concerns have been fully addressed. Current research assessing the effects of sagebrush seeding rates and multiple levels of grass competition on sagebrush establishment should further aid in defining and developing a big sagebrush establishment technology. The fact that big sagebrush has exhibited some seed dormancy and has been shown to retain seed viability for several years after being seeded greatly increases the probability of a good "precipitation and temperature year" occurring while the seed is still viable. This fact alone may make it desirable to seed big sagebrush at a higher rate than previously recommended to ensure an adequate seed bank for germination and establishment over several years. Even though big sagebrush seed is relatively expensive, this cost would be much lower than having to mobilize equipment and a contractor a second year to ensure adequate and desired sagebrush densities are achieved.

Evidence does not seem to support the fact that more easily established shrubs, such as fourwing saltbush, enhance establishment of big sagebrush; however, inclusion of multiple shrub species in the seed mixture has been shown to increase total shrub seedling density and greater plant community diversity.

Research has repeatedly highlighted the many benefits of direct-placed topsoil, such as AM inoculum, better soil physical characteristics, seedbank of native species, healthy microbial populations that ensure good nutrient cycling, and enhanced water infiltration and water storage capacity. Enhanced drought stress tolerance of big sagebrush seedlings when AM associations are present highlights an important factor in improving seedling survival in an arid/semiarid environment where soil moisture levels fluctuate dramatically in the surface few centimeters of the soil.

Mulch has also been shown to be critical to formation of "safe sites" for big sagebrush germination and establishment through microclimate modification. Stubble mulching is a desired practice over the use of straw mulch which is more costly, more labor intensive and has a greater potential to introduce non-desired and noxious weed species into reclaimed lands. Use of a stubble mulch has also been shown to have long-term benefits for water infiltration into the reconstructed soil profile (Schuman et al. 1980).

Reclamationists have recommended and in some instances planted big sagebrush in small islands with the intention that these islands serve as seed banks for further spread of the species into the revegetated areas. However, data by Gores (1995) and Lyford (1995) showed that natural recruitment of big sagebrush into revegetated mine lands from native stands of big sagebrush was generally limited to a few meters after 10-15 years. Lyford (1995) stated that natural recruitment decreased 50-fold when distance to the seed source exceeded 100 m. Therefore, this approach to aiding establishment of big sagebrush will probably not be effective within the bonding time frame.

Research within the last decade has produced a much better understanding of seedbed ecology of big sagebrush. Research aiding development of a seeding strategy for big sagebrush should also benefit establishment of other native shrub species.

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