EQUIPMENT AND STRATEGIES TO ENHANCE THE POST-WILDFIRE ESTABLISHMENT AND PERSISTENCE OF GREAT BASIN NATIVE PLANTS

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PROJECT SUMMARY

Annual grass invasion in the Great Basin has increased fire size, frequency and severity. Post-fire restoration to provide functional native plant communities is critical to improve resistance to weed invasion. Our ability to successfully re-establish mixtures of native grasses, forbs and shrubs, however, is limited. We examined the effects of the standard rangeland drill and a minimum-till drill, seeding strategies for small-seeded species, and Wyoming big sagebrush (*Artemisia tridentata* Nutt. spp. *wyomingensis* Beetle & Young) seeding rates on seeding success in burned shrub communities at four sites in the northern Great Basin. Seeded and recovering vegetation, as well as soil physical and chemical characteristics, were monitored for two growing seasons following treatment. In addition, provision was made for long-term evaluation of grazed and non-grazed seedings to assess community dynamics in relation to management practices. Results underscore the impact of precipitation and recovering residual species on seeded species emergence and establishment. Emergence of drill seeded species was generally enhanced when seeded through the rangeland drill compared to the minimum-till drill, but this effect was lost by the second year. Wyoming big sagebrush emergence was erratic, but tended to be greater when seeded through the minimum-till drill at moderate or high rates (approximately 250 and 500 pure live seed m^{-2}) compared to the low rate (50 pure live seed m^{-2}). Cheatgrass and other exotics were reduced and basal gap lengths decreased where native seedings established or residual natives recovered, but both increased where seedings failed due to low precipitation. Considerable soil erosion occurred in burned areas, as indicated by dust production, soil stability, and soil microrelief. Fire substantially increased dust flux rates due to decreased soil stability; however, neither drill affected these processes. Amounts of soil movement via dust flux rates and changes in soil microrelief varied throughout seasons but were not affected by drilling. While wildfire altered some soil micronutrients, drilling and seeding rates did not alter chemical responses to fire. Further work is needed to link plant and soil responses, which may help to explain plant establishment after fire and seeding treatments. Vegetation data from this research will be archived in the USGS Land Treatment Digital Library to inform future management and rehabilitation programs.

BACKGROUND AND PURPOSE

The cycle of wildfire and annual weed invasion has altered millions of acres of western shrublands and grasslands, disrupted ecosystem functioning, and increased the size, intensity and frequency of wildfires. These events have extended the fire season, reduced plant and animal diversity, and set the stage for invasion by secondary perennial weeds. These impacts are endangering native species and ecosystems, increasing risks to human life and property, and escalating public and private costs associated with wildfires. Post-fire rehabilitation provides a window of opportunity to stabilize and revegetate shrublands and grasslands where wildfire has substantially reduced exotic annual grass seed.

The wildfires of 1999 that burned more than 1.7 million acres in the Great Basin and shortages of seed supplies for subsequent rehabilitation led to an interagency agreement to improve supplies of native plant materials (USDI and USDA 2002). The current shift in policy from seeding exotic grass monocultures to planting mixtures of native species offers promise for improving ecosystem diversity, structure, and function (USDI and USDA 2002). However, our ability to establish mixtures of grasses, forbs and shrubs is limited. Government Accounting Office reviews of the U.S. Department of the Interior, Bureau of Land Management's (BLM) Emergency Stabilization and Rehabilitation (ES&R) programs in 2003 and 2006 stated that seeding success for native species was variable and long term persistence of native seedings is largely unknown (GAO 2003, 2006).

Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young), a landscape dominating shrub in the Intermountain West, is particularly vulnerable to human disturbances, susceptible to invasion by exotic annuals, and experiencing increasing fire frequency and intensity (Suring et al. 2005). In the Great Basin, Wyoming big sagebrush communities occupy 17.9 percent of the total area and about 63 percent of all sagebrush cover types (Comer et al. 2002). These cover types comprised thirty percent of the area burned in the Great Basin from 1994-2001 (Comer 2002, Suring et al. 2005). Rehabilitation of Wyoming big sagebrush communities is difficult due to the low and erratic rainfall and the presence or potential for exotic annual or perennial weed invasion following disturbance. Recent feedback from BLM field offices and research results indicate a need for development of 1) strategies for improving the success of Wyoming big sagebrush seedings, 2) cost-effective methods for establishing native communities, and 3) knowledge of factors affecting the long-term persistence of diverse seedings in response to management scenarios and climate variation (e.g. climate change, extended droughts).

The rangeland drill is durable, but best suited for seeding large-seeded exotic and native grass seeds, which must be drilled into the soil (Young and McKenzie 1982). It does not, however, create a seedbed appropriate for sagebrush or other small-seeded species that require surface seeding and good seed-to-soil contact. The rangeland drill is also not designed to plant mixtures of species with seeds that differ greatly in size and shape and which have differing seedbed requirements for germination and seedling emergence and establishment. In addition, its tilling action disrupts soil structure, biological soil crusts, and residual perennial natives surviving following wildfire or other disturbances. Tilling may result in altered nutrient cycling and contribute to the loss of soil carbon through wind and water erosion.

An alternative to the standard rangeland drill is the minimum-till rangeland drill. This drill is designed to reduce soil disturbance and provide more flexibility for planting different species combinations in separate rows. Objectives in developing this drill were to 1) provide hydraulic control of planting units, 2) increase control of seeding depth, 3) improve seed-to-soil contact with the addition of press wheels, and 4) enhance seed slot opening and closure. Press wheels can be replaced with impacter units for rows where small-seeded species are broadcast onto the soil surface to better firm these seeds into the soil.

Seeding rate recommendations for Wyoming big sagebrush vary widely because establishment is highly episodic in response to local climatic conditions. Seeding the small seeds with a rangeland drill causes the seeds to be planted too deep. As an alternative to seeding Wyoming big sagebrush through the rangeland drill, seed is often aerially broadcast in fall or in winter over snow. However, aerial broadcasting is often unsuccessful in drier Wyoming big sagebrush communities, where snowfall and snowpack can be variable (Dalzell 2004, Meyer and Monsen 1992). Seeding requirements for other small-seeded Great Basin natives, including many native forbs now seeing increased use in restoration, have not been determined. Seed of forbs, in particular, is in short supply and often expensive, thus seeding recommendations are urgently needed.

Exotic annuals, such as cheatgrass (*Bromus tectorum* L.), halogeton (*Halogeton glomeratus* [M. Bieb) C. A. Meyer) and Russian thistle (*Salsola tragus* L.), often gain dominance following wildfire. Entry of exotics into semi-desert shrublands can reduce the establishment of seeded native species and diminish habitat quality and forage availability for wildlife and domestic livestock. Halogeton alters soil chemistry by increasing pH, exchangeable sodium, electrical conductivity, and surface salt content (Duda et al. 2003), but its influence on soil microbiology is largely undocumented. It does not form mycorrhizal associations even when inoculum is present in the soil. Russian thistle density is reduced in the presence of mycorrhizal fungi (Allen and Allen 1988), but grasses can be increased in association with Russian thistle (Allen and Allen 1988). Little is known about the impact of drill type, seeding strategies and native seed mixes on the resistance of the seeded communities to exotic invasions. Similarly, the impacts of seeding practices on soil chemical and physical properties and native plant establishment and survival have not been examined. In light of these obstacles and unknowns, exotic grass monocultures are frequently employed in post-fire seedings.

Evaluation of seedings requires modification of standard ecological monitoring techniques. The proposed ES&R monitoring protocols (Herrick et al. 2005; Wirth and Pyke 2007) were adapted to evaluate emergence and establishment of seeded species, recovery of residual natives, and the presence of exotics. Monitoring is normally conducted during the first two growing seasons post-seeding to evaluate emergence and establishment. However, monitoring over longer time periods is required to investigate population dynamics, development of community structure, and the impacts of post-seeding management strategies.

This study addresses the biological and physical impacts of native seeding strategies following wildfire in four northern Great Basin big sagebrush communities (Figure 1). Specific objectives were to:

Figure 1. Location of post-fire seedings in the northern Great Basin.

1. Compare the abilities of the standard rangeland drill modified by the addition of triple seed boxes and an experimental minimum-till drill to plant native seeds of diverse sizes and shapes at differing rates, minimize surface disturbance and conserve soil structure and residual native species.
2. Identify seeding methodologies for improving establishment of Wyoming big sagebrush and other small-seeded species.
3. Evaluate post-treatment establishment and productivity of invasive plant species in response to rehabilitation treatments, seeded vegetation or seeding failure. Mycorrhizal fungi presence in association with exotic annual and native and seeded grasses is being examined in 2011-2012.
4. Evaluate changes in dust emissions and soil physical and chemical characteristics resulting from wildfires, seeding treatments, and recovering or seeded vegetation.
5. Apply and evaluate ES&R protocols developed by the U.S. Geological Survey to make quantitative vegetation measurements for comparing treatment effects.
6. Establish studies that permit long-term evaluation of livestock use on native ES&R seedings. Such future evaluations will occur beyond the time frame of this study.

STUDY LOCATIONS AND METHODS

Fall seedings were installed at four locations in the northern Great Basin following summer wildfires in Wyoming big sagebrush communities in 2007 (Mountain Home and Glass Butte), 2008 (Scooby), and 2010 (Saylor Creek). Site descriptions are provided in Appendices 1 and 2. Thirteen treatments tested combinations of drill type, seeding dates and techniques, and Wyoming big sagebrush seeding rates (Table 1). These treatments addressed methods for applying two seed mixes, one consisting of larger grass and forb seeds, which required soil coverage (drill mix), and a second mix containing small-seeded grass, forb and shrub seeds, which required surface seeding and firming into the soil surface (broadcast mix).

Drills utilized were the standard rangeland drill (P & F Services) and the minimum-till drill (RoughRider, Truax Co., Inc.) (Figure 2). Each drill seeded 10 rows spaced 30.5 cm apart per drill pass. The rangeland drill was modified to broadcast small seeds by raising the disk for the selected rows and pulling the seed tube from the disk assembly to allow seeds to drop onto the soil surface. Seeds were then covered by chains drug behind the drops. This technique was used at Glass Butte and Mountain Home. At Scooby and Saylor Creek, the drill was modified by replacing the standard drop tubes with 7.6-cm diameter aluminum pipes to improve seed flow. The minimum-till drill utilized fully hydraulic disk assemblies to plant larger seeds in a narrow furrow. Broadcast seeds passed through disk-less seed tubes and fell onto undisturbed soil, where patterned impacter wheels pressed them into the soil surface. The precise furrow openers and impacter wheels created a minimal amount of soil disturbance as compared to the standard rangeland drill.

Both drills were calibrated by USDA Natural Resources Conservation Service Aberdeen Plant Materials Center (Aberdeen PMC) personnel. Drills were configured to drill and broadcast seed in alternating rows.

Table 1. Seeding treatments applied post-fire in big sagebrush communities at four Great Basin locations. Treatments (30-m x 70-m plots) were applied in a randomized complete block design with five blocks at each location.

Treatment	Drill	Drill mix[1]	Broadcast mix[2]	Wyoming big sagebrush seeding rate[2]
C	Control (no drill, no seed)			
R0	Rangeland drill	No seed		
R1X		Drilled in alternate rows in fall	Broadcast through drill in alternate rows in fall	1X
R5X				5X
R10X				10X
R+fBC5X			Hand broadcast in fall	5X
R+wBC5X			Hand broadcast in winter	5X
M0	Minimum-till drill	No seed		
M1X		Drilled in alternate rows in fall	Broadcast through drill in alternate rows in fall	1X
M5X				5X
M10X				10X
M+fBC5X			Hand broadcast in fall	5X
M+wBC5X			Hand broadcast in winter	5X

[1]One drill mix was used for all seeding treatments.

[2]The broadcast mix varies among treatments only by the Wyoming big sagebrush seeding rate.

The composition of the seed mixes (Appendix 3) was adjusted to match site conditions to the extent possible, given the short window between burning and seeding. Seeding rates were based on standard BLM recommendations for post-fire rangeland seedings. Broadcast seeding mixes included Wyoming big sagebrush seed at three rates denoted by 1X, 5X and 10X (see Table 1 and Appendix 3). Forb seeding rates were sometimes limited by seed availability. Seed was mixed by Aberdeen PMC personnel. Rice hulls were added to both the drill and broadcast mixes following methods described by St. John et al. (2005) to maintain seeds of different weights in the mix, prevent bridging of light and fluffy seed, and to simplify drill calibration when planting complex seed mixes.

We included three late fall treatments with no seed: an undrilled control (no drill and no seed), rangeland drill with no seed, and minimum-till drill with no seed. The latter two treatments simulated failed seedings and permitted evaluation of the impact of each drill on the biological, physical, and chemical characteristics of the plot. Three additional treatments for each drill were installed by planting the drill and broadcast mixes through alternate seed drops in late fall. These treatments varied only by the amount of Wyoming big sagebrush seed (1X, 5X, or 10X) in the broadcast mix (see Appendix 3 for actual rates at each location). The final two treatments for each drill involved planting the drill mix through alternate seed drops in late fall. The broadcast mix with Wyoming big sagebrush at the 5X seeding rate was then applied by hand over the entire plot immediately after drill seeding or in winter. These two treatments simulated aerial seeding.

At each location the 13 treatments were applied to 30-m x 70-m plots arranged in a randomized complete block design with five blocks for a total of 65 plots (four blocks with 52 plots at Scooby). At Saylor Creek an additional minimum-till drill treatment (M+D) was added to determine whether water catchment for drill seeded rows could be improved by removing the depth bands. Perimeter fences were installed around the 65 plots to exclude livestock but not large ungulates.

Figure 2. Rangeland drill (left) with aluminum drop tubes for delivery of broadcast seeds and minimum-till drill (right) with impacter units that firm broadcast seeds onto the soil surface. Lower photos illustrate soil disturbance created by each drill.

An additional five randomized blocks of three treatments each (C, R5X and M5X) was established in 70-m x 90-m plots at each site, except at Scooby where four blocks were installed. These plots were not fenced, thus providing for long-term evaluation of livestock use on the persistence and population dynamics of grazed and nongrazed native seedings. Five unburned plots, each 30-m x 70-m were installed at Scooby and Saylor Creek.

Vegetation was monitored for two growing seasons at each site. Second year monitoring for the Saylor Creek location will be completed in 2012. Protocols for collecting vegetation data were modified from Herrick et al. (2005) and Wirth and Pyke (2007). Five 20-m transects were established perpendicular to the long axis of each plot. Density of seeded species and presence of all non-seeded species were recorded for each of four 0.5-m x 1-m quadrats along each transect. Cheatgrass density was recorded in 20-cm x 20-cm subplots in each quadrat. Cover (foliar, basal and intermediate layers by species) was recorded using the line-point-intercept method at 20 points along each transect. Length of gaps greater than 20 cm between the bases of perennial species occurring along each transect were recorded. Gap data was summarized as the total length of gaps in each plot that fell into the categories of 20-50 cm, 51-100 cm, 101-200 cm, or >200 cm. Each gap category was then expressed as the proportion of the total transect length (100 m) it occupied in each plot.

Treatment effects on the biomass of exotic, native residual, and seeded species were examined at the Scooby site in 2010 and 2011. Vegetation in two 0.25-m x 1.0-m quadrats placed at random locations along the second and fourth transects in each plot (a total of four quadrats per plot) was clipped and sorted by 1) individual seeded forb species, 2) all native grasses bagged together (seeded or residual), 3) individual invasive exotics (cheatgrass, halogeton, and Russian thistle), and 4) all other nonseeded native or exotic forbs bagged together. Quadrats were placed 2 m from the transect lines to preclude interference with other measurements. Plant samples were oven dried (60^{o}C for 48 hrs) and their biomass was recorded. In June and July 2011, soil samples for mycorrhizal analysis were collected beneath grasses in drill-seeded rows and under halogeton and cheatgrass in five treatments (C, R0, R5X, M0, M5X). Soil and mycorrhizal analysis of these samples will be completed in winter 2011-2012.

Baseline soil chemistry and texture at Scooby and Saylor Creek was determined before treatments were applied by taking thirty 12.5-cm cores to form a composite for each experimental plot. Additionally, several soil physical and chemical properties were measured throughout the experiment. Microrelief, compaction, and infiltration were measured in the control (C0), rangeland drill with no seed (R0), and miminum-till drill with no seed (M0) plots. Chemistry, stability, wind erosion and moisture were measured on the same plots plus the R5x and M5X treatments. Soil measurements were also measured in the unburned plots. Soil properties were sampled as follows:

1. *Surface compaction* was measured separately for drill and broadcast rows and for interspaces between rows with a pocket penetrometer. Surface compaction was also measured under the canopy of sagebrush and in the interspace in the unburned plots.
2. In control plots we measured *microrelief* in undisturbed areas. In minimum-till drill plots, micro-relief was measured in the drill furrow and adjacent broadcast row. In rangeland drill plots the microrelief meter was centered over the furrow to span both broadcast and furrow areas to capture all variation in surface relief. Microrelief was only measured in the interspaces in the unburned plots.
3. We examined *chemical properties*, including organic matter, nitrogen, potassium, phosphorus, magnesium, calcium, pH, cation exchange capacity, and sodium adsorption ratio (SAR) from samples taken before treatments were applied. Resin capsules were placed in the furrow and broadcast areas to monitor soil nutrient availability throughout the experiment. Resin capsules were also placed under the canopy of sagebrush and in the interspace in the unburned plots.
4. We analyzed *texture* using a hydrometer. Thirty samples per plot were taken from the top 12.5 cm before drilling and bulked to form a composite.
5. *Soil stability* was assessed using soil stability test kits as described in Herrick et al. (2009). Stability measurements were done in broadcast and furrow areas in burned plots and in the interspace and under sagebrush canopy in the unburned plots.
6. We quantified soil loss through *wind erosion* using BSNE (Big Springs Number Eight) dust traps located in the center of each plot.
7. *Soil moisture* was monitored at a depth of 5-10 cm with Decagon EC5 probes. Probes were placed in broadcast and furrow areas, as well as under sagebrush canopies and in the interspace of unburned plots.
8. *Water infiltration* into the soil was measured in broadcast and furrow areas in burned plots and in the interspace and under sagebrush canopy in unburned plots using a Decagon mini-disk infiltrometer with 2 cm of suction.

RESULTS

Precipitation (Figure 3)

- With the exception of May 2008 and June 2009, both Mountain Home and Glass Butte received low precipitation during the first two years following seeding.
- Scooby and Saylor Creek each experienced a wet spring in the year following seeding; neither site was exposed to extended dry periods following seeding.
- With the exception of Saylor Creek, the seeding locations each developed a snow cover in winter. Saylor Creek was open and exposed to wind erosion through most of the 2010-2011 winter. As a result, the winter hand broadcast seeding treatment was applied over open soil at Saylor Creek and over snow at the other three locations.

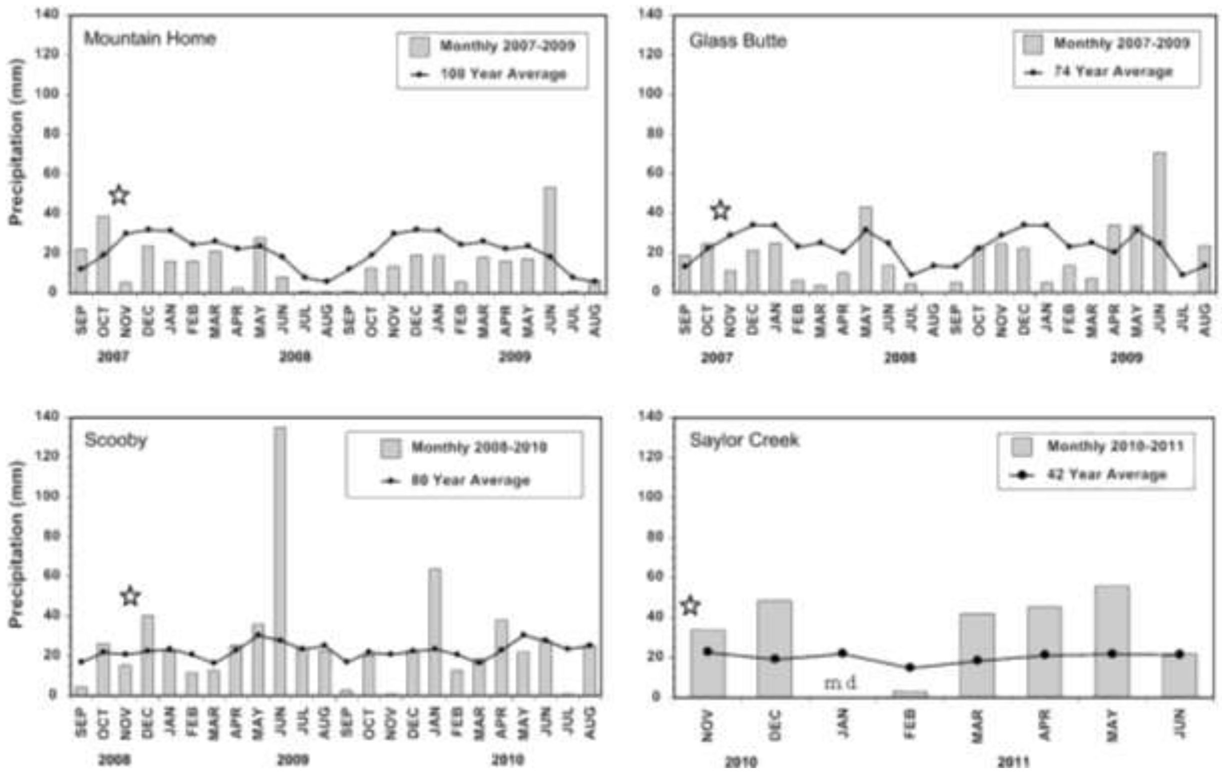

Figure 3. Monthly and long-term precipitation for northern Great Basin post-fire seedings (WRCC 2011). ☆ = planting date, m.d. = missing data.

Response to Seeding Treatments at Northern Great Basin Locations

Cheatgrass density

- In 2008 cheatgrass density at Mountain Home varied among treatments and was nearly three times greater in the undrilled control (C0) and M0 treatments than in the rangeland drill treatments with the exception of the R0 and R+wBC5X treatments (Figure 4). These two treatments and all seeded minimum-till treatments were intermediate and did not differ from the others. Cheatgrass density was not determined in 2009 as the species dominated the site, making counts difficult. Aerial cover of cheatgrass increased significantly from 2008 (18.2±0.8%) to 2009 (49.6±1.3%), but there were no differences among treatments.
- At Glass Butte, neither cheatgrass density nor aerial cover differed among treatments. Cheatgrass density increased from 0.6±0.1 plants m^{-2} in 2008 to 15.1±1.65 plants m^{-2} in 2009, while its aerial cover increased from 2.5±0.4% in 2008 to 8.6±0.8% in 2009.
- Cheatgrass density at Scooby increased from 26.1+7.5 plants m^{-2} in 2009 to 178.5+32.8 plants m^{-2} in 2010 with no differences among treatments. There was an interaction between treatments and years for aerial cover of cheatgrass (Figure 5). In 2009 aerial cover was greater on the undrilled control than on any other treatment except the unseeded minimum-till treatment which was intermediate and did not differ from any other treatment. In 2010 aerial cover of cheatgrass was more than twice as great on the undrilled control and unseeded minimum-till drill treatments as on any of the remaining treatments. Aerial cover was greater on the unseeded rangeland drill treatment than on the M1X and M+fBC5X treatments. Aerial cover was similar on all seeded treatments in both years and remained below 10%.

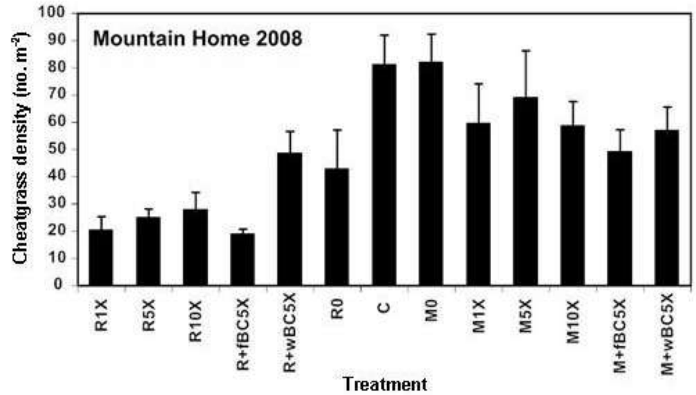

Figure 4. Treatment means and standard errors for cheatgrass density at the Mountain Home post-fire seeding in 2008. Cheatgrass density varied among treatments ($P < 0.05$). See table 1 for treatment descriptions.

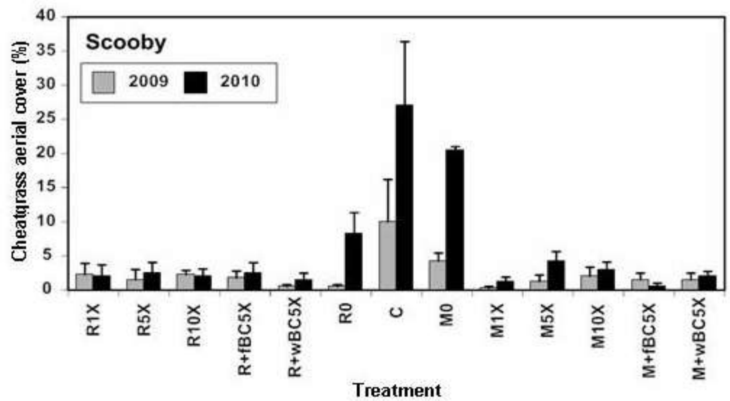

Figure 5. Interaction means (treatment:year, $P < 0.05$) and standard errors for aerial cover of cheatgrass at the Scooby post-fire seeding by treatment in 2009 and 2010. See table 1 for treatment descriptions.

- Vegetation at Saylor Creek was poorly developed at the time of sampling in 2011 due to the cool spring. Cheatgrass density (2.8 $\pm$ 0.2 plants m^{-2}) and aerial cover (3.2$\pm$0.3%) did not vary among treatments.

Emergence and establishment of seeded species

- Drill seeded grasses dominated the seeded vegetation at all sites.
- The total density of seeded species decreased by about 74% between 2008 and 2009 at Mountain Home (14.0$\pm$0.5 to 3.6$\pm$0.3 plants m^{-2}) with no difference among treatments (Figure 6). There was an interaction between treatments and years for broadcast shrubs, which were dominated by Wyoming big sagebrush. Broadcast shrub density was greater in the M10X treatment than in all other treatments in 2008. In addition, broadcast shrub density in the M5X treatment exceeded density in the M+wBC5X, R+wBC5X and R1X treatments. Density on all other treatments in 2008 and all treatments in 2009 was similar with less than 0.1 shrubs m^{-2}.
- At Glass Butte the total density of seeded species declined by more than 50% between 2008 and 2009 (15.6$\pm$1.0 to 7.1$\pm$0.3 plants m^{-2}) (Figure 6). There was an interaction between year and treatment in

density of drill seeded grasses. Density of emerging drilled grasses was greater for the M5X and M10X treatments than the R+fBC5X and the M+fBC5X and M+wBC5X treatments in 2008. By 2009, density of drill seeded grasses had declined and was similar on all treatments. The density of drill seeded forbs declined 2008 and 2009 while the density of broadcast seeded grasses increased. Few broadcast forbs were noted in either year. The density of broadcast shrubs, primarily Wyoming big sagebrush, declined from 2008 to 2009 and also varied among treatments. Density was greater for the R+fBC5X treatment than for the M1X or either hand broadcast minimum-till drill treatment with the remaining treatments intermediate and similar to the others.

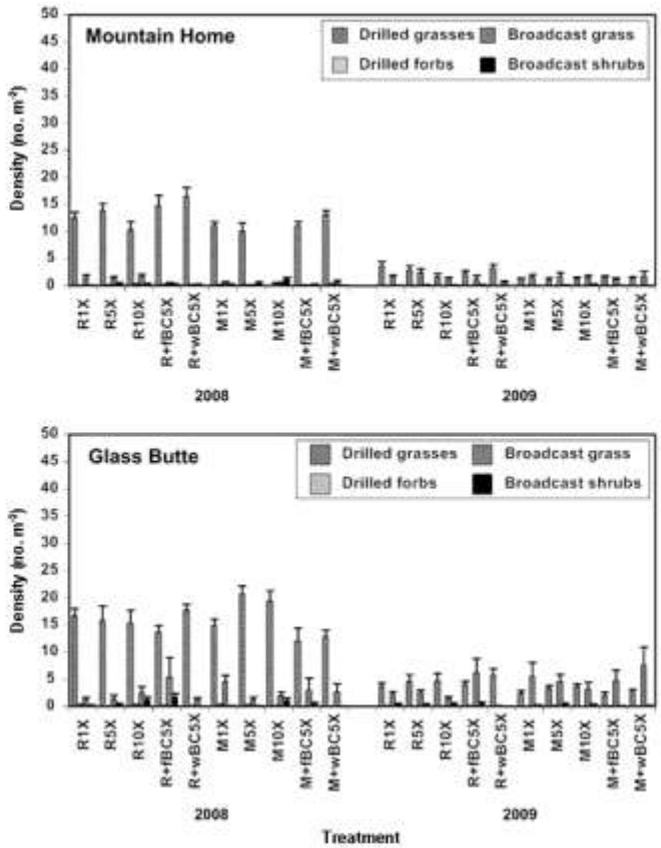

Figure 6. Means and standard errors for density of seeded species at Mountain Home (above) and Glass Butte (below) post-fire seedings by seeded treatment in 2008 and 2009. Significant differences ($P < 0.05$) occurred at Mountain Home for drilled grasses (year and treatment), drilled forbs and broadcast grasses (year), and broadcast shrubs (year:treatment). At Glass Butte significant differences ($P < 0.05$) occurred for drilled grasses (year:treatment), drilled forbs and broadcast grasses (year) and broadcast shrubs (year and treatment). See table 1 for treatment descriptions

- Total density of drilled grasses at Scooby was similar across treatments and years with the exception that density on three of the rangeland drill treatments (R1X, R+fBC5X, R+wBC5X) exceeded density on the remaining treatments in 2009, but not in 2010. The density of drilled forb species did not vary with treatments or year, while the density of broadcast forbs increased from 2009 to 2010. Density of broadcast grass was greater on the M5X plot than on the rangeland drill treatments with the exception of the R5X treatment with no difference between years. Density of broadcast shrubs, primarily big sagebrush, did not differ between years and was greatest on the M10X treatment.

- The total density of all seeded species (18.1$\pm$3.8 plants m^{-2}) as well as density of drilled grasses and forbs was generally similar across treatments at Saylor Creek. An exception was the greater density of drilled grasses in the R5X treatment than in the M1X or M+wBC5X treatments. Broadcast grass density was lower in the two winter broadcast treatments (R+wBC5X and M+wBC5X) than in the M5X or M10 treatments, while broadcast forb density was lower in the R+wBC5X than in the M5X treatment. Broadcast shrub (big sagebrush and rubber rabbitbrush) establishment for the M10X treatment was greater than the remaining treatments, with the exception of the M5X and M+D treatments.

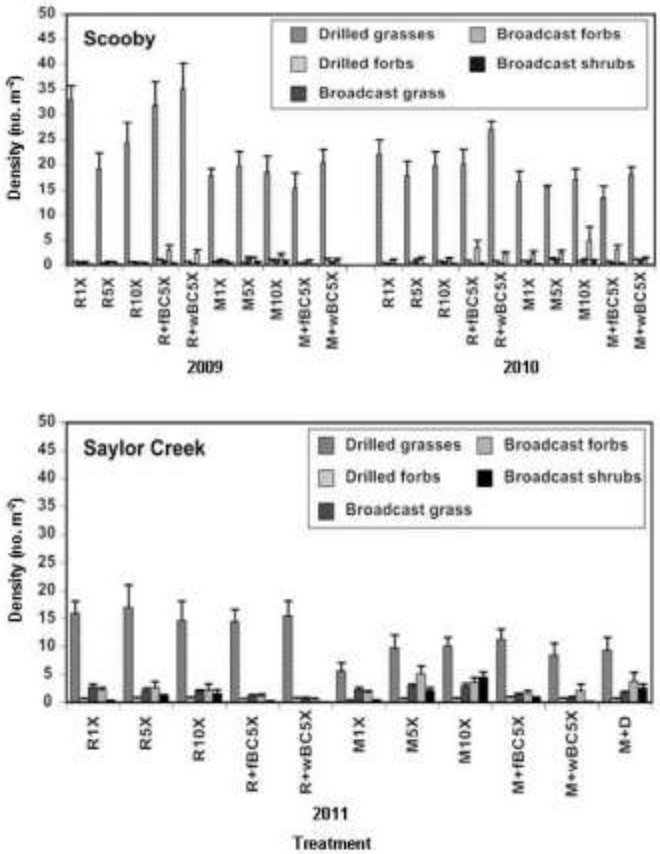

Figure 7. Means and standard errors for density of seeded species at Scooby in 2009 and 2010 (above) and Saylor Creek in 2011 (below) post-fire seedings by seeded treatment and year. Significant differences ($P < 0.05$) occurred at Scooby for drilled grasses (year:treatment), broadcast forbs (year), and broadcast grasses and shrubs (treatment). At Saylor Creek significant treatment differences ($P < 0.05$) occurred for drilled grasses and broadcast grasses, forbs and shrubs. See table 1 for treatment descriptions

Development of aerial cover

- Aerial cover at Mt. Home was dominated by exotics, primarily cheatgrass and annual mustards (Figure 8). An interaction between treatments and years indicated that with the exception of the R1X and R5X treatments, aerial cover of exotics did not differ between 2008 and 2009. The R1X and R5X produced less exotic cover than the other treatments in 2008, but similar cover in 2009. From 2008 to 2009 aerial cover provided by seeded species increased from 2.9+0.4% to 3.4+0.5% and total aerial cover increased from 60.4$\pm$1.6% to 68.8+1.2%. Aerial cover provided by residual natives was less than 0.5% in both years.

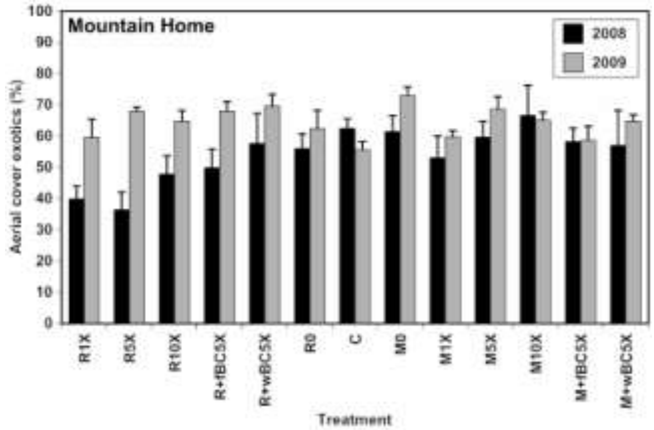

Figure 8. Interaction means (year:treatment, P < 0.05) and standard errors for aerial cover of exotics at the Mountain Home post-fire seeding by treatment in 2008 and 2009. See table 1 for description of treatments.

- Aerial cover at Glass Butte increased from 33.3±1.4% in 2008 to 59.1±1.1% in 2009 and was dominated by recovering residual natives, which increased from 22.0±1.0% to 32.8±0.8%. Significant increases in seeded species (7.0±0.6% to 13.8±0.8%) and exotics (3.0±0.4% to 13.1±0.9%) occurred over the same time period. None of the cover categories varied with treatment.
- Aerial cover of seeded species was similar among treatments at Scooby in 2009 (Figure 9), but increased by 4.6 times by 2010 in all seeded treatments, while aerial cover remained unchanged in the three unseeded controls. Aerial cover of residual natives declined from 2009 to 2010. Residual cover was native greater in the M0 treatment than in the R1X, R5X or M1X treatments with the remaining treatments intermediate and similar. Aerial cover of exotic species was similar across years and treatments with the exception that aerial cover of exotics on the three unseeded controls increased by 6.9 times from 2009 to 2010. Total vegetative aerial cover did not vary among treatments, but was twice as great in 2010 as in 2009.

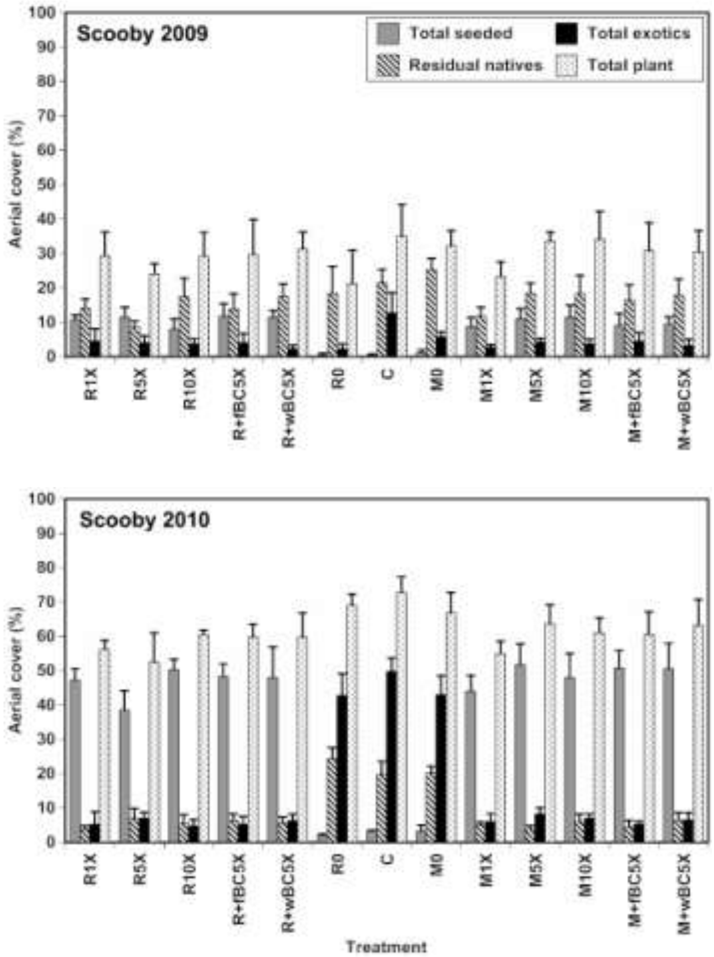

Figure 9. Means and standard errors for aerial cover of seeded species, exotics, residual natives (annual and perennial plants), and total aerial cover at the Scooby post-fire seeding by treatment in 2009 and 2010. Significant differences ($P < 0.05$) occurred for aerial cover of seeded species and exotics (year x treatment), residual natives (year and treatment), and total vegetative aerial cover (year). See table 1 for treatment descriptions.

- Plant growth was minimal at the time of sampling at Saylor Creek in 2011 due to the cool spring. Aerial cover provided by seeded species (4.2±0.4%), residual native species (2.2±0.3%), exotic species (3.4±0.4%) and total aerial cover (9.6± 0.7%) did not vary among treatments.

Distribution of basal gaps

- With initial establishment of seeded perennials in 2008 at the Mountain Home seeding, all basal gap categories were well represented (Figure 10). By 2009, seeded perennials had declined and the proportion of the total transect length represented by the three smaller basal gap categories decreased by factors of 6.1 to 9.7 times with no differences among treatments. There was a treatment by year interaction for the >2 m basal gap category. In 2008, the proportion of >200 cm basal gaps was greater for the R1X and R5X treatments than for the M0 treatment with the remaining treatments intermediate and not differing from the other treatments. By 2009 the proportion of >2 m basal gaps had increased for all treatments and did not vary with treatment.

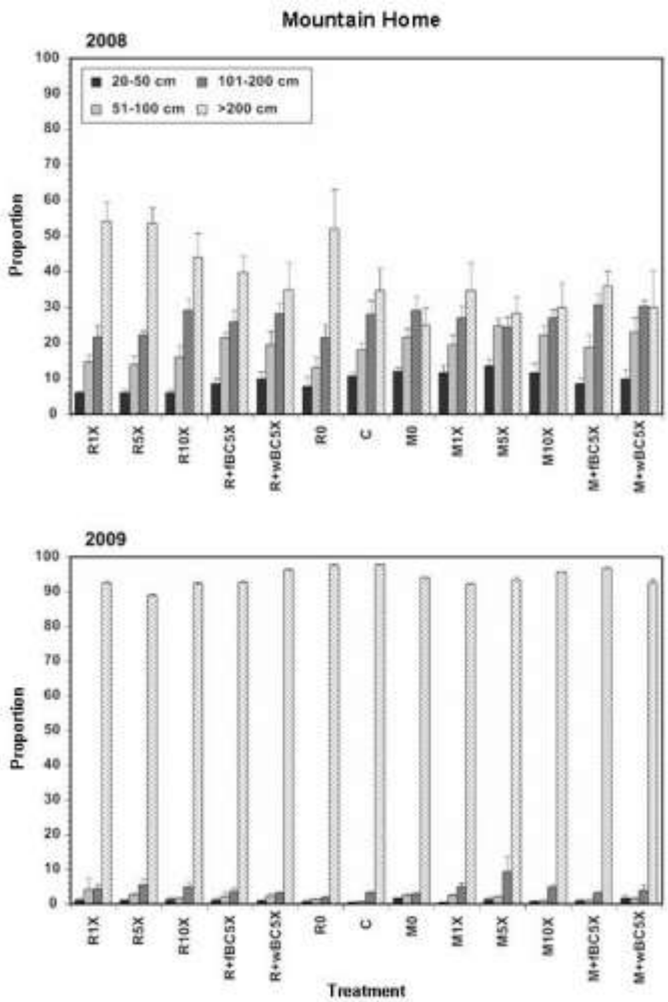

Figure 10. Means and standard errors for the proportion of the total transect length in each plot (100 m) occupied by each basal gap category (distance between bases of perennial plants intersecting the transect) at the Mountain Home post-fire seeding. Significant differences (P < 0.05) occurred for the 20-50 cm, 51-100 cm , and 101-200 cm basal gap categories (year) and the >200 cm gap category (year: treatment). See table 1 for treatment descriptions.

- With rapid recovery of native perennials, large basal gaps were infrequent at Glass Butte in 2008 and 2009. There were no differences among treatments for any gap category. The proportion of 20-50 cm and 101-200 cm basal gaps decreased from 2008 to 2009 while the proportion of 51-100 cm and >200 cm basal gaps remained unchanged.
- Development of the drill seeded rows reduced basal gaps at Scooby where the > 200 cm basal gap category dominated all treatments in 2009 but declined in all seeded treatments by 2010 (Figure 11). The three smaller basal gap categories were similar among seeded treatments each year and generally increased in 2010; they were nearly absent in the unseeded controls both years.

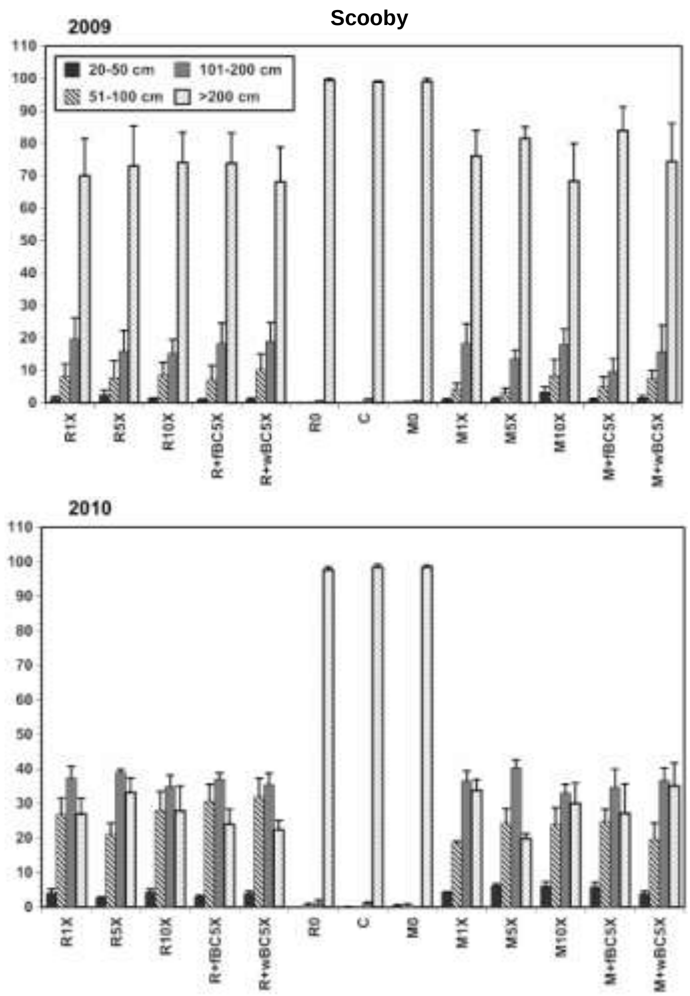

Figure 11. Means and standard errors for the proportion of the total transect length in each plot (100 m) occupied by each basal gap category (distance between bases of perennial plants intersecting the transect) at the Scooby post-fire seeding. Significant differences ($P < 0.05$) occurred for the 20-50 cm, 51-100, 101-200 basal gap categories (year) and the >200 cm gap category (year:treatment). See table 1 for treatment descriptions.

- At Saylor Creek, the proportions represented by individual basal gap categories in 2011 did not vary among treatments. The > 2 m basal gaps constituted more than 85% of the total basal gap length.

Richness of native residual species

- The number of residual native species (annuals and perennials) exhibited little variation among treatments at any site.
- At Mountain Home there were more residual natives in the R1X treatment (5.9$\pm$0.4) than in the M1X treatment (3.1$\pm$0.5), with all others intermediate and not differing from the other treatments. Richness did not differ between years.
- Residual native species (12.5$\pm$0.2) did not vary among treatments or years at Glass Butte.
- At Scooby residual natives increased from 7.0+0.3 species in 2009 to 11.3+4 species in 2010.
- The number of residual native species (8.0$\pm$0.2) did not vary among treatments at Saylor Creek in the first year following seeding.

Productivity of exotic invasives, native residuals and seeded species

- Total plant biomass was comparable among treatments in 2010, ranging from 247.5 g m^{-2} in the R10X treatment to 121.9 g m^{-2} in the controls.
- Total production of exotic invasives (halogeton, cheatgrass, and Russian thistle) was greatest in the three unseeded controls and was at least five times as great as in the seeded treatments (Figures 12, 13). This difference resulted primarily from reductions in Russian thistle and cheatgrass biomass in the seeded treatments; halogeton biomass did not differ among treatments. Russian thistle production in the R0 treatment was greater than in the undrilled control and all seeded treatments in 2010. The M0 treatment was intermediate and similar to both. These differences were lots in 2011.
- Native grass production (seeded and residual native grasses together) was greater in seeded treatments than in the unseeded controls except for the R5X, R+fBC5X and M5X treatments, which were intermediate and did not differ from other treatments (Figure13).

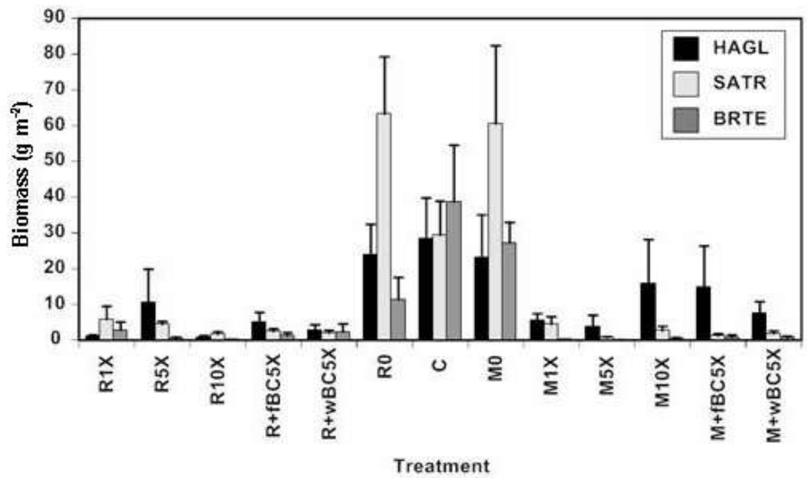

Figure 12. Exotic species biomass at the Scooby fire in the second year following seeding (2010) under 13 treatments. Bars are standard errors of means within each species. Biomass differs among treatments within Russian thistle (SATR, $P < 0.0001$) and cheatgrass (BRTE, $P < 0.0001$). Halogeton did not differ among treatments (HAGL, $P = 0.0865$).

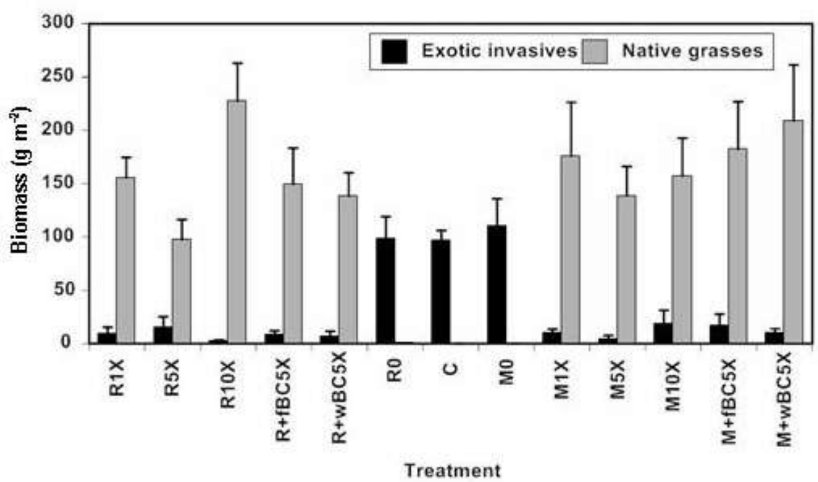

Figure 13. Native grasses (seeded and residual) and exotic invasives (Russian thistle, halogeton and cheatgrass) biomass at the Scooby fire in the second year following seeding (2010) under 13 treatments. Exotics and native grasses differed among treatments ($P < 0.0001$ in both cases).

- Seeded forbs were absent from the controls, and their biomass did not differ among seeded treatments (Figure14).
- Residual forbs (native and exotic, excluding halogeton and Russian thistle) consisted primarily of annual mustards and were more than twice as productive in the unseeded drilled controls as in the seeded treatments. Residual forb biomass in the non-drilled control was intermediate and did not differ from the other treatments.
- Because total biomass production did not differ among treatments, production of seeded species and native grasses combined appear to have reduced the productivity of total exotics and residual native and exotic forbs.

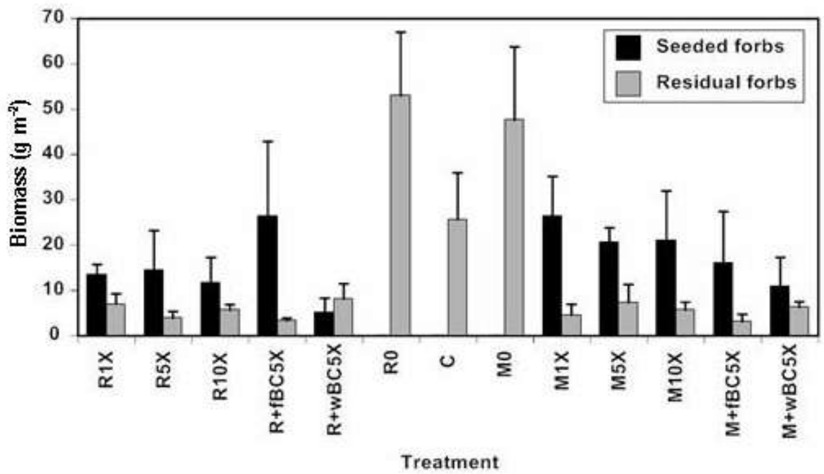

Figure 14. Biomass of seeded and residual annual and exotic forbs (excluding Russian thistle and halogeton) at the Scooby fire in the second year following seeding (2010) under 13 treatments. Residual forbs differed among treatments, $P < 0.0001$.

Soil chemical and physical properties

Soil texture and baseline chemistry are reported in Appendix 2.

- *Resin bag* data at the Scooby seeding revealed several differences in soil nutrient availability (Table 2; Figure 15). Potassium was the only nutrient that varied by microsite where K levels were significantly higher under the canopy of sagebrush than in the shrub interspace. Many nutrients varied by season, including Cu, Fe, K, Na, P and Zn. Furthermore, Cu, Na and P differed among treatments and by season. Seasonal changes in Cu availability showed Cu increased from spring-summer to summer-fall and then decreased in fall-spring in burned plots, while there was no significant difference among seasons in unburned plots. Na followed the same pattern in the drilled plots; however, Na decreased in summer-fall only in undrilled control plots. Phosphorus levels showed somewhat of an opposite trend; during the summer-fall season P decreased and then rebounded in the drilled and control plots during the fall-spring season. Phosphorus increased in the unburned plots during the summer-fall season and then decreased over winter.

Table 2. Soil nutrient levels measured in three seasons (spring-summer 2009, summer-fall 2009, fall 2009 – spring 2010) across drill and seeding treatments. Nutrient levels were determined using Dowex® Marathon® MR-3 hydrogen and hydroxide form ion exchange resin beads.

Nutrient	Treatment		Season		Season X Treatment	
	DF = 5		DF = 2		DF = 10	
	F value	P value	F value	P value	F value	P value
Ca	1.37	0.2417	0.09	0.9163	0.73	0.6914
Cu	2.53	**0.0329***	4	**0.021***	0.76	0.0667
Fe	0.91	0.4785	4.71	**0.0109***	0.64	0.7794
K	1.3	0.267	9.21	**0.0002***	1.23	0.28
Mg	1.2	0.3131	1.01	0.3688	0.91	0.5263
Mn	0.84	0.5259	2.9	0.0593	0.96	0.4796
Na	10.07	**<0.0001***	7.65	**0.0008***	2.37	**0.0137***
P	1.5	0.1939	9.99	**0.0001***	4.77	**<0.0001***
S	2.12	0.0676	1.02	0.3649	1.2	0.2978
Zn	3.86	**0.0029***	22.25	**<0.0001***	0.98	0.4664
	Significance p<0.05		*Bold are significant			

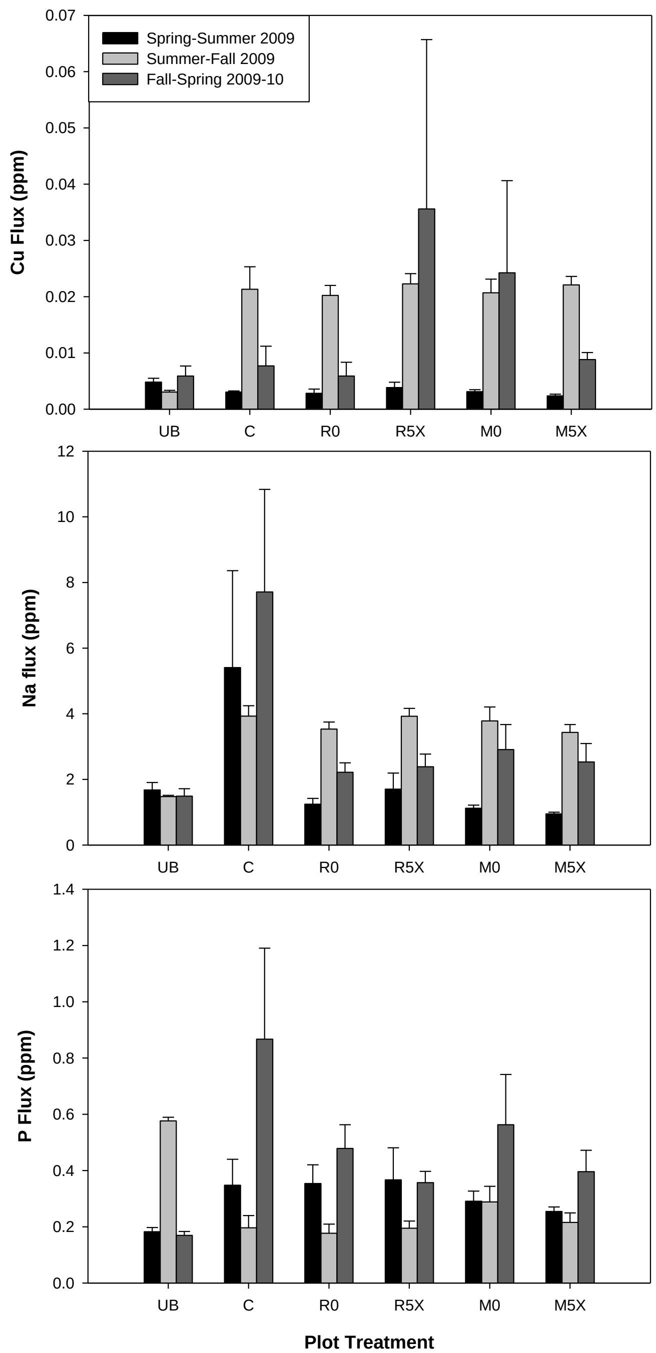

Figure 15. Nutrient availability from resin bags for copper, sodium, and phosphorus, which varied by treatment and season (mean ± SEM).

- *Surface compaction* was measured in the fall of 2008 and the spring of 2009. In fall of 2008, compaction was higher in rangeland furrows, rangeland tire tracks, and minimum-till tire tracks compared to undrilled controls, minimum-till broadcast and furrows, as well as unburned interspaces and sagebrush canopies (data not shown). In spring of 2009, compaction was significantly greater overall in burned plots with greatest compaction remaining in the tire tracks of both drills.
- *Microrelief* (variation in soil surface relief) was significantly greater in rangeland plots compared to unburned, control and minimum-till plots (Figure 16). Microrelief gradually decreased from the time

of drilling (November 2008) until March 2010; however, microrelief increased when measured in July 2010. This suggests that the furrows may be gradually filled in over time, but that a wind (or water) event can destabilize the soil thus increasing microrelief again.

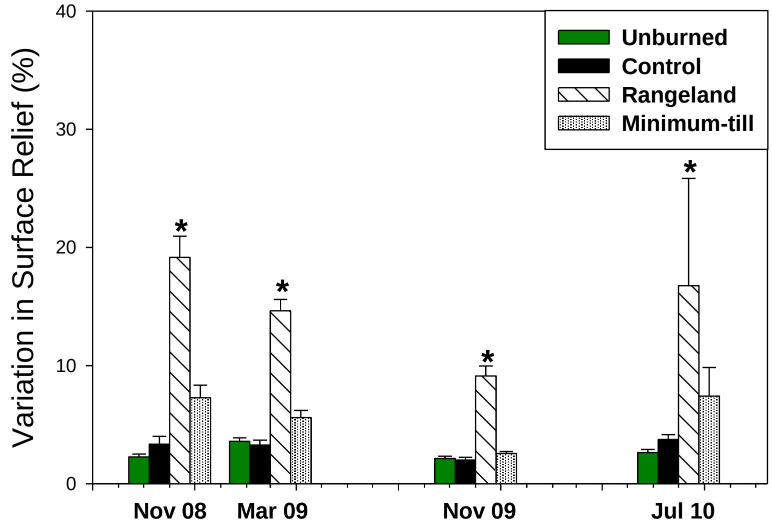

Figure 16. Variation in soil surface relief (± SEM) in unburned and burned plots and in rangeland and minimum-till drill plots. Significant differences among treatments within season are indicated with an asterisk when $P < 0.05$.

- *Soil stability* was reduced by over 50% in burned plots compared to unburned plots (Figure 17). Soil stability was significantly greater in the interspace than under the sagebrush canopy in unburned plots. In burned plots, stability was significantly greater in the broadcast than furrow areas during the first year, but differences between broadcast and furrow areas were lost in the second year. Soil stability responses were not significantly different between drill types or seeding rates.

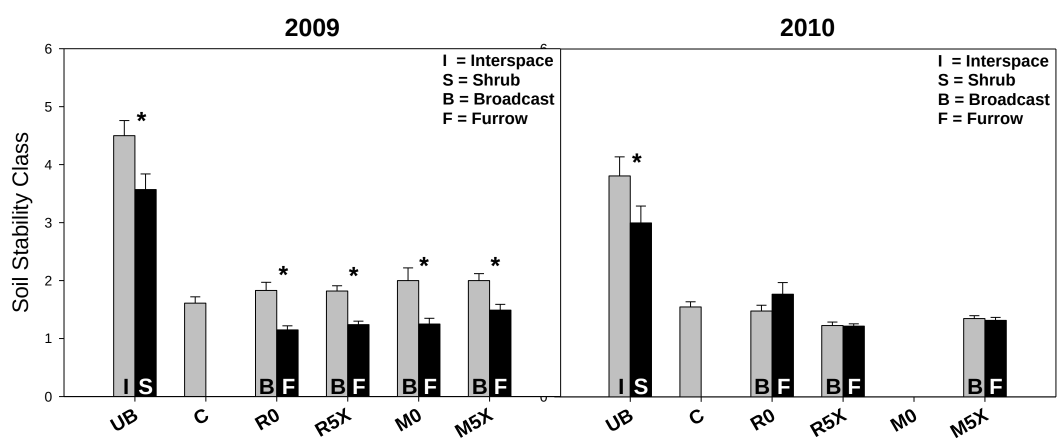

Figure 17. Soil stability (± SEM) in unburned and burned plots and in rangeland and minimum-till drill plots with different seeding rates. 1 = lowest stability; 6 = highest stability. Significant differences between locations within a treatment are indicated with an asterisk when $P < 0.05$.

- *Soil loss* through wind erosion was 10-600 times higher in burned plots versus unburned plots; however, drilling had no significant affect on dust flux rates and there was no significant difference between the two drill types (Figure 18). Dust flux rates peaked during the sample period of March –

July 2009. Dust flux rates substantially decreased during the following year until measurements ceased in July 2010.

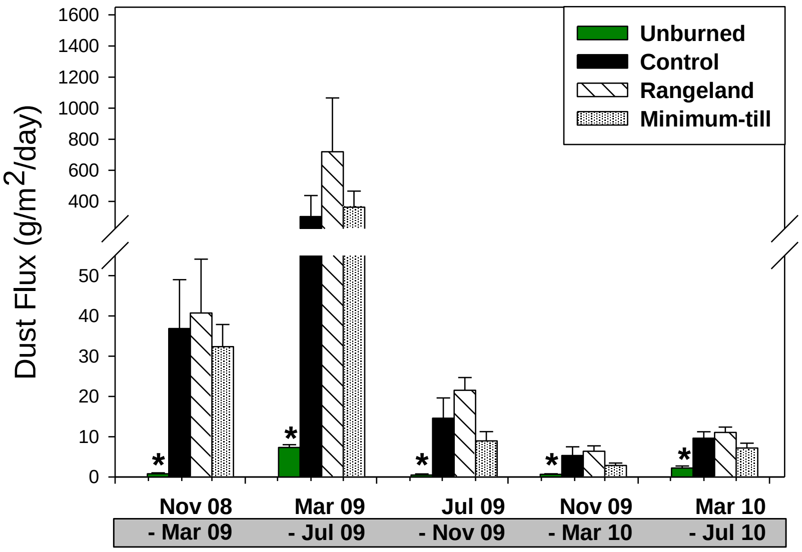

Figure 18. Dust flux rates (g/m^2/day) as measured by BSNE (Big Springs Number Eight) sampler in unburned plots, as well as burned plots in rangeland or minimum-till drill plots with no seeding or 5X seeding treatments. Error bars represent ± standard error. Significant differences among treatments within season are indicated with an asterisk when $P < 0.05$.

- *Soil moisture* was collected throughout the experiment. Due to the large data set, we are still analyzing soil moisture data.

- *Water infiltration* into the soil in burned plots was only reduced in broadcast portions of the rangeland drill treatments; otherwise there was no alteration of infiltration properties (data not shown). In unburned plots, infiltration in the interspaces of the sagebrush canopy was similar to burned controls, however, infiltration was reduced under sagebrush canopy presumably due to subcritical water repellency.

Data Archive and Availability – USGS Land Treatment Digital Library
Vegetation data will be archived under the Land Treatment Digital Library (LTDL) to support future management, rehabilitation and monitoring. For each rehabilitation study and associated fire, we will enter the project into the LTDL and link it to the current fire number of each fire. We will attach the data files to the LTDL project along with the shape files of those projects. These files will be permanently archived within the LTDL, but the data will not be made available to the public until the release date provided by the investigator has passed. Prior to the release date, the contact information for the investigator will be available and those who desire to access the data must request it from the investigator. The LTDL will initially be available for the USDI Bureau of Land Management staff, but eventually will be hosted on the internet (http://greatbasin.wr.usgs.gov/ltdl/) for the public to access the information and data that are available for each site.

MANAGEMENT IMPLICATIONS

The decision to install native seedings must be based on an evaluation of fire conditions, the remnant seedbank, pre-fire vegetation, fire and land use history, weather cycles, and other biotic and abiotic factors. Ecological site descriptions and other available site data can aid in decision making. Recovering native vegetation, seeds of exotic invasives present in high densities in the soil seed bank, and ongoing drought are all factors that can contribute to a decision against seeding.

Post-seeding precipitation is critical; lack of timely or adequate precipitation can negate or seriously impair the best efforts to install a native seeding. Seedling emergence and survival of seeded species are likely to be reduced when precipitation is low, leaving a void for invasion by exotic annuals. Although precipitation and other environmental risk factors cannot be managed, preparation or selection of seedbeds with minimal weed seeds; selection of seeding equipment and strategies that provide appropriate seedbed conditions for germination, emergence and establishment; careful calibration and operation of drills; selection of plant materials appropriate to site conditions; and careful post-seeding management can improve the probability of seeding success.

Differences in seedling establishment between the standard rangeland drill and the minimum-till drill were not clear-cut. Results at Scooby suggest emergence of drill-seeded grasses was improved when they were seeded with the rangeland drill, but this difference was lost by the second year. Broadcast seeding through the minimum-till drill and pressing the seed into the soil with the impacter unit tended to increase emergence of the small-seeded species. Wyoming big sagebrush was responsive to seeding at the medium and high rates (234 and 495 PLS m^{-2}) at Scooby, particularly when seeded through the minimum-till drill. Hand broadcasting small-seeded species in fall or winter simulated aerial seeding and provided highly erratic results. These treatments can be successful, but success can be reduced by poor seed-to-soil contact, and in the case of the winter broadcast treatment, an inadequate period of exposure to cool moist conditions required to release the physiological dormancy common to many forb species.

Biomass data from the Scooby seeding demonstrated that native seedings effectively reduced exotic annual grass and forb production following wildfire. Because exotic annuals can produce large numbers of seed in the absence of competitive neighbors, post-fire reseeding is critical for limiting exotic annual success. Results also indicated that exotic biomass increased on unseeded drilled controls (M0, R0), which simulated seeding failures, relative to unseeded controls that were not drilled.

Basal gaps provide an indication of community vulnerability to water erosion. They are easily measured and related well to perennial community development, whether seeded or native.

While we found that wildfire increases the risk of soil erosion substantially, our results suggest that tilling may not increase that risk. However, the methodology used for dust flux could be improved. Separating out treatment effects was difficult due to small plot size and close proximity of plots. Due to aerial mixing of soil particles, we believe we may have not been able to identify treatment differences. However, our microrelief data suggests more soil movement results from use of the rangeland drill compared to the minimum-till drill. These results are likely to vary based on soil type. Managers should consider the potential risk of erodibility when selecting post-fire seeding strategies.

Soil nutrients varied across seasons and in different microsites at unburned sites, but fire and drilling caused few predictable patterns in soil nutrient availability. We are still awaiting results for soil N, which often responds strongly to fire. Additionally, nutrient availability is dependent on water availability and soil type; thus, further work may focus on teasing out relationships between nutrients, water, and soil type. Soil nutrient data may be more informative if linked with plant physiological data, such as nutrient uptake rates, tissue chemistry, and water relations. We suggest that managers consider existing soil texture, water availability, and nutrient availability to match those indicators with species that would do well in those particular situations.

Our conclusions after two years of monitoring are preliminary. Our results are most applicable to similar sites and post-seeding weather patterns. Monitoring over a longer term is necessary to evaluate the development of community dynamics in response to environmental conditions and management programs.

RELATIONSHIP TO OTHER RECENT FINDINGS

Collaborators in this proposal are participating in related research efforts that augment or synthesize knowledge of wildland restoration in the sagebrush and Great Basin steppe:

- *Diverse Seed Mixes for Post-wildfire Reseeding: Conditional Importance of Seeding Method (Cox, Shaw, Pellant)*. This study examined equipment and seeding rates for post-fire seedings in northern Nevada.
- *Great Basin Native Plant Selection and Increase Project (Shaw, Pellant, Hild, Ganguli, Newingham, St. John, Ogle)*. This ongoing research program seeks to increase native seed supplies for the Great Basin and equipment and technology for their use on wildlands. Major objectives are development of genetically appropriate native plant materials for major biogeographic regions, cultural practices for agricultural seed production, restoration technology for re-establishing diverse native plant communities, and science delivery.
- *Assessment of Range Planting as a Conservation Practice (Shaw is a co-author with other collaborators)*. This review of rangeland planting practices is being prepared for the USDA Natural Resources Conservation Service (NRCS) Conservation Effects Assessment Project and provides an extensive literature review and database to guide development of NRCS recommendations and Standards for rangeland plantings.
- *Diversifying Crested Wheatgrass Stands with Native Species (Organized by Shaw and Pellant working with a number of researchers)*. Studies in four states are examining techniques for controlling crested wheatgrass through combinations of chemical and mechanical treatments and using the minimum-till drill to re-establish Wyoming big sagebrush communities
- *Effects of Post-fire Rehabilitation Treatments on Soil Erosion across Ecological Sites (Newingham).* This project is examining the effects of the rangeland drill on wind-driven soil erosion across soil types and ecological sites.
- *Influences of Soil and Spatial Properties on* Bromus tectorum *Distribution after Fire (Newingham).* This study aims to explain spatial variation in seeding success and *B. tectorum* with soil physical and hydrologic properties.

Related studies by other researchers examine aspects of native plant establishment, ecological restoration strategies, and the impacts of restoration practices. Jeremy James, ARS Burns, Oregon, is initiating a systems approach to seedling establishment aimed at identifying bottlenecks to seedling establishment and developing tools and strategies to address these limitations. Bruce Roundy at Brigham Young University is developing thermal accumulation models for seedling root penetration of forbs, grasses and cheatgrass that can be used with soil water and temperature data from the Great Basin to predict seedling root growth and survival for wet and dry years. Susan Meyer, USFS Rocky Mountain Research Station, Provo, Utah, and a group of researchers are examining potential biocontrols for cheatgrass, which could provide an essential tool for site preparation prior to seeding. Roger Sheley and a team of ARS researchers are conducting the Area-wide Project in the Great Basin to design ecologically based invasive plant management and restoration practices using plant successional principles.

FUTURE WORK NEEDED

While our results have answered several questions, it inevitably has prompted additional research questions to further our understanding of rehabilitating sagebrush ecosystems. Future research projects may include:

- A more detailed investigation of post-drilling soil movement (i.e., erosion and deposition) effects on seedbed properties.
- Evaluation of effective minimum-tillage techniques that reduce disruption of soil aggregates and physical soil crusting.
- Determination of wildfire and seed drilling effects on water erosion.
- Examination of the effects of soil redistribution by drilling on snow capture and snowmelt.
- Examination of seed placement and movement within the soil profile over time due to soil wetting and drying.
- Evaluation of seedling emergence in the face of soil chemical or physical crusts for species commonly used in wildland rehabilitation.
- Identification of inter- and intra-specific variation in seed characteristics and plant functional traits that may enhance germination, emergence and establishment under stressful biotic and abiotic conditions.
- Examination of inter- and intra-specific competition among restoration species and between restoration species and exotic weeds to aid in developing more effective seeding mixes and strategies.
- Continue modification of seeding equipment to provide increased flexibility in creating appropriate microsite conditions for an array of native plant species.
- Accelerate research on cheatgrass die-off and potential biocontrols for cheatgrass to provide effective tools for site preparation.
- An assessment of soil redistribution effects on ant and pollinator recolonization following wildfire and drill seeding.
- Examination of altered food availability for granivores due to seeding efforts.
- Evaluation of livestock grazing effects on post-wildfire rehabilitation efforts. While we have designated plots to remain grazed and ungrazed, future funding is needed to pursue these efforts.
- Development and validation of a drill-seeding risk assessment framework based on soil chemical and physical properties to improve seeding efficacy and reduce detrimental effects of seeding activities.
- Development of weather and climate modeling tools for management and restoration applications in rangeland management and restoration.
- Development of a tool for assessing suitability of burned areas for re-establishment of native communities and determination of appropriate seeding equipment and methods.
- Compilation of a database of revegetation species' characteristics pertinent to germination, establishment, functional traits and life cycles that will aid in selection of materials for development of native seed mixes.
- Conduct long-term monitoring to assess development of community structure, function, dynamics in native seedings, as well as suitability of resulting communities in meeting specific management goals, such as sage-grouse habitat restoration.
- Augment data in the Land Treatment Digital Library by adding data on soils, weather, seed mixes (seed origin, storage conditions and duration, mixing procedures including use of diluents), seedbed conditions, and seeding equipment including details on the seed-to-soil delivery system (number of mixes, rows of each planted, drill-to-soil delivery).
- Addition of post-fire and post-rehabilitation treatment monitoring to include monitoring soil properties.

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PRODUCTS SUPPORTED by JFSP 07-1-3-12

Manuscripts

Manuscripts will be completed following second year data collection (summer 2012) at the Saylor Creek seeding location.

Ganguli, AC, Newingham BA, and Chatterjee A. *In preparation*. Accuracy of two soil moisture sensors for natural resource applications. Expect to submit to Soil Science Society of America in 2012.

Ganguli AC, Newingham BA, and Chatterjee A. *In preparation*. Seed drilling effects on soil infiltration properties in the sagebrush steppe after wildfire. Expect to submit to Restoration Ecology in late 2012.

Love B, Cane JL. *In preparation*. Comparison of plot and plotless methods for estimating forb density on rangelands.

Newingham BA, Ganguli AC. *In preparation*. Comparing the effects of post-fire seeding techniques on soil erosion in a dryland ecosystem. Expect to submit to Restoration Ecology by early 2013.

Shaw NL, Hild A, Cox R, Ganguli AC. *In preparation*. Comparison of equipment and strategies for enhancing post-fire establishment of native species in the northern Great Basin. Expect to submit to Restoration Ecology by early 2013.

Shaw NL, Cox R. *In preparation*. Native species establishment from fall seedings. Expect to submit to Restoration Ecology by early 2013.

Shaw NL, Pellant M, Olwell P, Jensen S, McArthur ED. 2008. Native plant development and restoration program for the Great Basin, USA, p. 454. In: Organizing committee of 2008 IGC/IRC Conference, eds: Multifunctional grasslands in a changing world. Vol. II. Guangdong People's Publishing House, Guangzhou, China.

Taylor M, Hild AL. *In preparation*. Influence of native grass and forb rehabilitation seedings on exotic annuals. Expect to submit to Restoration Ecology by early 2013.

Wissinger BD, Newingham BA, Ganguli AC. *In preparation*. Plant nutrient availability following wildfire and restoration practices in sagebrush communities. Expect to submit to Journal of Arid Environments in late 2012.

Master of Science Thesis

Taylor, M. 2012. In preparation. Response of exotic, native residual and seeded species to post-fire seeding treatments at the Scooby wildfire site, northern Utah. University of Wyoming, Laramie.

Technical Note

St. John L, Cornforth B, Simonson B, Ogle D, Tilley D. 2008. Technical Note 20: Calibrating the Truax Rough Rider drill for restoration plantings. U.S. Department of Agriculture, Natural Resources Conservation Service, Aberden Plant Materials Center, Aberdeen, ID. 14 p. [Online: http://www.plant-materials.nrcs.usda.gov/pubs/idpmctn7659.pdf]

Field Tours and Demonstrations

2009 U.S. Department of the Interior, Bureau of Land Management – Nevada, Emergency Stabilization and Rehabilitation annual meeting, Elko, NV. N. Shaw provided a field tour discussion of drill seeding studies.

2009 Field demonstration: Equipment, seed mixes, and seeding strategies. Conducted by JFSP 07-1-3-12 cooperators during Workshop: Developing a Successful Native Plant Program, Ontario, OR. Equipment operation and calibration was also filmed for production of a DVD "Calibrating your rangeland drill" by the U.S. Department of Agriculture, Forest Service Missoula Technology and Development Center, Missoula, MT and JFSP cooperators. (Copies of the DVD are available on request from: wo_mtdc_pubs@fs.fed.us)

2011 Society for Range Management, Utah Section Summer Tour, Park Valley, UT. N. Shaw discussed results at the Scooby seeding.

2011 Saylor Creek and Nevada seedings tour for U.S. Department of the Interior, Bureau of Land Management and other agency personnel. N. Shaw discussed the seedings and results.

2011 Saylor Creek seeding tour with Dr. Newingham's Restoration Ecology class from the University of Idaho.

2011 Saylor Creek site visit with University of Idaho interdisciplinary team focusing on resiliency of sagebrush ecosystems led by Dr. Newingham.

Invited Presentations

Shaw NL. 2008. A collaborative science-based program to provide native plant materials and restoration. It's about the land: success in BLM Partnerships. Society for Range Management/American Forage and Grassland Council, 2008 Joint Annual Meeting, Louisville, KY.

Shaw NL, R Cox, and M Pellant. 2008. Native plants and seeding methods for the Great Basin. Restoration and rehabilitation of grazing lands. Society for Range Management/American Forage and Grassland Council, 2008 Joint Annual Meeting, Louisville, KY.

St. John L. 2008. Management strategies and plant materials for rangelands – the role of Plant Materials Centers. Society for Range Management , Utah Section Annual Meeting, Provo, UT.

St. John L. 2008. Testing and selecting plants for rangeland rehabilitation. Eastern Idaho Weed Control Association, Idaho Falls, ID.

Shaw N. 2009. Equipment and strategies for post-fire seedings. Nevada BLM Emergency Stabilization and Rehabilitation Meeting, Elko, NV.

Ganguli AC. 2010. Trials and tribulations of wildland restoration. North Dakota State University, School of Natural Resource Sciences Seminar Series, Fargo, North Dakota.

Pellant M. 2010. Successful restoration of native plant communities in the Great Basin depends on….? National Native Seed Conference, Snowbird, UT.

Shaw NL. 2010. A collaborative science-based program to provide native plant materials and restoration technology for the Great Basin. National Native Seed Conference, Snowbird, UT.

Newingham BA and AC Ganguli. 2011. Soil responses to restoration seeding techniques. Intermountain Native Plant Summit, Boise, ID.

Cox R, M Pellant, and N Shaw. 2012. Seeding Wyoming big sagebrush in the northern Great Basin. Rangeland Technology and Equipment Council Annual Workshop: Sagebrush Re-establishment Practices, Spokane, WA.

Ganguli AC, BA Newingham, and NL Shaw. 2012. Wildfire, weeds, and seeds: Improving rangeland rehabilitation efforts in the Great Basin. North Dakota State University Environmental and Conservation Sciences Greebag Seminar Series, Fargo, ND.

Contributed Presentations

Cox RD, NL Shaw, and M Pellant. 2008. Reestablishing diverse native Wyoming big sagebrush communities: a comparison of seeding equipment. Society for Range Management/American Forage and Grassland Council Joint Annual Meeting, Louisville, KY.

Cox RD, NL Shaw, and M Pellant. 2009. The effectiveness of rangeland and minimum-till seed drills for large-scale restoration of sagebrush wildlands. Ecological Society of America Annual Meeting, Albuquerque, NM.

Newingham BA, AC Ganguli, and NL Shaw. 2009. Comparing the effects of fire and restoration drilling on soil properties in the Great Basin. Great Basin Native Plant Selection and Increase Project Annual Meeting, Boise, ID.

Pellant M. 2009. Seeding and site preparation. Developing a Successful Native Plant Program, Ontario, OR.

Shaw N, R Cox, A Ganguli, and J Truax. 2009. Seeding strategies and equipment for re-establishing Wyoming big sagebrush communities. Great Basin Native Plant Selection and Increase Project Annual Meeting, Boise, ID.

St. John L. 2009. Aberdeen Plant Materials Center 2008 Activities – Great Basin Native Plant Selection and Increase Project. Great Basin Native Plant Selection and Increase Project Annual Meeting, Boise, ID.

Truax J. 2009. Truax Roughrider drill: purpose and evolution. Developing a Successful Native Plant Program, Ontario, OR.

Shaw, N, R Cox, and J Truax. 2010. Native plant selection, seed biology, seeding equipment, and seeding technology. Great Basin Native Plant Selection and Increase Project Annual Meeting, Salt Lake City, UT.

Shaw N, J Truax, E Denney, M Fisk, and N Williams. 2010. Post-fire seeding strategies and native plant materials for the northern Great Basin. Great Basin Native Plant Selection and Increase Project Annual Meeting, Salt Lake City, UT.

Taylor MM, AL Hild, NL Shaw, and EK Denney. 2010. Establishment of exotic and seeded species in post-fire seeded sites in northern Utah. Society for Range Management, Wyoming Section Annual Meeting, Laramie, WY.

Wissinger BD, AC Ganguli, and BA Newingham. 2010. Plant nutrient availability following wildfire and restoration practices in a sagebrush community in northwestern Utah. Ecological Society of America Annual Meeting, Pittsburgh, PA.

Newingham BA and AC Ganguli. 2011. Comparing the effects of post-fire seeding techniques on soil erosion in a dryland ecosystem. Association for Fire Ecology Interior West Conference, Snowbird, UT.

Taylor MM, AL Hild, NL Shaw, and EK Denney. 2011. Establishment of invasive species following post-fire rehabilitation seeding. Society for Range Management Annual Meeting, Billings, MT.

Ganguli AC and BA Newingham. 2012. Seed drilling effects on soil infiltration properties in the sagebrush steppe after wildfire. Society for Range Management Annual Meeting, Spokane, WA.

Newingham BA and AC Ganguli. 2012. Evaluating post-fire seeding techniques on soil erosion in the Great Basin. Society for Range Management Annual Meeting, Spokane, WA.

Shaw N, R Cox, M Pellant, L St. John, J Truax, A Ganguli, and A Hild. 2012. Equipment and strategies to enhance post-wildfire establishment of Great Basin native plants. Society for Range Management Annual Meeting, Spokane, WA.

Taylor MM, AL Hild, NL Shaw, EK Denney and M Fisk. 2012. Response of natives to exotic presence in post-fire seedings. Society for Range Management Annual Meeting, Spokane, WA.

Taylor SD and BA Newingham. 2012. Influences of soil and spatial properties on *Bromus tectorum* distribution after fire. Society for Range Management Annual Meeting, Spokane, WA.

Project Website

JFSP 07-1-3-12 Equipment and strategies to enhance the post-wildfire establishment and persistence of Great Basin native plants: http://www.fs.fed.us/rm/boise/research/shrub/fire.shtml

Data Archive

Incorporation of JFSP 07-1-3-12 vegetation data into the USGS Land Treatment Digital Library (LTDL) http://greatbasin.wr.usgs.gov/ltdl/Default.aspx. Vegetation data will be archived in the LTDL following completion of publications for the project.

Appendix 1. Northern Great Basin seeding locations, wildfire and seeding dates, and site descriptions.

	Mountain Home	Glass Butte	Scooby	Saylor Creek
Location	42°58'42" N, 115°37'57" W	43°31'44" N, 119°54'4" W	41°51"16" N, 113°2'46" W	42°39'43" N, 115°28'18" W
County, State	Elmore, ID	Lake, OR	Box Elder, UT	Elmore, ID
Wildfire (date)	6 Jul 2007	5 Jul 2007	22 Sep 2008	29 Jun 2010
Fall seeding	29-30 Oct 2007	31 Oct-1 Nov 2007	18-19 Nov 2008	27-28 Oct 2010
Winter broadcast	18 Jan 2008	16 Jan 2008	29 Jan 2009	15 Feb 2011
Elevation (m)	911	1430	1422-1475	1204
Annual precipitation (mm)[1]	178-305	203-305	203-356	203-330
Frost-free days[1]	100-170	50-90	100-150	90-170
Soil[1]	Coarse-silty, mixed, superactive mesic Xereptic and Xeric Haplocalcids	Ashy, glassy, frigid Vitriorrandic Haploxerolls	Loamy- skeletal, mixed, mesic Xeric Haplocalcids; Sandy-skeletal, mixed, mesic Xeric Torriorthents	Fine-silty, mixed, superactive, mesic Haploxeralfic Argidurids, Durinodic Xeric Haplargids, and Xeric Natridurids

[1]Soil Survey Staff (2011).

Appendix 2. Bulk soil chemistry and texture (means and ranges) at northern Great Basin seeding locations .

Soil Variable	Mountain Home	Glass Butte	Scooby	Saylor Creek
OM (%)	2.1 (1.3-3.2)	2.7 (1.5-3.6)	2.1 (0.9-3.4)	2.1 (1.2-3.2)
pH	7.4 (6.9-8.0)	6.8 (6.4-7.5)	8.2 (8-8.5)	7.5 (6.8-8.1)
Sand (%)	42 (32-64)	71 (57-77)	35 (9-54)	11.2*
Silt (%)	44 (28-56)	17 (12-28)	38 (15-73)	53.8*
Clay (%)	14 (6-16)	13 (11-17)	28 (13-42)	35.0*
N (ppm)	27 (9-49)	15 (6-29)	13 (6-22)	8 (4-22)
K (ppm)	362 (176-512)	565 (307-869)	561 (315-1092)	409 (304-560)
P (ppm)	35 (14-75)	21 (11-47)	10 (5-14)	20 (12-27)
CEC	13.7 (5.3-21.7)	11.6 (5.9-16.1)	14.8 (11.4-19.2)	12.5 (5.9-17.9)

* At Saylor Creek site where soil texture was determined from one composite sample for the site.

Appendix 3. Seed mixes for post-fire seedings in the northern Great Basin.

				PLS*/m^2		
			PLS (%)	1X**	5X	10X
MOUNTAIN HOME	Broadcast mix					
	Artemisia tridentata spp. *wyomingensis*	Lincoln/Blaine/Jerome Co., ID (1230 m)	20.9	52	262	525
	Ericameria nauseosa	Uinta Co., WY (2060m)	27.0	86	86	86
	Poa secunda	Mountain Home Germplasm	83.9	91	91	91
	Penstemon deustus	Northern Great Basin - pooled	56.2	76	76	76
			Total Broadcast	305	515	778
	Drill mix					
	Pseudoroegneria spicata	Anatone Germplasm	86.3	67	67	67
	Achnatherum hymenoides	'Rimrock'	85.7	51	51	51
	Elymus elymoides	Toe Jam Creek Germplasm	91.6	47	47	47
	Sphaeralcea munroana	Utah Co., UT (1470 m)	53.2	93	93	93
	Eriogonum umbellatum	Northern Great Basin - pooled	61.0	8	8	8
			Total Drill	266	266	266
			Total Drill + Broadcast	571	781	1044
GLASS BUTTE	Broadcast mix					
	A. tridentata ssp. *wyomingensis*	Elko/Humboldt Co., NV (1220-1830 m)	29.3	52	234	495
	Ericameria nauseosa	Uinta Co., WY (2060 m)	27.0	86	86	86
	Poa secunda	Mountain Home Germplasm	83.9	91	91	91
	Penstemon deustus	Northern Great Basin - pooled	56.2	76	76	76
			Total Broadcast	305	487	748
	Drill mix					
	Pseudoroegneria spicata	Anatone Germplasm	86.3	67	67	67
	Achnatherum hymenoides	'Rimrock'	85.7	51	51	51
	Elymus elymoides	Toe Jam Creek Germplasm	91.6	47	47	47
	Sphaeralcea munroana	Utah Co., UT (1470 m)	53.2	93	93	93
	Eriogonum umbellatum	Northern Great Basin - pooled	61.0	11	11	11
			Total Drill	269	269	269
			Total Drill + Broadcast	574	756	1017
SCOOBY	Broadcast mix					
	A. tridentata spp. *wyomingensis*	Sanpete Co., UT (1460 m)	17.5	52	234	495
	Ericameria nauseosa	Sanpete Co., UT (1460 m)	14.8	86	86	86
	Poa secunda	Mountain Home Germplasm	81.6	91	91	91
	Achillea millefolium	Eagle Germplasm	88.2	100	100	100
	Penstemon cyaneus	Lincoln Co., ID (1370 m)	69.2	76	76	76
			Total Broadcast	405	587	848
	Drill mix					
	Pseudoroegneria spicata	Anatone Germplasm	88.9	67	67	67
	Achnatherum hymenoides	'Rimrock'	98.0	51	51	51
	Elymus elymoides	Toe Jam Creek Germplasm	94.3	47	47	47
	Sphaeralcea munroana	Uintah Co., UT (1550 m)	65.8	93	93	93
	Eriogonum umbellatum	Northern Great Basin - pooled	50.4	11	11	11
			Total Drill	269	269	269
			Total Drill + Broadcast	674	856	1117
SAYLOR CREEK	Broadcast mix					
	A. tridentata spp. *wyomingensis*	Power Co., ID (1390 m)	28.4	50	250	500
	Ericameria nauseosa	Utah Co., UT (1650 m)	40.5	85	85	85
	Poa secunda	Mountain Home Germplasm	82.0	100	100	100
	Achillea millefolium	Eagle Germplasm	94.3	100	100	100
	Penstemon speciosus	Northern Great Basin - pooled	57.8	15	15	15
			Total Broadcast	350	550	800
	Drill mix					
	Pseudoroegneria spicata	Anatone Germplasm	80.0	60	60	60
	Achnatherum hymenoides	'Rimrock'	96.6	50	50	50
	Elymus elymoides	Emigrant Germplasm	97.0	35	35	35
	Achnatherum thuberianum	Snake River Plain - pooled	55.4	30	30	30
	Hesperostipa comata	Millard Co., UT	77.6	20	20	20
	Sphaeralcea munroana	Uintah Co., UT (1550 m)	61.0	40	40	40
	Astragalus filipes	Dry River, Deschutes Co., OR (1330 m)	90.0	14	14	14
			Total Drill	249	249	249
			Total Drill + Broadcast	599	799	1049

1. Pure live seed.
2. Drill seed mix does not vary among treatments. Broadcast mix varies only by big sagebrush seeding rate, see Table 1.