ESTABLISHING WYOMING BIG SAGEBRUSH ON MINED LANDS IN WYOMING[1]

by

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Abstract. Revegetation of mined rangelands in the western U.S. requires that a diverse, self-generating plant community be established that includes native woody shrubs that provide important wildlife habitat. Wyoming Department of Environmental Quality, Land Quality Division, on August 6, 1996, amended their revegetation standards to include a shrub density requirement that had been sought by environmental and wildlife groups for over two decades. This standard requires that 1 shrub m^{-2} be re-established on 20% of the disturbed area and that 50% of this density be comprised of the dominant species present before mining. In Wyoming and much of the western rangelands, this typically requires the re-establishment of Wyoming big sagebrush (*Artemisia tridentate* ssp. *wyomingensis*). Hence, much research has been accomplished in the last 10-15 years to develop a better understanding of its seed physiology, seedbed ecology, and to develop cultural practices that will aid in its re-establishment. Research has increased our knowledge in many of these important areas of sagebrush re-establishment ecology and have greatly enhanced our ability to establish big sagebrush by direct seeding; however, climatic factors have a great influence on the success of its re-establishment. The paper also compares the cost of direct seeding compared to transplantation of nursery grown seedlings to meet the shrub density standard and shows that direct seeding costs only a fraction of the cost of transplantation. Further research efforts should be concentrated on further improving direct seeding technology and enhanced production of good quality seed.

Additional Key Words: direct seeding, success, cost, transplantation.

Introduction

Revegetation of mined lands in the western U.S. includes much more than just establishing a perennial grass community to protect the soil resource from erosion. In the past two decades regulatory agencies and environmental groups have spent considerable time and effort to ensure that native shrubs are re-established on mined lands in the Great Plains and Great Basin of the western U.S. These lands must be reclaimed to a diverse, self-generating plant community that includes native woody shrubs that provide important wildlife habitat, as well as livestock forage. In fact, considerable effort, from both a regulatory and environmental standpoint has been aimed at a single species, Wyoming big sagebrush (*Artemisia tridentate* ssp. *wyomingensis*). Hence, much research has been undertaken to better understand seed physiology, germination, dormancy, viability, seedbed ecology, and cultural practices for establishment of Wyoming big sagebrush on mined lands. This paper reviews the recent research and uses some of the data to make seeding recommendations and to compare the cost of direct seeding to transplantation of sagebrush to meet the shrub density standard for mined lands in Wyoming.

Seed Considerations

Wyoming big sagebrush seed is very small, making it difficult to harvest, process and plant. Young and Young (1992) report that there are 3500-3800 seeds g^{-1},

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while Bai et al. (1997) reported 3100-4500 seeds g^{-1} for five Wyoming collections. Sagebrush seed availability and quality are very dependent upon yearly climatic conditions because most of the seed used in land reclamation are collected from native stands. However, more emphasis and interest is being directed toward seed production under cultivated field conditions and irrigation, which will ensure a more consistent quality and availability of seed. Seed availability will become a more important consideration in the future because demand for Wyoming big sagebrush seed has increased dramatically over the last few years as land management agencies attempt to revegetate large land areas affected by fire and invasive species. However, with good sound planning and use of good cultural practices by these agencies, the impact on seed availability and cost could be greatly reduced.

Harvesting seed from native big sagebrush stands requires careful observation and timing. Young and Young (1992) reported that seed needs to be harvested as soon after seed ripening as possible. In fact, Walton et al. (1986) believe that viable, ripe seeds will fall from the seed stalks within the first seven days after ripening. However, Bai et al. (1997) found significant amounts of viable Wyoming big sagebrush seed in the seed stalks in February. These inconsistent findings may be associated with variance in climate and seed quality between eco-regions.

Seed processing by using a debearder is common and has been found to have no detrimental effects on seed germination (percentage or rate), seedling vigor, or shelf-life (Booth et al. 1997). However, seed storage is a topic in which much additional research is needed to fully understand the effects of the various environmental conditions utilized for seed storage. Bai et al. (1997) and Shaw and Booth (1999) found a full range of seed responses to various seed storage conditions, leaving one to conclude that no single seed storage protocol has been shown to be superior or is used as a standard.

Germination of big sagebrush is believed to be genetically regulated and has evolved to ensure its survival under the wide range of climatic conditions exhibited within its wide geographical distribution in the western U.S. (Meyer and Monsen 1992). Monsen and Meyer (1990) and Shaw (1994) stated that understanding specific germination requirements for a subspecies is essential to developing an appropriate seedbed ecology (seedbed preparation, planting methods, equipment, mulch) that will enhance germination and establishment.

Big sagebrush seed has been reported to have a relatively short lived viability of only a few months (Young and Evans 1989); however, researchers have shown Wyoming big sagebrush to have some seed dormancy (McDonough and Harniss 1974; Booth et al. 1997). Soil moisture has been shown to be a critical factor in big sagebrush germination and germination rate (Sabo et al. 1979; Walton et al. 1986). Schuman and Booth (1998) and Schuman et al. (1998) have shown that good quality Wyoming big sagebrush seed broadcast on the soil surface with some type of mulch may persist for at least four years with additional natural recruitment occurring as "safe sites" develop and temperature and soil moisture conditions become optimum for seed germination and seedling development. In fact, Cawker (1980) and Lyford (1995) concluded that inadequate moisture is the predominant factor in determining big sagebrush mortality during and after the first growing season. Therefore, it is not surprising that Maier (1999) found above average December and January precipitation (following year of establishment) positively correlated to big sagebrush establishment in Wyoming. Weldon et al. (1959) reported that light level was critical to sagebrush seed germination; hence, seeds on the surface of the soil can readily experience wide moisture conditions.

Seedbed Considerations

In the last two decades much research has evaluated the role and effect of the seedbed on big sagebrush establishment (Schuman et al. 1998; Robertson 1972; Monsen and Meyer 1990). Schuman et al. (1998) found that some type of mulch (surface straw mulch or stubble mulch) greatly increased the establishment of big sagebrush on mined lands. They concluded that the mulch reduced soil water evaporation, reduced diurnal temperature fluctuations, and aided in the development of "safe sites" for sagebrush to germinate and become established (Schuman et al. 1998; Schuman et al. 1980). "Safe site" development is not simply a modification of microclimate factors but also includes mycorrhizal inoculum that will enhance seedling development and survival. The stubble mulch also increased soil moisture conservation by trapping snow during the winter months (Schuman et al. 1980) which will greatly aid seed germination and seedling development. Monsen and Meyer (1990) also found that big sagebrush germination and establishment was enhanced by snow management through placement of snow fencing to increase the probability of snow drifting on direct seeded plots. Schuman et al. (1998) also found that direct placed topsoil significantly increased first year sagebrush seedling densities on mined land compared to topsoil that had been stockpiled for 5 years. They concluded that the improved sagebrush seedling density was attributed to the improved physical, chemical and biological properties of the direct placed topsoil that manifested these benefits in greater soil moisture and greater mycorrhizal inoculum levels. Stahl et al. (1998) followed this study with a greenhouse study using soil from the same mine site and showed that seedlings growing in topsoil with good levels of mycorrhizal inoculum exhibited significantly greater drought stress tolerance than those grown on non-mycorrhizal topsoil and this increased drought stress tolerance became more pronounced as the seedling aged. Therefore, giving the mycorrhizal seedlings a definite advantage during the period of time (limited seedling root elongation) they are most susceptible to wide swings in soil moisture common in semiarid climates. In a separate phase of the field study reported on by Schuman et al. (1998), Schuman and Booth (1998) reported no differences in sagebrush establishment between direct placed and stockpiled topsoil over 4 years. However, one must keep in mind that biological and physical characteristics of the stockpiled topsoil treatment change with time and it is likely that after 12-18 months, mycorrhizal inoculum was no longer an issue because of the reinoculation of the stockpiled topsoil by wind and other means (Schuman et al. 1998, Loree and Williams 1984). Schuman et al. (1998) also found that even though mycorrhizal spore counts were significantly lower in stockpiled topsoil compared to direct-placed topsoil, sagebrush seedling infection, 1 year after initial seedling emergence, was not different between the two topsoil sources. They also showed no difference between sagebrush seedling density and topsoil source in subsequent years of evaluation because of continued establishment of sagebrush from remaining viable seed. However, eight years after sagebrush seeding, the average seedling density on stockpiled topsoil was 1.96 compared to 3.22 seedlings m^{-2} on the direct-placed topsoil treatment (G.E. Schuman, unpublished data, 2000). Even though this large difference was not found to be statistically significant, it definitely has great biological importance when assessing the shrub density against the required standard. Schuman and Booth (1998) showed significant increases in sagebrush establishment over a four year period from a single sagebrush seeding date. Schuman and Booth (1998) also reported that use of a "pioneer species" (in this case *Atriplex canescens*) did not enhance recruitment of Wyoming big sagebrush as postulated by researchers (Booth 1985; Meyer 1990; Wagner et al. 1978) or diminish its recruitment even when over-seeded with Wyoming big sagebrush in subsequent years.

Several researchers have reported that one of the major constraints in successfully establishing big sagebrush on mined lands through direct seeding has been the direct competition for soil moisture by the perennial grasses seeded concurrently with the big sagebrush (Schuman et al. 1998; Blaisdell 1949; Jones 1991; Cook and Lewis 1963; Sturges 1977; Eissenstat and Caldwell 1988; Richardson et al. 1986.) Schuman et al. (1998) found significantly higher initial sagebrush seedling density when seeded without grass compared to being seeded concurrently with grasses at 16 or 32 kg PLS ha^{-1} seeding rates. Richardson et al. (1986) also found that grass and forb seeding rates of 13 kg PLS ha^{-1} prevented mountain big sagebrush establishment; however, elimination of grasses and forbs provided good seedling establishment. Fortier (2000) evaluated the effects of three Wyoming big sagebrush seeding rates (1, 2, and 4 kg PLS ha^{-1}) and seven grass seeding rates (0, 2, 4, 6, 8, 10, and 14 kg PLS ha^{-1}) on sagebrush seedling establishment. After two growing seasons, she found no statistically significant effect of grass seeding rate (competition) on sagebrush establishment; however, at grass seeding rates above 10 kg PLS ha^{-1} a 60% reduction in sagebrush seedling density (Figure 1) was observed, although data variance prevented this large difference from being significant. She also believes that soil moisture competition did not begin to express itself until late in the second growing season because of the above normal precipitation in the first year and spring and early summer of the second year. It is interesting to note that second year planted grass biomass did not differ for grass seeding rates of 4-14 kg PLS ha^{-1} and grass seedling density was not different for the 6-10 kg PLS ha^{-1} grass seeding rates. However, sagebrush density was greatly reduced at the grass seeding rate of 14 kg PLS ha^{-1} (Figure 1). Because of these trends, Fortier (2000) recommended that grass seeding rates of 6-8 kg PLS ha^{-1} and sagebrush seeding rates of ≥ 2 kg PLS ha^{-1} be used to reclaim mined lands to the regulatory requirement of 1 shrub m^{-2} on 20% of the reclaimed landscape. This assessment takes into consideration the longer-term survival of sagebrush seedlings found by Kriger et al. (1987) and Schuman (G.E. Schuman, unpublished data, 2000). Kriger et al. (1987) found that 33% of the newly established sagebrush seedlings were still alive after 11 years in northwestern Colorado and Schuman (G.E. Schuman, unpublished data, 2000) reported 59% survival of Wyoming big sagebrush seedlings after 8 years at a study site in the Powder River Basin of Wyoming. Fortier (2000) also found significant increases in sagebrush seedling density for all three sagebrush seeding rates for any given sample date during the 2 year study. However, Fortier (2000) did not show a significant increase in sagebrush seedling density the second year for the 1 kg PLS ha^{-1} sagebrush seeding rate

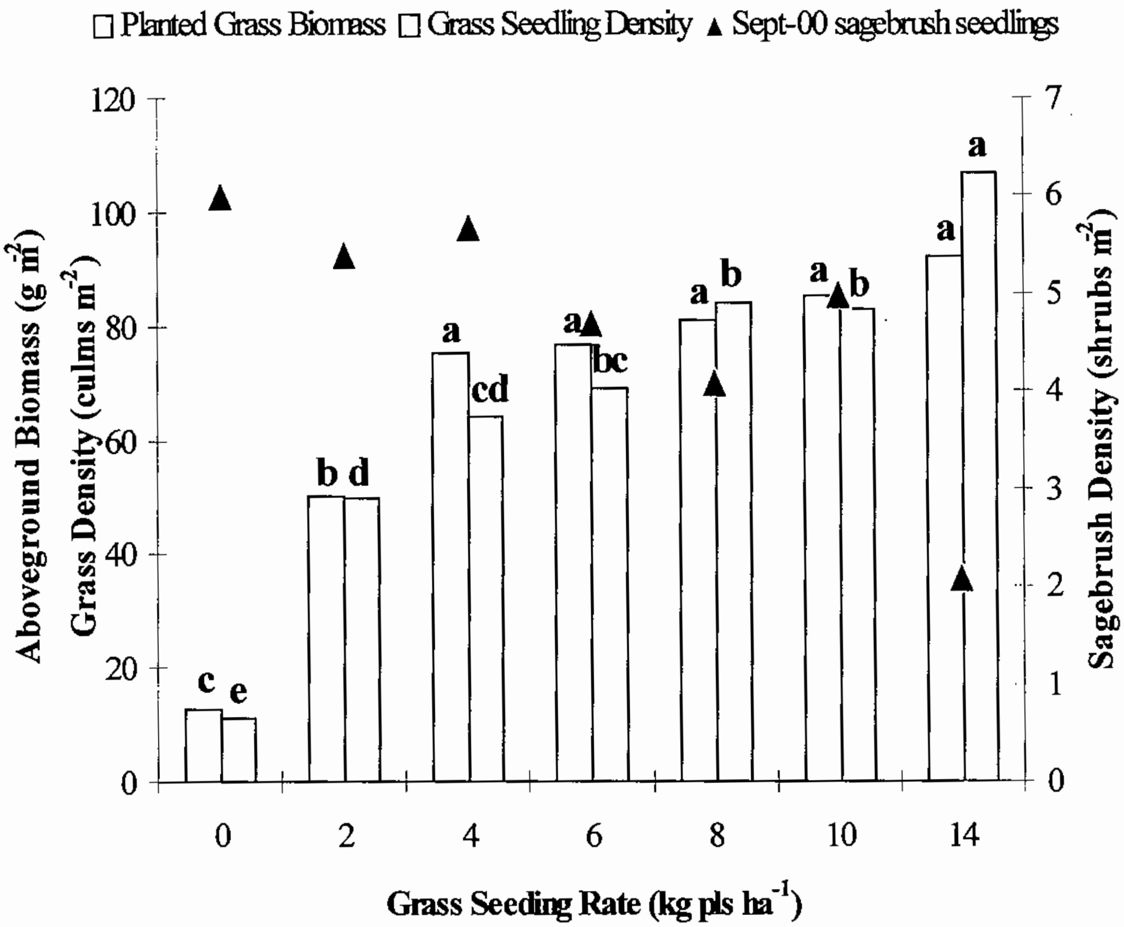

Figure 1. Aboveground planted grass biomass and grass seedling density (columns) with sagebrush density (triangles) across seven grass seeding rates, 2000. Grass seedling density means with the same lowercase letter do not differ ($LSD_{0.05}$=2.89). Grass biomass means with the same lowercase letter do not differ ($LSD_{0.05}$=3.07)(Fortier 2000).

but did show significant increases for the 2 and 4 kg PLS ha^{-1} sagebrush seeding rates. The 2 and 4 kg PLS ha^{-1} sagebrush seeding rates may seem high, but Booth et al. (1999) reported that mined lands reclaimed prior to 1985 exhibited shrub densities directly related to seeding rates up to 1000 seeds m^{-2}. For comparison, a sagebrush seeding rate of 3 kg PLS ha^{-1} results in about 1050 seeds m^{-2}, indicating the 2 and 4 kg PLS ha^{-1} sagebrush seeding rates are not excessive.

Since recent Wyoming big sagebrush establishment research has shown multi-year viability of the seed under field conditions, Schuman (1999) recommended that higher sagebrush seeding rates be used to ensure that viable seed is available when a more "optimum climatic year" occurs. He further states that this increased seed cost would be much less costly than mobilizing a contractor a second time (year) to achieve required shrub establishment. Also, the likelihood of successful sagebrush establishment would be reduced because competition from herbaceous species would likely be greater in the subsequent years. Maier (1999) studied native stands of Wyoming big sagebrush and found stand cohort intervals ranged from 1.88 to 2.71 years. This further supports the theory of enhanced establishment over a period of years from a single seeding if viable seed is available.

Other Establishment Considerations

Much discussion has occurred over the past 2-3 decades as to the role and potential of nursery grown shrub seedlings being transplanted on mined lands to meet the shrub density requirements or using transplant beds as seed sources for natural recruitment to meet these density requirements. Also more recently, the rapid increase in Wyoming big sagebrush seed costs has renewed the interest and/or raised questions as to whether transplantation is a viable option. In the next few paragraphs we will discuss the costs and potential for seedling transplantation to achieve the shrub density standards and compare that to direct seeding costs.

Kleinman and Richmond (2000) stated that transplant stock for Wyoming big sagebrush can be more than \$2.00 seedling^{-1}. Therefore, the cost to achieve 1 seedling m^{-2} on 20% of a hectare would require 2000 seedlings at a cost of \$4000 ha^{-1} of reclaimed land. This would assume 100% survival which would be very optimistic considering the semiarid climate and highly variable precipitation of the region. Miekle (2000) cited estimates of 23 to 90% survival over 5-6 years depending on whether sagebrush plants were fall or spring planted. However, he also states that there are very few actual studies where survival has been monitored. Numerous reclamationists have stated that survival of transplantation stock is very low. Therefore, if only 25% of the transplanted seedlings survive, then the initial cost of planting 8000 seedlings would be \$16000 ha^{-1}. Even if the cost could be reduced by 50 or 75% and survival was 100%, the cost would still be \$2000 and \$1000 ha^{-1}, respectively.

Miekle (2000) proposes the use of "seed production plots" and "facilitation beds" for establishment of Wyoming big sagebrush on mined lands. The "seed production plots" would be developed using transplantation stock and planted in a windbreak fashion (maybe a single row) as a source of viable seed. "Facilitation beds" would be areas between the "seed production plots" that would lend themselves to natural recruitment of sagebrush from the "seed production plots." The facilitation beds would be planted to vegetation that is less aggressive/competitive and more susceptible to invasion by big sagebrush. The main concern with this approach is the fact that natural recruitment of Wyoming big sagebrush has been shown to be very limited and in fact is the premise for the success of managing or controlling big sagebrush with fire or herbicides. Sagebrush fruits are not structurally designed for wind or animal dispersal (West and Durham 1991); therefore, dispersal is limited to a few meters from the parent plant (Young and Evans 1989). In fact, it has been estimated that 85-90% of the seeds fall within 1 m of the parent plant (Wagstaff and Welch 1990; Young and Evans 1989). Lyford (1995) reported that natural recruitment was very limited and only found 0.10 seedlings m^{-2} within 50 m of the native stand of Wyoming big sagebrush when assessing several older mined land reclamation sites in Wyoming. He also concluded that the density of the native sagebrush plants had no effect on recruitment. Johnson and Payne (1968) also suggested that native sagebrush stands adjacent to treated areas was of no importance as a seed source for reinvasion due primarily to competition from grasses within the treated area. Miekle's (2000) proposed "facilitation beds" may help to alleviate some of the competition; however, no data was shown to evaluate this proposed practice. Another concern with natural recruitment from "seed production plots" is that Wyoming big sagebrush seedlings will not produce seed for the first 4 years (West 1988), thereby, limiting the chance of adequate seedling establishment and distribution to meet the shrub density requirement within the 10 year bonding period of reclaimed coal mined lands. The shrub density requirement must be met the last 2 years of the bonding period.

Using data from two recent research studies accomplished in the Powder River Basin of Wyoming the following cost comparisons for direct seeding under several scenarios is offered. We assume that the seed used has 3500 seeds g^{-1} and that the seed is of good quality (example: 85-90% viable and ~25% PLS). To make the following estimates we used Wyoming big sagebrush seedling densities of 4.0 and 7.5 seedlings m^{-2} observed after 2 years when seeded at the rate of 2 and 4 kg PLS ha^{-1} with a grass rate of 8 kg PLS ha^{-1} (Fortier 2000). We assume long-term survival rates of 33 and 59% obtained by Kriger et al. (1987) and Schuman (G.E. Schuman, unpublished data, 2000) and seed costs of \$100, \$200 and \$300 kg^{-1} PLS for sagebrush seed. Seeding costs are not considered in this scenario because it is generally broadcast at the same time the grass mixture is being drilled and grass seeding would also be a cost in the transplantation scenario above. Table 1 shows the estimated cost per seedling and per 2000 surviving seedlings per hectare for two sagebrush seeding rates, the three sagebrush seed costs used and the two survivals. The number of 2000 seedlings ha^{-1} is used to represent the regulatory required density of 1 seedling m^{-2} over 20% of the land area (hectare).

As is fairly evident, the cost of direct seeding, even considering the high seed costs, opportunity for successful establishment, and the long-term seedling survival, is a small fraction of the cost of nursery stock transplantation. If we were to use the best scenario of \$0.50 per transplanted seedling and 100% survival and compare that to the highest direct seeding cost and lowest seedling survival rate; direct seeding would still only cost 9.6% of what transplantation would cost to

Table 1. Estimates of costs per Wyoming big sagebrush seedling and values in ( ) represent the cost per hectare to establish 2000 seedlings.

Sagebrush Seedling Density		Seed Cost kg^{-1} PLS					
		$100		$200		$300	
		Survival Rate					
		33%	59%	33%	59%	33%	59%
sdlgs m^{-2}		Cost $seedling^{-1}$ (cost ha^{-1})					
1.32[a]	2.36	$0.015 ($30)	$0.008 ($17)	$0.030 ($60)	$0.019 ($34)	$0.045 ($90)	$0.025 ($51)
2.48[b]	4.43	$0.016 ($32)	$0.009 ($18)	$0.032 ($64)	$0.018 ($36)	$0.048 ($96)	$0.027 ($54)

[a] These sagebrush seedling densities represent 33 and 59% survival of the densities measured (4.0 seedlings m^{-2}) by Fortier (2000) at the sagebrush seeding rate of 2 kg PLS ha^{-1} and 8 kg PLS ha^{-1} grass seeding rate. [b] These sagebrush seedling densities (seedlings m^{-2}) represent 33 and 59% survival of the density (7.5 seedlings m^{-2}) measured by Fortier (2000) at the sagebrush seeding rate of 4 kg PLS ha^{-1} and 8 kg PLS ha^{-1} grass seeding rate. Cost per hectare values are rounded to the nearest full dollar.

meet the shrub standard. If we were to use the present day estimated costs of transplantation (Kleinman and Richmond 2000) with 100% survival, direct seeding would only cost 2.4% of the cost of transplantation.

The authors realize that seed availability and cost may become a significant consideration in meeting the shrub standard on mined lands in Wyoming where Wyoming big sagebrush is the required species in most situations, but we believe that economics will remain the driving force behind the decisions made by the industry and regulatory personnel in determining the option used in establishing this shrub on mined lands. Seed use efficiency might be much better with nursery grown seedlings, but costs will likely dictate the use of direct seeding and over-ride the seed-use-efficiency concerns/considerations. Demand for native shrub seed will result in improved seed collection and processing and improved cultural practices for orchard production of these species. In fact, local producers have recently begun producing Wyoming big sagebrush under seed orchard conditions (Richard Dunne, personal communication, 1999) to more consistently meet the demand for good quality seed. There may be brief periods of seed shortages but demand will greatly aid in the development of seed production and in direct seeding practices. Even considering the vast differences in cost between direct seeding vs transplantation, there may be small, site specific areas and instances where the use of nursery grown transplantation might be used to meet a very specialized objective. But it is difficult to visualize transplantation being used to meet the shrub standard in general reclamation practices considering the several magnitude difference in costs which will not be easily overcome even with major advances in transplantation technology.

Summary

Much research has been accomplished within the last three decades in attempting to better understand the ecology of Wyoming big sagebrush establishment on mined lands. The interest in this subject was even further raised when the Wyoming Department of Environmental Quality, Land Quality Division established shrub density re-establishment requirements for lands affected after August 6, 1996. This standard requires that a density of 1 shrub m^{-2} be re-established on 20% of the land area affected and that 50% of the density must be composed of the predominant shrub prior to disturbance. Since Wyoming big sagebrush is widely distributed over Wyoming, that means that it will likely be a major component of the pre-mine plant community and therefore must be re-established on 20% of all coal mined lands to meet the shrub standard. In fact, all lands classified as "grazing/wildlife habitat" must have a shrub component on the other 80% of the reclaimed land, but no specific density is required. Much recent research has been done to better understand the seedbed ecology and seed ecology to enhance establishment of this species from direct seedings. This research has resulted in a better understanding of the role of mulches, topsoil quality, competition, arbuscular mycorrhiza, and seed viability and how these factors can be managed to greatly improve seedling establishment through direct seeding. At today's technology and economics direct seeding is more economical than nursery stock transplantation techniques to meet the shrub density standard. The economic comparisons shown indicate that great advances in transplant technology would be necessary to overcome the huge differences in shrub establishment costs between transplantation and direct seeding and these authors believe that research and technology development should be concentrated in the area of direct seeding and enhanced, good quality, seed production.

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