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Converting Crested Wheatgrass Stands to Enhance Big Sagebrush: A Literature Review

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ABSTRACT

Greater sage-grouse (Centrocercus urophasianus) *is a high priority species for federal and state land management agencies. Sage-grouse are sagebrush* (Artemisia spp.) *obligates requiring sagebrush for their survival throughout the year. Sagebrush has been removed and replaced with crested wheatgrass* (*Agropyron cristatum & A. desertorum*) *throughout the West. The objectives of this paper were to review the literature (99 papers), as well as consult experts, to determine which methods are most likely to eliminate crested wheatgrass and establish sagebrush. No technique eliminates crested wheatgrass in a single application. Grazing and fire have no long-term impacts on crested wheatgrass. Mechanical treatments, such as plowing, disking, and cultivating reduce and eradicate crested wheatgrass, but a flush of invasive annual grasses following mechanical disturbance can make establishment of seeded species difficult. It appears that the best way to reduce crested wheatgrass cover and establish sagebrush is to spray crested wheatgrass with glyphosate in early spring for two consecutive years at a rate of 1.1 kg/ha of active ingredient. Then, sagebrush should be seeded in the late fall using a compact row seeder or Brillion cultipacker at a rate of 0.22 kg/ha pure live seed.*

INTRODUCTION

Greater sage-grouse (*Centrocercus urophasianus*) is a high priority species for federal and state land management agencies. In 2005 there were three petitions to list greater sage-grouse as threatened or endangered under the Endangered Species Act of 1973 (U.S. Fish and Wildlife Service 2005). Breeding populations of sage-grouse have declined by 17 to 47 percent throughout much of their range during the last 70 years due to decreases in the quality and quantity of sagebrush habitats (Connelly and others 2000). Sage-grouse are sagebrush (*Artemisia* spp.) obligates requiring sagebrush for their survival throughout the year (Connelly and others 2000). Sagebrush has been removed and replaced with crested wheatgrass (*Agropyron cristatum* (L.) Gaertn. & *A. desertorum* (Fisch. ex Link) J.A. Schultes) throughout the West (Lorenz 1986). Crested wheatgrass stands form monocultures, with low sagebrush cover and understory plant species diversity (Heidinga and Wilson 2002, Henderson and Naeth 2005). The Bureau of Land Management (BLM) in Montana has committed funds to restore crested wheatgrass to sagebrush to provide more suitable sage-grouse habitat (J. Parks personal communication, Sept 2007).

The objectives of this paper are to review the literature, as well as consult experts, to determine which methods are most likely to be successful to eliminate crested wheatgrass and establish sagebrush to improve sage-grouse habitat. Crested wheatgrass elimination techniques reviewed include grazing, burning, chemical and mechanical treatments. Sagebrush establishment techniques reviewed include drilling and broadcasting seed.

METHODS

This study was based on a review of 99 papers. Eighteen papers were government reports, seven were theses, seven were published in symposium proceedings, and the 67 remaining were peer-reviewed, scientific studies. Twenty-five studies dealt with sage-grouse habitat requirements, and the remaining 74 dealt specifically with modifying crested wheatgrass stands or establishing sagebrush. Four of the 74 crested wheatgrass studies were observational, but relied on long-term records to reach their conclusions. Results from the literature presented in this review were included if there was a significant *P*-value (0.05). Differences of opinion between papers were resolved by giving preference to long-term replicated studies with strong experimental designs. All 99 studies were reviewed to reach management recommendations.

In order to ensure that our conclusions and management recommendations were reasonable, we consulted seven experts experienced with crested wheatgrass and sagebrush establishment. Experts were chosen based on experience or volume of published reports. The experts included Mike Pellant, Idaho State BLM Great Basin Initiative Coordinator, Nancy Shaw, United States Forest Service (USFS) Research Botanist, Dr. Bruce Roundy, Brigham Young University Plant and Wildlife Sciences Professor, Dr. Jane Mangold, U.S. Department of Agriculture, Agriculture Research Station Ecologist, Steve Monsen, USFS Botanist (retired), Kyle Wendtland, Antelope Mine Powder River Basin, Wyoming, and Stuart Wengreen, Simplot Grower Solutions Certified Crop Advisor. There were no major discrepancies between the scientific literature and expert opinion. To be included in this review, corroboration by two or more experts was required. I also asked experts for information and advice not included in the scientific literature that would help land managers.

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LITERATURE REVIEW

Sage-Grouse Habitat Requirements

Sage-grouse are a sagebrush obligate species and require large tracts of relatively continuous sagebrush cover (Connelly and others 2000). Sage-grouse require sagebrush throughout the entire year. Sagebrush comprised 62 percent of the year-long diet of adult sage grouse and essentially 100 percent of their winter diet in Montana (Wallestad and others 1975). Sage-grouse require a variety of shrubs in different quantities for wintering, breeding, nesting, and brood-rearing (Connelly and others 2000, Crawford and others 2004).

Sage-grouse are completely dependent on sagebrush communities throughout the winter (Wambolt and others 2002). During the winter, sage-grouse commonly use medium to tall sagebrush communities on south and west facing slopes (Connelly and others 2000), as well as sagebrush habitats with 12 (Woodward 2006) to 20 percent canopy cover in Montana (Wallestad and others 1975). Sage-grouse used areas with 1.2 shrubs/m^2 in central Montana (Woodward 2006). Sage-grouse feed almost exclusively on sagebrush throughout the winter, with big sagebrush (*A. tridentata* Nutt.) dominating their diet (Wallestad and others 1975). Other sagebrush species such as low sagebrush (*A. arbuscula* Nutt.), black sagebrush (*A.nova* A. Nels.), fringed sagebrush (*A. frigida* Willd.), and silver sagebrush (*A. cana* Pursh) are consumed depending on availability (Wambolt and others 2002).

Lekking or breeding habitat is typically located in open areas surrounded by sagebrush, which may include ridgetops, swales, dry lakebeds, burned areas, or plowed fields (Connelly and others 1981, Gates 1985). Sage-grouse males tend to form leks in areas that are within or adjacent to potential nesting habitat (Connelly and others 2000). Sagebrush, herbaceous plant cover, and insects are major components of the lek habitat (Connelly and others 2000).

During the pre-laying period, 50 to 80 percent of the hen's diet is sagebrush (Barnett and Crawford 1994, Crawford and others 2004). Pre-laying hens need a diversity of forbs high in calcium, phosphorus, and protein (Barnett and Crawford 1994). The quality of the pre-laying areas may impact nest initiation rate, clutch size, and future reproductive successes (Barnett and Crawford 1994). During the pre-laying period habitat use centers around low sagebrush and Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis* Rydb.; (Crawford and others 2004).

Sage-grouse require sagebrush stands with 15 to 38 percent sagebrush cover for nesting and almost always nest under sagebrush (Connelly and others 2000, Lane 2005, Sika 2006, Woodward 2006). In Montana 91 percent of sage-grouse nested under sagebrush, with less than two percent nesting under crested wheatgrass (Lane 2005). In another study in Montana, 91 percent were located under sagebrush and six percent were located in either seeded grasslands (includes crested wheatgrass) or alfalfa fields (Sika 2006). Nest success is higher (53 percent) when sage-grouse are able to use sagebrush, compared with non-sagebrush nests (22 percent) (Connelly and others 1991). Sage-grouse nest selection is related to sagebrush height and cover (Crawford and others 2004, Klebenow 1969). Sage-grouse nest sites commonly occur in sagebrush stands with 15 to 38 percent sagebrush cover, 3 to 30 percent herbaceous plant cover and 14 to 34 cm grass heights (Connelly and others 2000). The average height of sagebrush associated with nests was between 29 to 80 cm, with nests commonly under the tallest sagebrush within a stand (Connelly and others 2000, Wallestad and Pyrah 1974). In central Montana, sage-grouse nest habitats had 15 percent shrub cover with an average height of 28 cm and a density of 1.4 shrubs/m^2 (Woodward 2006). Another study in Montana found that nesting habitat had shrub cover of 9 to 12 percent (Moynahan 2004). Sage-grouse depend on grasses and forbs in the understory, which may provide scent, visual, and physical barriers to potential predators (Delong and others 1995).

Brood-rearing areas are commonly in upland sagebrush habitat (Connelly and others 2000). Most are relatively open stands of sagebrush with 14 percent canopy cover and ≥15 percent herbaceous plant cover (Martin 1970, Sveum and others 1998, Wallestad 1971). Most (90 percent) brood sites are located in Wyoming big sagebrush while less than four percent are found in crested wheatgrass (Lane 2005). In central Montana, brood sites had 14 percent shrub cover with an average shrub height of 28 cm and a density of 1.4 shrubs/m^2 (Woodward 2006). Most brood areas are characterized by high plant species richness with abundant forbs and insects (Drut and others 1994a , Dunn and Braun 1986, Klott and Lindzey 1990). Diets of sage-grouse chicks included 34 genera of forbs and 41 families of invertebrates in Oregon (Drut and others 1994b). Forbs and insects comprise the majority of chick diets until they are 12 weeks old, when sagebrush becomes a major component (Klebenow and Gray 1968). As the growing season progresses, more mesic habitats, such as riparian areas, are used as forbs desiccate (Crawford and others 2004, Wallestad 1971).

Crested Wheatgrass History

Between 13 to 17 million ha of crested wheatgrass have been planted in North America (Bakker and Wilson 2004) since it was introduced from Russia in 1897 (Dillman 1946, Lorenz 1986). In the early 1900s, crested wheatgrass, a drought and cold resistant plant, quickly became the most commonly used introduced perennial grass species for revegetation in the northern Great Plains and much of the West (Laycock 1981, Rogler and Lorenz 1983, Sharp 1986). Crested wheatgrass was used to control erosion, increase livestock forage, control weeds, and reduce wildfires (Lorenz 1986, Smoliak and Dormaar 1985 , Young and Evans 1986). The first large scale plantings of crested wheatgrass was prompted by large sheep losses to halogeton *(Halogeton glomeratus* (Bieb.) C.A. Mey.) poisoning (Mathews 1986). Land managers needed a perennial plant that would suppress and crowd out halogeton (Mathews 1986).

Crested wheatgrass has been planted over a large portion of the historic and current range of sage-grouse (Connelly and others 2000, Rogler and Lorenz 1983, Schroeder and others 2004). Crested wheatgrass forms large homogenous stands, lacking the sagebrush and plant species diversity required by sage-grouse (Crawford and others 2004, Heidinga and Wilson 2002). Sagebrush cover is lower in crested wheatgrass stands when compared to native sagebrush grasslands (McAdoo and others 1989). Large crested wheatgrass stands become monocultures and displace native plant species, such as sagebrush, for 40 to 50 years (Hull and Klomp 1966, Looman and Heinrich 1973, Marlette and Anderson 1986). Where sagebrush is completely removed sage-grouse will cease to nest (Klebenow 1969). Dense crested wheatgrass stands reduce feed and structure for sage-grouse adults and chicks (Pellant and Lysne 2005) by excluding native grasses, shrubs, and forbs. Lower plant species diversity in crested wheatgrass result in reduced populations of invertebrates necessary for survival and growth of sage-grouse chicks (DeLuca and Lesica 1996). Increasing sagebrush within crested wheatgrass stands would improve habitat for sage-grouse throughout the year.

Crested Wheatgrass Conversion

Because crested wheatgrass competes for light, nutrients and water, it must be reduced or eliminated to facilitate the establishment of sagebrush (Pellant and Lysne 2005). The greatest obstacle to seedling establishment in any habitat is the vegetation currently established in that habitat (Grubb 1977). Control of herbaceous vegetation is necessary for successful sagebrush establishment, because grasses out compete young shrubs (Kiger and others 1987). Crested wheatgrass is a prolific seed producer and has a large, viable seed bank in the soil, which may affect the success of suppression or eradication strategies (Marlette and Anderson 1986, Pellant and Lysne 2005). We review the use of grazing, fire, mechanical and/or chemical treatments to determine the best method to reduce crested wheatgrass cover sufficient for sagebrush establishment.

Grazing

Crested wheatgrass can withstand heavy grazing for a number of years (Caldwell and others 1981, Cook and others 1958, Hull 1974, Hull and Klomp 1966, Laycock and Conrad 1981). Crested wheatgrass stands in Idaho were heavily grazed for over 20 years, but were still vigorous and showed no signs of deterioration (Hull and Klomp 1966). Heavy use (up to 70 percent) alone has been shown to have little long-term impact on crested wheatgrass stands (Frischknecht and Harris 1968). Crested wheatgrass persisted after 20 years of annual heavy spring grazing (Hubbard 1949), even though grazing occurred when it should be most deleterious (Olson and Richards 1988). Mowing crested wheatgrass in the fall did not reduce the basal area compared to the control the following spring (Lodge 1960). When grazing pressure was removed, stands recovered quickly, doubling yields two seasons after grazing ceased (Hull and Klomp 1966).

Clipping may not have an impact on crested wheatgrass cover, but seed production can be reduced to zero (Cook and others 1958, Hansen and Wilson 2006). Growth may be reduced under cumulative, repetitive defoliation due to reduced root growth and thus reduce its ability to take up nutrients (Hansen and Wilson 2006). Even though seed production was reduced, it has been shown that overall crested wheatgrass cover is unaffected by long-term grazing (Caldwell and others 1981, Frischknecht and Harris 1968, Hull 1974, Hull and Klomp 1966, Laycock and Conrad 1981).

Burning

Burning crested wheatgrass has no long-term impacts on biomass production (Lodge 1960, Romo and others 1994). Fall burning to rejuvenate pastures reduced the yield of crested wheatgrass, but in the following years, production equaled or exceeded controls (Lodge 1960). Spring burning reduced crested wheatgrass production for two years, but returned to control levels after two years. The vegetative cover of crested wheatgrass was unchanged two seasons following spring or fall burns in two separate studies almost 35 years apart in Saskatchewan (Lodge 1960, Romo and others 1994). The cost of prescribed burning varies between approximately $10.00 and $80.00/ha depending on the size of the burn (Gee and Biermacher 2007). Because burning does not reduce crested wheatgrass cover, it is not a useful pretreatment for sagebrush establishment.

Mechanical Treatments

Mechanical treatments are effective in removing or reducing vigor in crested wheatgrass plants (Pellant and Lysne 2005). Common treatments include disking, rototilling, cultivating, and harrowing (Pellant and Lysne 2005).

In Canada, double disking reduced crested wheatgrass basal area 60 percent , but the treatment effect was not permanent (Lodge 1960). Rototilling or disking reduced crested wheatgrass cover by 72 to 87 percent, after which crested wheatgrass cover was 13 to 17 percent (Bakker and others 1997, Wilson and Gerry 1995). Spring plowing effectively eliminated crested wheatgrass for two years (Lorenz and Rogler 1962).

Two tillage treatments were applied for 2 consecutive years to reduce crested wheatgrass prior to planting native plant species in an arid (17.4 cm annual precipitation) portion of Utah (Cox and Anderson 2004). In one treatment, a cultivator completely removed all existing vegetation and mixed the soil to 18 cm. In the second, a harrow was used to uproot some, but not all crested wheatgrass plants . Cultivation reduced crested wheatgrass cover by 84 to 93 percent and harrowing reduced cover by 50 to 67 percent. Essentially no seedlings survived without a disturbance (tilling, harrowing, chemical application). Treatments created openings that persisted long enough to allow seeded native species to establish.

The effectiveness of mechanical treatments varies greatly and problems with increased soil erosion and weed entry may impact their usefulness for establishing native plant species (Pellant and Lysne 2005). The drawbacks associated with mechanical treatments include the increased susceptibility to wind and water erosion , loss of the soil structure, disruption of soil moisture and nutrient cycling, and the increased risk for establishment of undesirable species (Bakker 1996). Facilitation of topsoil erosion is of particular concern when treatments result in complete removal of crested wheatgrass (Lorenz and Rogler 1962). Tillage also damages desirable, native plants that may be present within crested wheatgrass stands.

A flush of invasive annual grasses following mechanical disturbance can make establishment of seeded species difficult (King and others 1989). In the Great Basin, cheatgrass (*Bromus tectorum* L.) invades sites that have been mechanically disturbed making establishment of sagebrush difficult (M. Pellant, personal communication, October 2007). Cheatgrass is an introduced annual grass that dominates 1.3 million ha of public lands in the Great Basin and another 30.8 million ha are classified as either infested or susceptible to cheatgrass invasion (Pellant and Hall 1994). Annual weedy species such as cheatgrass reduce the success of sagebrush establishment (Cook 1974). In Utah, cheatgrass cover was not affected by tilling, harrowing, or herbicide applications (Cox and Anderson 2004). It is crucial to know if invasion by cheatgrass or other invasive weeds is a risk before mechanical treatments are performed.

Prices of various mechanical treatments range from $59/ha to plow, $39/ha to disk and $35/ha to harrow, which are based on custom farming rates (S. Wengreen, personal communication, October 2007). Mechanical treatments are effective in reducing crested wheatgrass cover enough to establish sagebrush, but may not be worth the risk of invasion by weedy annual grasses like cheatgrass.

Chemical Treatments

The use of appropriate herbicides can help control crested wheatgrass and thus improve the opportunity for establishment of seeded species (Whisenant 1999). Application of glyphosate (*N-[phosphonomethyl]glycine*), a generalist herbicide, has been shown to be effective in reducing vigor or causing mortality of crested wheatgrass (Bakker and others 2003, Romo and others 1994, Wilson and Gerry 1995, Wilson and Partel 2003). Glyphosate applications reduce growth of treated crested wheatgrass plants for about eight weeks, providing a period of reduced competition (Gobin 1994). Herbicide application at the correct phenological stage (8 to 15 cm height) is crucial for determining treatment effectiveness. Applications in the early spring when crested wheatgrass is beginning growth and before desired native species initiate growth, appears to be the most effective (Ambrose and Wilson 2003, Bakker and others 1997, Bakker and others 2003, Peat and Bowes 1995, Romo and others 1994). Glyphosate applications should not be relied upon to completely eliminate crested wheatgrass (Cox and Anderson 2004, Romo and others 1994, Wilson and Partel 2003).

Cox and Anderson (2004) found that two herbicide applications reduced crested wheatgrass cover by 2 to 77 percent in Utah. Sagebrush and rabbitbrush (*Ericameria nauseosa* (Pallas ex Pursh) Nesom & Baird) were then seeded into treated plots using three methods (Cox and Anderson 2004). Crested wheatgrass cover was reduced to 4 percent the first year and 14 percent the second year. There was little to no establishment of sagebrush or rabbitbrush when crested wheatgrass cover was above 14 percent. Thus 14 percent provides an approximate threshold for the maximum crested wheatgrass cover allowed for establishment of shrubs in crested wheatgrass stands (Cox and Anderson 2004). Sagebrush and rabbitbrush emergence was 1.5 plants/m^2 in drilled plots and 0.6 plants/m^2 in broadcast and covered plots when glyphosate was applied in early spring for two consecutive years prior to planting (Cox and Anderson 2004). Tilling the seedbed prior to drilling resulted in 2.1 plants/m^2, while harrowing prior to drilling resulted in 1.1 plant/m^2. Although the tillage/drill treatment combination resulted in the highest shrub establishment, even the lower density of 0.6 plants/m^2 would be an acceptable density if these shrubs fully established. Plots were reexamined in the second growing season to assess establishment. Tilled and drilled plots resulted in 3.9 shrubs/m^2 and harrow and drill plots resulted in 1.8 shrubs/m^2 . Herbicide and drilled plots resulted in 2.1 shrubs/m^2 and broadcast and cover plots yielded 0.9 shrubs/m^2. Establishment data is consistent with emergence data, where tilled plots had the highest rates of shrub establishment. The second year of the study had little emergence or establishment of any seeded plant species due to a lack of precipitation. During the first year there was above average precipitation in February and March which facilitated the establishment of seeded species (Cox and Anderson 2004).

Glyphosate applications are useful in reducing the cover of crested wheatgrass, especially after two early spring applications (Bakker and others 1997, Bakker and others 2003, Cox and Anderson 2004, Johnson 2004). A twice repeated spring application of glyphosate in Saskatchewan reduced crested wheatgrass yields by 77 percent (Gobin 1994). Another study in Saskatchewan applied glyphosate in early spring for two consecutive years and mean crested wheatgrass cover was reduced from 5 to 36 percent (Wilson and Gerry 1995). Cover of crested wheatgrass was reduced by 5 to 93 percent canopy cover in chemical treated plots compared to control plots after seven years of herbicide applications (Wilson and Partel 2003). In all of these studies crested wheatgrass cover was reduced below the required threshold of 14 percent for successful sagebrush establishment.

Although glyphosate does not completely eradicate crested wheatgrass, it works well for suppressing crested wheatgrass enough to allow for seeded plant species to have a competitive advantage for establishment. Treatments should be repeated, since crested wheatgrass may recover following treatment (Hansen and Wilson 2006). Applying glyphosate for two consecutive springs appears to reduce crested wheatgrass cover enough to establish sagebrush (Cox and Anderson 2004). Because drought years have a large impact on the establishment, seed may have to be applied a few times if there are years of below average precipitation (Cox and Anderson 2004, Johnson 2004). The price of spraying herbicide at a rate of 1.1 kg/ha of active ingredient (Bakker and others 1997, Bakker and others 2003, Hansen and Wilson 2006, Wilson and Partel 2003) is approximately $34/ha (S. Wengreen, personal communication, October 2007). Herbicide applications do not cause the large scale soil disturbances that mechanical treatments do, making them a better option for avoiding weed invasion (M. Pellant, personal communication, October 2007).

Sagebrush Establishment

Sagebrush can be seeded once crested wheatgrass cover has been reduced to below 14 percent (Cox and Anderson 2004). Desired plant species, such as sagebrush or other native plants, must be planted as seeds or as bare root stock. Successful sagebrush seedings should result in a shrub density of at least 1.2 to 1.4 shrubs/m^2. This is an average based on the areas occupied by sage-grouse during nesting, brood-rearing, and wintering in central Montana (Woodward 2006). Typically, long term survival rates of seeded sagebrush are less than 60 percent (Schuman and Belden 2002 , Kiger and others 1987), so it may not be possible to fully evaluate seeding success until 8 or more years after initial seeding (Schuman and others 2005).

Seedbed Ecology and Preparation

Precipitation can negatively or positively influence species composition, productivity, survival, and establishment (Bleak and others 1965, Lauenroth and others 1994, Sala and others 1988, Weaver 1950) . Climatic conditions strongly influence establishment even with proper site preparation and seeding methods (Call and Roundy 1991, Cox and Anderson 2004, Johnson 2004). Establishment of shrubs such as sagebrush can be difficult. Many failures are due to inadequate soil moisture at the time of germination and during the initial growth period (Holmgren 1956). Drought is the main cause of sagebrush seedling mortality (Meyer 1992). Late fall or early winter are the best times to plant sagebrush, as this is when sagebrush seed disperses naturally and soil surfaces are likely to be moist (Shaw and others 2005). Seedings have been most successful when done in the late fall or early winter just prior to snowfall (Lambert 2005, Monsen 2000, Stevens and Monsen 2004). Sagebrush seeding in the spring is not recommended (Meyer 1992). Sagebrush seed requires 20 to 30 days of moisture to germinate; surface moisture within the top 0.2 to 0.5 cm of soil is critical (S.B. Monsen, personal communication, October 2007).

Exploiting weather conditions can help improve sagebrush seeding success (S.B Monsen, personal communication, October 2007; M. Pellant, personal communication, October 2007; K. Wendtland, personal communication, October 2007). In the Powder River Basin of Wyoming, seeding sagebrush prior to storms in the late fall provides the best opportunity for establishment (K. Wendtland, personal communication, October 2007). The amount and timing of winter snowfall has a large impact on sagebrush seedling emergence. A single late-winter snowfall made the difference between zero percent emergence at one site and 80 percent emergence at a similar site in Wyoming (Monsen and Meyer 1990). Emergence is rarely achieved unless winter snow is present (Meyer 1992).

Big sagebrush should be planted on a firm seedbed with only a light covering of soil. Rough seedbeds may bury the seed too deeply (Shaw and others 2005). Providing a very firm seedbed is crucial for sagebrush establishment, so it may be necessary to use a cultipacker or some machinery to pack down the soil (K. Wendtland, personal communication, October 2007). It is crucial that seed not be buried too deeply (Monsen 2000, Lambert 2005). Site preparation or planting methods that create a loose, sloughing seedbed should be avoided (Meyer 1992).

Sagebrush Seeding Rates

Suggested seeding rates for basin big sagebrush (*A. tridentata* Nutt. ssp. *tridentata)*, Wyoming big sagebrush and mountain big sagebrush (*A. tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle) vary depending on the type of project. Mine reclamations use a larger amount of seed when compared to large-scale rangeland projects.

Sagebrush seeding rates for mine reclamation projects range from 1 to 4 kg/ha pure live seed (PLS) (Hild and others 2006, Schuman and Belden 2002, Schuman and others 1998, Schuman and others 2005, Vickland and others 2004). Large-scale rangeland projects typically use a much lower seeding rates, ranging from 0.05 to 0.56 kg/ha PLS (Dalzell 2004, Lambert 2005, Meyer 1992, Monsen 2000, Shaw and others 2005). A typical seeding rate when drilling sagebrush ranges from 0.05 to 0.22 kg/ha PLS (Lambert 2005, Meyer 1992, Monsen 2000, Shaw and others 2005). Broadcast seeding normally requires 33 to 50 percent more seed to be used compared to drilling, with seeding rates ranging from 0.22 to 0.56 kg/ha PLS (Dalzell 2004, Meyer 1992, Monsen 2000, Stevens and Monsen 2004). We recommend a seeding rate of 0.22 kg/ha PLS when drilling, and a rate of 0.33 kg/ha PLS when broadcast seeding.

The current market price of sagebrush seed may dictate the amount of seed used. Sagebrush seed ranges from $70 to $300/kg PLS depending on the current market price and availability (Schuman and others 2005). Current market prices (2007) for big sagebrush subspecies seed range from $101 to 168/kg PLS (K. Wengreen, personal communication, October 2007). A midrange price of $135 /kg PLS will be used for economic analysis in this paper.

Drilling

The rangeland drill or other single disk drills can be used to plant sagebrush seeds. Drilling commonly requires 33 to 50 percent less seed than broadcast seeding (Stevens and Monsen 2004). Big sagebrush may be seeded through drills if seed is dropped on or near the soil surface then covered lightly by press wheels or by pulling a cultivator behind the drill (Lambert 2005, Shaw and others 2005). The seed drill should be set to place the sagebrush seed 0.2 cm into the soil (Lambert 2005), placing seeds deeper than 0.6 cm reduces emergence (Monsen 2000).

In Nevada, sagebrush was seeded using a traditional rangeland drill to a depth of 0.6 to 1.3 cm and only 1.2 seedlings/m^2 established, while leaving the seed on the soil surface resulted in 99 to 101 seedling/m^2 (Monsen and Meyer 1990). In Utah, sagebrush and rabbitbrush were seeded using a Truax rangeland drill and John Deere Flex Drill set to a depth of 1 cm and 1.4 to 3.9 seedling/m^2 established and were present the following year (Cox and Anderson 2004). Drill seeding sagebrush and rabbitbrush in crested wheatgrass following cultivation resulted in 50 percent more emergence (2.1 seedlings/m^2) than broadcast seeding only and broadcast seeding followed by covering (Cox and Anderson 2004).

Many devices have been used to compact the soil surface, resulting in increased sagebrush seedling establishment. These devices are not necessarily drills, but utilize a tractor to go over the soil surface, which is why they have been included in this section. The Oyer compact row seeder compacts the soil then presses the seed into the soil surface (Lysne 2005). In Nevada, use of the Oyer compact row seeder resulted in very high initial sagebrush seedling density (646 seedlings/m^2) and 1-year survival (101 seedlings/m^2; Monsen and Meyer 1990). A second implement, the Brillion cultipacker seeder broadcasts the seed over the soil surface then presses it into the soil (Lysne 2005). In Nevada, use of the Brillion cultipacker resulted in emergence of 352 sagebrush seedlings/m^2 and 1-year survival of 99 seedling/m^2 (Monsen and Meyer 1990). A Truax Rough Rider drill with brillion wheels was recommended by 3 experts that have experience with establishing sagebrush within crested wheatgrass stands (J. Mangold, personal communication, October 2007; M.Pellant, personal communication, October 2007; N. Shaw, personal communication, October 2007). According to preliminary results, the Truax Rough Rider drill with brillion wheels resulted in sagebrush establishment of 1.3 seedlings/m^2 (N. Shaw, personal communication, October 2007).

The cost of drilling seed is highly dependent on the amount of sagebrush seed used and can range between $25 to 40/ha (M. Pellant, personal communication, October 2007). Using a drill at a rate of $33/ha, and a heavy seeding rate of 0.22 kg/ha PLS would be approximately $63/ha. Drilling sagebrush seed has resulted in sagebrush establishment densities to meet the average found in areas occupied by sage-grouse in central Montana (Woodward 2006).

Broadcast Seeding

Conventional tilling and seeding methods may be impractical on some rangelands due to rocky or steep terrain. These sites require land managers to utilize broadcast seeding. Large areas can be seeded with sagebrush quickly using aircraft (Monsen 2000). Aerial broadcasting is often easier than drilling seed, since topography is not a limiting factor (Monsen 2000). Broadcast seeding helps to keep seeds near the soil surface, which is important for planting sagebrush (Shaw and others 2005).

In Idaho, big sagebrush failed to establish on 23 of 25 fire rehabilitation projects when aerially seeding was used without seedbed preparation (Dalzell 2004). In Utah, broadcast seeding followed by covering the seed resulted in 46 percent more sagebrush and rabbitbrush seedlings than broadcast seeding alone (Cox and Anderson 2004). Coverage of broadcast seed using chains, harrows, rails, or other implements is recommended to ensure that seed comes into contact with soil surface (Stevens and Monsen 2004). Light anchor chaining increased seedling density at Dry Creek Drainage, Idaho from approximately 0.6 shrubs/m^2 on unchained sites to 6.4 shrubs/m^2 on chained sites with similar south and west aspects (Monsen 2000). Chaining increased seedling establishment and produced more uniform stands. On a mine reclamation project in

Wyoming, sagebrush seed was broadcast seeded using a precision broadcast seeder with cracked corn to accomplish uniform seed distribution and flow through the seeder. Seeding rates between 1 to 4 kg/ha PLS were used and had sagebrush establishment densities of 1.0 to 4.5 shrubs/m^2 after 6 years (Williams and others 2002).

The price of broadcasting sagebrush seed is highly dependent on the amount of sagebrush seed used. The cost of broadcasting depends on the method used. Aerial broadcasting costs $12 to 19/ha, while broadcasting on the ground costs $25 to 40/ha to apply (M. Pellant, personal communication, October 2007). Using an aerial application at a rate of $16/ha and a heavy seeding rate of 0.33 kg/ha PLS would cost approximately $61/ha.

Interseeding and Transplanting

Interseeders and transplanters are another category of mechincal equipment that may be used to remove competition in narrow bands while planting shrubs in a one-pass operation (Giunta and others 1975, Stevens 1992, Stevens and others 1981). Two methods for removing vegetation prior to interseeding or transplanting include scalping or herbicide (Stevens 1992). Scalping is done using modified disks or a plow pulled behind a tractor; it must be wide and deep enough to remove or kill all seeds or rhizomes of existing vegetation (Stevens 1992). Existing vegetation can also be killed in strips or spots with herbicide. Sprayed areas can then be seeded by drill or broadcast seeding (Stevens 1992). Scalping or herbicide gives seeded plants a chance to become established before competing vegetation reinvades (Stevens 1992). The width of the scalp or herbicide spray area depends on the density, vigor, and growth form of the major species in the existing vegetation, the species to be interseeded and site conditions (Stevens 1992). Results from interseeding and transplanting are variable depending on local conditions, use of proper techniques, and plant materials used (Stevens 2004).

Interseeding techniques can be used to plant seedlings mechanically in areas that have been scalped or sprayed with herbicide. Scalped areas should be at least 61 cm wide when planting shrubs (Giunta and others 1975). One study suggested that scalp width should be at least 100 cm wide, an optimum width of 150 cm (Van Epps and McKell 1978).

Sagebrush seedlings (12 to 20 cm tall) have been planted in early spring using field-grown bare root stock or greenhouse-grown containerized plants (Lambert 2005). Springtime is optimal for transplanting because soil moisture is high, temperatures are low, and chance of rainfall is high (Stevens 2004). Transplanting bare root stock may be superior to container-grown stock (Stevens and others 1981). First year survival rates are commonly 80 percent or higher (Lysne 2005), although losses following the first year can range from 46 to 69 percent (Stevens and others 1981). It is recommended that sagebrush seedlings be randomly placed in clumps or blocks on the best sites within the restoration area. Typically, only small critical areas are planted because of the high cost of using planting stock (Lysne 2005). These sites will become fertile islands of big sagebrush as they mature, and provide a seed source for natural regeneration (Lambert 2005). However, natural regeneration would take many years since sagebrush seeds are very small (0.018 g/100 seeds to 0.025 g/100 seeds depending on variety) and maximum dispersal distances are in the range of 30 m, but 85 to 90 percent fall within 1 m of the canopy (Young and Evans 1989).

The cost of bare root stock or greenhouse-grown containerized plants of Wyoming big sagebrush can be greater than $2/seedling, therefore to achieve the 1 shrub/m^2 density would require a minimum of 2,000 seedlings at a cost of $4,000/ha (Schuman and others 2005). Large-scale plantings would not be cost-effective across all rangelands, making this a viable option only for small restoration projects.

CONCLUSIONS

Crested wheatgrass forms large homogenous stands lacking the sagebrush and plant species diversity required by sage-grouse (Crawford and others 2004, Heidinga and Wilson 2002). The purpose of this paper was to determine the best methods to suppress crested wheatgrass in order to establish sagebrush to enhance these areas for sage-grouse based on the current scientific literature. Crested wheatgrass cover must be reduced for sagebrush to be seeded and successfully established, thus improving areas for sage-grouse habitat. The presence of sagebrush is the best predictor for sage-grouse use. No technique has proven to eliminate crested wheatgrass in a single application. Repeated treatments or combinations of treatments may be necessary to reduce crested wheatgrass biomass and increase the establishment of seeded species.

Sagebrush establishment is most successful when using a drill with a seeding rate of at least 0.22 kg/ha PLS (Lambert 2005, Monsen and Meyer 1990, Meyer 1992, Monsen 2000, Shaw and others 2005). According to S. Monsen (personal communication 2007), the method of seeding sagebrush is not a crucial factor, however, it is critical that sagebrush seed is not buried too deeply. This means that you can probably drill or broadcast seed sagebrush, although higher establishment rates have been achieved using drills with light soil covering.

Achieving a shrub density of 1 shrub/m^2 would be acceptable, however 1.2 to 1.4 shrubs/m^2 would provide better habitat for sage-grouse (Woodward 2006). It may not be possible to evaluate seeding success until at least eight years after initial seeding (Schuman and others 2005).

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