COLORADO DIVISION OF WILDLIFE – AVIAN RESEARCH PROGRAM
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TITLE: Restoring energy fields for wildlife
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EXECUTIVE SUMMARY

Effective wildlife habitat restoration requires re-establishing complete plant communities. Techniques for achieving this goal in oil and gas fields are often uncertain because of the variety of habitats impacted and the difficulty of preventing weed invasion. An impacted area of particular concern is the Piceance Basin gas field because of its value to mule deer, sage-grouse, and other wildlife. This project addresses the need for improved reclamation techniques in the Piceance Basin by implementing research experiments in twelve locations which span a large range of elevation and climatic variability.

At lower elevations in the Piceance Basin, cheatgrass (*Bromus tectorum*) presents a major obstacle to reclamation. At higher elevations, reclamation is easier to achieve, but reliable methods for restoring broadleaf forbs and shrubs is yet lacking. The border between areas requiring a focus on weed control and those amenable to a focus on forbs and shrubs is not always clear. In order to test techniques over their full range of potential usefulness, a series of experiments with overlapping treatments was initiated. These experiments were begun in two phases. Phase I uses simulated pipeline disturbances as a

template, was implemented in 2008, and has now generated preliminary results. Phase II uses simulated well pads as a template, was initiated in 2009, and consists of several experiments.

The Phase I experiment compares two approaches to controlling cheatgrass and promoting native plants: applying imazapic herbicide (Plateau™, BASF orporation) and using soil tillage. The tillage treatments examined were Disking (D), Rolling (R), Disking+Rolling (DR), and Vibratory drum rolling (V). Plateau is a selective herbicide for cheatgrass with unknown effects on germination of many desirable rangeland plants. The tillage treatments were of interest because cheatgrass has been shown to be sensitive to seed burial and soil compaction. Plateau was effective at reducing cheatgrass seedling density at 2 of 6 study locations, where it reduced density by 95% or more. The lack of effect at some sites may have been due to high Sodium Absorption Ratio in the soil, which may have prevented the herbicide from infiltrating the soil surface. The D tillage treatment was broadly effective at both reducing cheatgrass seedling density and increasing native seedling density, but the R and V tillage treatments had no discernable effect. The D treatment was implemented in late September or October, when cheatgrass seeds were just beginning to germinate. Disking at that time and then immediately planting appears to be a useful technique for controlling cheatgrass and promoting native plant establishment.

Phase II consists of four experiments: the Mountain Top experiment (implemented in 4 high elevation locations), the Strategy Choice experiment (implemented in 4 mid-elevation locations), the Gulley experiment (implemented in 4 low elevation locations), and the Competition experiment (implemented in 2 mid-elevation locations).

The goal of the Mountain Top experiment is to determine the relative value of seeding versus creating favorable conditions for naturally dispersing seeds in promoting diverse, mixed plant communities in areas with desirable surrounding vegetation. There are three treatments: large Holes created with a backhoe, Brush mulching with scraped vegetation, and Seeding. The Holes and Brush treatments were designed to capture snow and naturally dispersing seed. The Seeding treatment contained native grasses, forbs, and shrubs in quantities typically used in reclamation areas in the Piceance Basin.

The goal of the Strategy Choice experiment is to determine optimum reclamation choices in unclear situations: the surrounding plant community is largely native and desirable, but contains some threatening weeds. This experiment contains a Holes/Brush treatment which is similar to that of the Mountain Top experiment except that both Holes and Brush were applied in concert rather than as separate treatments. This experiment also contains a seed mix treatment: The High Competition seed mix was designed to minimize chances of weed invasion, and the Low Competition seed mix was designed to maximize plant the diversity of the resulting plant stand. The final treatment is Plateau herbicide, applied just prior to planting.

The goal of the Gulley experiment is to test more thorough and continually effective weed control techniques in areas highly infested with cheatgrass. Two types of weed control strategies were employed: controlling seed already in the seed bank, and preventing dispersal of weed seed from the surrounding plant community. To control the seed bank, the effectiveness of Plateau is compared to that of fallowing with pendamethilin (Pendulum™, BASF Corporation). Pendulum is a broad-spectrum pre-emergent herbicide with an effective life of about six months. To control weed seed dispersal, plots were surrounded with windowscreen seed dispersal barriers. A pilot study of seed dispersal conducted in 2009 indicated that cheatgrass seeds may disperse 30 feet or more over bare soils, and cheatgrass seed was found caught in the dispersal barriers soon after they were erected.

The goal of the Competition Experiment is to examine the effect of soil additions on the competitive ability of wheatgrasses versus cheatgrass. This study differs from those above in that cheatgrass seed was added to the experimental plots in known quantities. Two types of soil additions were tested: a super absorbent polymer, and a soil binding agent. Super absorbent polymers reduce plant water stress by increasing the water holding capacity of the soil. Soil binding agents reduce erosion and may be helpful in reducing cheatgrass germination. The two soil additions were tested both with and without soil compaction by rolling with a heavy roller.

Implementation of all Phase II experiments, with the exception of the fallowed plots in the Gulley experiment, was completed in 2009. Both Phase I and Phase II experiments will be monitored for at least three additional growing seasons. The costs, benefits, and constraints of all treatments shown useful in promoting complete plant communities will be discussed.

INTRODUCTION

Preserving wildlife habitat quality in oil and gas fields requires effective reclamation of impacted areas. Successful reclamation for wildlife involves overcoming the threat of weed invasion, preventing soil loss, and promoting natural plant succession so that diverse, native plant communities are established. A thorough understanding of site-specific factors, such as topography, soils, climate, and land use history, are required for making informed reclamation choices. Obtaining this kind of information for oil and gas fields, however, is difficult due to the spatial pattern of disturbance.

The disturbances caused by oil and gas fields, in contrast to many other kinds of development, are small in acreage but large in number, and each is connected via pipelines and access roads which may extend across hundreds of thousands of acres. The complexities of gathering knowledge at appropriate scales, administering recommendations for the multitude of sites, and enforcing standards over such large areas often results in reclamation that falls short of the most basic standards (Avis 1997, Pilkington and Redente 2006). Addressing these challenges is imperative, as the fragmented pattern of development means that wildlife and wildlife habitat are affected over a much larger acreage than that directly occupied by development activities (Sawyer et al. 2006, Bergquist et al. 2007, Walker et al. 2007). The goal of this study is to address the knowledge gap by replicating tests of promising reclamation techniques in many locations within an ecologically diverse oil and gas field.

The Piceance Basin is a natural gas field in northwestern Colorado which provides an ideal laboratory for conducting large-scale studies of reclamation techniques. The area is currently experiencing an unprecedented level of natural gas development, it provides critical habitat for the largest migratory mule deer herd in the United States, and it has a complex topography which ensures that a wide range of precipitation, soil development, and plant community types are represented. Furthermore, the Piceance Basin is partly but not wholly invaded by the troublesome weed cheatgrass (*Bromus tectorum*), allowing an opportunity to assess control measures for this weed in an area where such measures may have the most effect.

Cheatgrass invasion presents a serious obstacle to effective reclamation in the study area (Pilkington and Redente 2006), and the possibility exists that gas development could facilitate weed invasion into undisturbed habitat (Bergquist et al. 2007). Because of the potential for weed invasion to reduce wildlife habitat quality (Trammell and Butler 1995), several components of this research study specifically address weed control: When is it necessary? What are its ecological costs? What methods work best, and in which environments? What can be done to improve the competitive advantage of desirable vegetation?

Even in areas where weed invasion is not a problem, reclamation techniques can be improved. A particular challenge is the re-establishment of plant diversity, as many times, the outcome of reclamation efforts is a stand of grasses, which does not serve the nutritional needs of wildlife well. Several components of this research study address the question of how to best foster diverse plant communities in areas where weed pressure is non-existent or moderate.

The focus for all of the studies is on sagebrush (*Artemesia tridentata*) communities, because of the need for better techniques for re-establishing these communities (Lysne 2005), their widespread distribution, and their importance to wildlife.

APPROACH

Twelve research locations were chosen within the Piceance Basin in sagebrush habitats (Figure 1, Table 1). These twelve locations span most of the range of elevation, soil type, vegetation, and precipitation to be found in the area. The lowest elevation site, SK Holdings (SKH) lies at 1561 m (5120 ft), has alkaline, clayey soils, and is characterized by high cheatgrass cover with interspersed Basin Big Sagebrush. The highest elevation site, Square S (SQS), lies at 2676 m (8777 ft), has a sandy loam soil, and has a mixture of non-noxious forb, grass, and Mountain Big Sagebrush cover. Due to the extreme variability of the study sites, it proved inadvisable to conduct identical experiments at all sites. The implemented design consists of five experiments, each conducted in 2-6 locations, some of which contain treatments which are also represented in other experiments. The overlap of treatments allows the experiments to relate to one another in a way that will permit broad-scale conclusions, if appropriate, while the differences in the experiments permit tailoring of particular treatments to those portions of the landscape where they are potentially useful.

Two types of disturbances, a simulated pipeline and a simulated well pad, were created to provide templates for the experiments. The major difference relevant to reclamation in these two types of disturbances is in the length of time topsoil is stockpiled. Pipeline disturbances measured 11 m wide by 52 m long and were simulated using a bulldozer and a backhoe. Vegetation was scraped and discarded, the top 20 cm of topsoil was scraped and stockpiled, and then a 1m wide by 1m deep trench was dug. Trenches were left open 3 weeks, and then the subsoil was replaced and the topsoil spread evenly over the site. This work was completed in 6 locations in August and September of 2008. Well pad disturbances measured 31m X 52m and were simulated using a bulldozer. Vegetation was cleared, the top 20 cm of topsoil was scraped and stockpiled, and then the subsoil

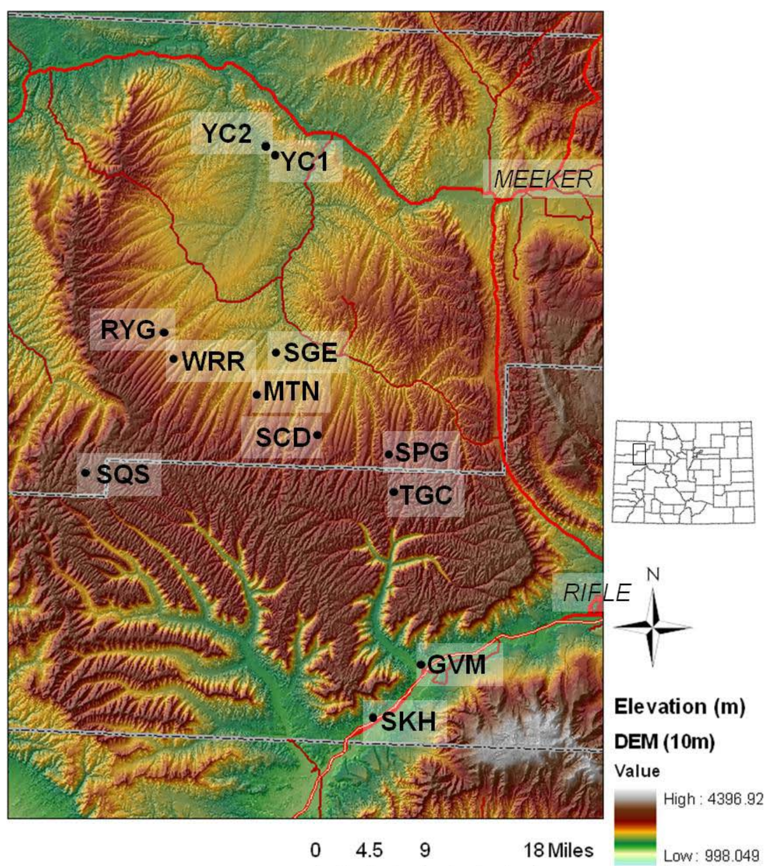


Figure 1. Location of the twelve research locations within the Piceance Basin.

was cut and filled to create a level surface. The initial work was completed in July and August of 2008, and the surface was kept weed-free for one year by repeated hand-spraying of emerging plants with 2% (v/v) glyphosate. In August of 2009, the subsoil was recontoured to approximate the original contour, and the stockpiled topsoil respread evenly across the surface of the site. Simulated well pads were created in 12 locations, each with slopes of 5% or less. One experiment (called hereafter the Pipeline Experiment) was conducted on the simulated pipeline disturbances, and the remainder of the experiments was conducted on the simulated well pad disturbances. All sites were fenced with 2.4 m (8 ft.) fencing after experiments were implemented.

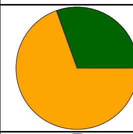
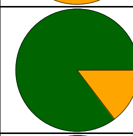
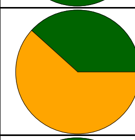
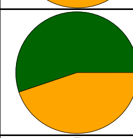
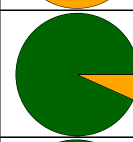
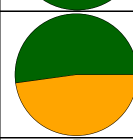
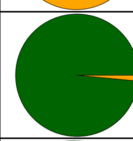
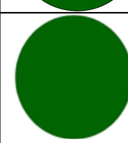
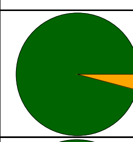
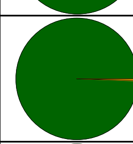
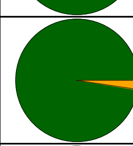
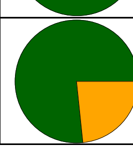
SITE CHARACTERIZATION

Vegetation at all sites was characterized by 4-7 point-intercept transects 10 m in length placed systematically in undisturbed vegetation 10 m from the edge of the disturbed area. Fifty hits per transect were recorded to species following the method outlined by Herrick (Herrick et al. 2005). Percent cover was assessed between 7/1/09 and 7/20/09, and results are summarized in Table 1.

Soils across the Piceance Basin vary widely. Soil characteristics at each study site were determined by sampling the top 20 cm from 8 undisturbed locations within 10 m of the research area between 6/15/09 and 6/17/09. Samples were aggregated for each site and analyzed for pH, electrical conductivity (EC) sodium absorption ratio (SAR), organic matter (OM), nitrate nitrogen, P, K, Zn, Fe, Mn, Cu, Ca, Mg, Na, K, and particle size distribution by the Soil, Water, and Plant testing laboratory at Colorado State University, Fort Collins, CO. Results are summarized in Appendix 1.

Rain and air temperature data were recorded at 6 sites in 2009 [Yellow Creek 1 (YC1), Yellow Creek 2 (YC2), Ryan Gulch (RYG), Wagon Road Ridge (WRR), Grand Valley Mesa (GVM) and SKH] using RG3-M data logging rain gauges (Onset® Computer Corporation, Bourne, MA) installed on guyed posts at each site. Rain data was recorded in 2 mm intervals, and temperature data was recorded every 30 min.

Table 1. Ownership, elevation, vegetation, and experiments conducted at study sites. Relative cover is for undisturbed ground adjacent to the study area in the 2009 growing season. At sites below 7,000 ft, non-natives are primarily cheatgrass. At higher elevations, non-natives were primarily seeded pasture grasses such as bulbous bluegrass and Kentucky bluegrass.

Code	Name	Landowner	Elev. m (ft)	Experiment(s) Conducted	RelativeCover Native NonNative
SKH	SK Holdings	Williams	1561 (5120)	Pipeline Gulley	
GVM	Grand Valley Mesa	Williams	1662 (5451)	Pipeline Strategy Choice	
YC2	Yellow Creek 2	DOW	1829 (5999)	Pipeline Gulley	
YC1	Yellow Creek 1	DOW	1905 (6248)	Pipeline Gulley	
SGE	Sagebrush	BLM	2004 (6573)	Strategy Choice Competition Seed Dispersal	
RYG	Ryan Gulch	Williams	2084 (6835)	Pipeline Gulley	
MTN	Mountain Shrub	BLM	2183 (7160)	Strategy Choice	
WRR	Wagon Road Ridge	Williams	2216 (7268)	Pipeline Strategy Choice Competition Seed Dispersal	
SCD	Scandard	BLM	2342 (7681)	Mountain Top	
SPG	Sprague (formerly called Snowpile)	Conoco	2445 (8019)	Mountain Top	
TGC	The Girls' Claims	Encana	2527 (8288)	Mountain Top	
SQS	Square S	DOW	2676 (8777)	Mountain Top	

EXPERIMENT UPDATES

PIPELINE EXPERIMENT

Conducted at 6 sites: YC1, YC2, RYG, WRR, GVM and SKH (Table 1, Figure 1).

Background

The goal of the pipeline experiment is to evaluate the effectiveness of tillage treatments vs. an herbicide treatment at controlling cheatgrass and promoting establishment of native plants. Oil and gas disturbances are amenable to tillage manipulations, as the ground is already disturbed and access routes for heavy equipment have already been created. In agricultural settings, combining lower levels of herbicide with tillage treatments, such as disk cultivation, has proven effective for controlling weeds (Mulugeta and Stoltenberg 1997, Mohler et al. 2006). Soil manipulations may be particularly effective for controlling cheatgrass because cheatgrass is sensitive to seed burial (Wicks 1997), does not germinate well in even slightly compacted soil surfaces (Thill et al. 1979), and is less competitive in denser soils (Kyle et al. 2007). Tillage manipulations examined include disking (D), compaction with a heavy roller (R), compaction with a vibratory drum roller (V), disking plus compaction with a heavy roller (DR), and a control (C).

The herbicide investigated is Plateau ™ (ammonium salt of imazapic, BASF Corporation, Research Triangle Park, NC), as it has been shown to reduce cheatgrass with little effect on some perennial grasses (Kyser et al. 2007). However, it may also reduce vigor and density of established forbs (Baker et al. 2007), and little is known about its effect on germination of desirable species. Plateau was applied at 420 g/acre (6 oz./acre) along with glyphosate at 560 g/acre (8 oz./acre). The study design is split-plot factorial with Herbicide as the whole plot and Tillage treatments as subplots (Figure 2).

Vegetation at the six study areas varied from near complete dominance of cheatgrass at SKH to an intact and nearly completely native community at WRR (Table 1). Sites were seeded the second week in October 2008 using a Tye Pasture Pleaser rangeland drill, with grasses and forbs/shrubs seeded in alternate rows. The seed mixture contained 8 native grasses, 7 native forbs, and 3 native shrubs, and was applied at 8.6 PLS/acre.

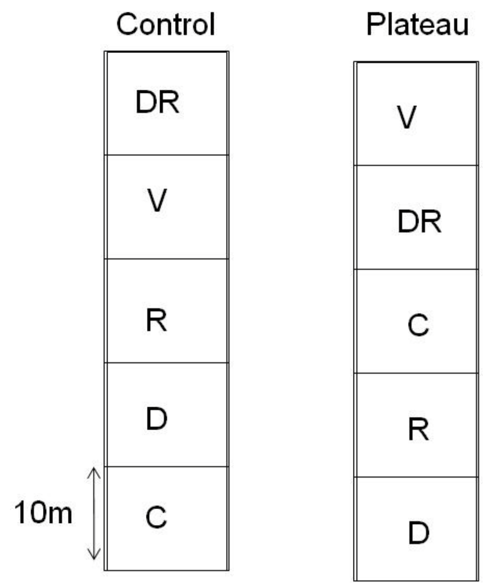


Figure 2. Layout of the Pipeline Experiment at one of six sites. D= Disked, R= Rolled, DR= Disked and Rolled, V= rolled with Vibration, C= Control.

Objectives for 2009

2009 was the second year for the pipeline experiment. Our first objective was to quantify the effect of each soil tillage treatment, as well as the creation of the pipeline disturbances themselves, on the density of the soil. Our second objective was to understand the first post-treatment year response of native plants and cheatgrass to the treatments. Our final objective was to analyze data collected and draw preliminary conclusions.

Quantifying Soil Density

We used two methods to quantify soil density: sampling the soil using a drop-hammer double cylinder soil corer, and measuring the resistance of the soil to penetration using a Jornada cone penetrometer (Herrick and Jones 2002). Penetrometer measurements are much more easily obtained, but because penetration resistance depends on soil moisture, penetration resistance is poor choice for comparing differences between sites or between treatments which might alter soil moisture (Miller et al. 2001). Therefore, we used soil bulk density samples to compare sites and to compare on-disturbance vs. off-disturbance locations. We augmented this with penetrometer measurements to quantify within-site differences between the tillage plots.

Soil samples were taken in September of 2008 using a 30.5 cm (12 in.) AMS core sampler fitted with 6 abutting 5.1 cm (2 in.) long inner cylinders. Five cores were taken in undisturbed, adjacent areas to each research site, and three cores were taken from each of the two plots receiving the C soil treatment. Each soil core was divided into 6 known-volume depth increments by removing the inner cylinders and using a piece of metal flashing to separate soil from adjoining cylinders. Samples were stored in plastic bags and were analyzed in June of 2009 by drying each sample to a constant weight and dividing dry weight by the volume of the sample (Krzic et al. 2000).

Penetrometer measurements were taken in May of 2009. Five penetrometer readings were taken in each plot. The number of hammer drops required to move the penetrometer through the soil was recorded for each 5 cm depth increment from 4 cm to 29 cm, and the force required to penetrate the soil was calculated for each depth fraction in each plot. To check for differences in soil moisture among plots, which could compromise the value of penetrometer readings, we took concurrent volumetric soil moisture measurements for a depth of 0-20 cm using a Hydrosense® Time-Domain-Reflectrometry probe (Campbell Scientific, Logan, UT) in 10 locations in each plot.

Quantifying cheatgrass propagule pressure

The six study sites chosen for this experiment had cheatgrass present in varying quantities. Prior work has shown that the quantity of weed seeds, or "propagule pressure" is important in understanding the outcome of revegetation (DiVittorio et al. 2007). We quantified cheatgrass propagule pressure at each study site using 0.1 m^2 seed rain traps constructed of posterboard covered with Tree Tanglefoot (The Tanglefoot Company, Grand Rapids, MI), a sticky resin. Eight (8) traps were set in systematically chosen locations in undisturbed vegetation surrounding each site. Cheatgrass seeds were counted and removed from traps biweekly from 5/15/09 until 8/26/09. Tanglefoot was reapplied as necessary to ensure a sticky surface. Total growing season cheatgrass propagule pressure (seeds/m^2) was calculated from these data.

Quantifying vegetation response to treatments

Seedling counts were conducted in May and July of 2009 for nine locations within each plot, which were selected systematically by throwing a hoop within each of nine cells created by placing an imaginary "tic-tac-toe" board over each plot. In May, only cheatgrass seedling densities were recorded, and in June, both cheatgrass and native seedling densities were recorded. A 1 m wide buffer zone surrounding each plot was excluded from measurement. Because seedling density varied widely from site to site, the size of the hoop was allowed to vary from 300 to 3000 cm^2 so that an area sufficient for sampling was obtained. A total of 90 counts were done per site, and the density of seedlings was calculated for each plot from seedling counts and hoop areas.

Data analysis

Our general approach was to use analysis of variance (ANOVA) in SAS PROC MIXED (SAS Institute Inc., Cary, NC) to analyze differences in responses to treatments. Treatments were included as fixed effects, and a Site blocking term was included as a random effect. For bulk density, separate analyses were done for each depth fraction, and the fixed effect was a location variable (on or off pipeline). For penetration resistance, separate analyses were done for each depth fraction, and the fixed effects were the soil tillage treatments. For soil moisture, the fixed effects were the soil tillage treatments, and a retrospective power analysis in SAS ANALYST was also performed.

For cheatgrass seedling density and native seedling density, models with different combinations of fixed effects were compared using Akaike's Information Criterion, adjusted for small sample size (AIC_c). The models included Plateau treatment (P), the Tillage treatments (D, R, and V) and two-way interactions among them as fixed effects in various combinations (Table 2). In addition, models including penetration resistance in the 4-9 cm depth fraction (PR) in lieu of tillage variables were also considered. A total of 18 models were tested. In all models, site was included as a random effect, and an adjustment for the split-plot design was incorporated into the RANDOM statement. For cheatgrass seedling density, a REPEATED statement allowed incorporation of both May and June seedling counts into the same analysis. The magnitude of treatment effects were evaluated using ESTIMATE statements in the model with the lowest AIC_c value.

The effect of Plateau was also analyzed separately for each site, using only the Control tillage plots with individual counts as replicates within an ANOVA in SAS PROC GLM.

Means are presented ± standard errors.

Table 2. Results of model selection for competing models of cheatgrass density. W_r values can be interpreted as the probability that a given model would prevail if tested again against the other models in the set. D=Disked, P=Plateau, PR= penetration resistance, R= Rolled, V= rolled with Vibration.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
D, P, and P*D interaction	1459.2	0.00	1.00	**0.22**
P, PR and P*PR interaction	1460.0	0.87	0.65	0.15
P, PR	1460.6	1.47	0.48	0.11
D, P	1461.0	1.85	0.40	0.09
D, P, P*D interaction, R	1461.2	2.09	0.35	0.08
PR	1461.3	2.11	0.35	0.08
D	1461.3	2.17	0.34	0.08
P	1462.2	3.07	0.22	0.05
D, P, R	1463.1	3.92	0.14	0.03
D, R	1463.3	4.19	0.12	0.03
V	1463.8	4.64	0.10	0.02
R	1464.2	5.05	0.08	0.02
D, P, R, P*R interaction	1465.0	5.87	0.05	0.01
D, P, V, P*V interaction	1465.1	5.91	0.05	0.01
D, P, R, V	1465.3	6.14	0.05	0.01
D, R, D*R interaction	1465.6	6.42	0.04	0.01
P, R, P*R interaction	1465.8	6.67	0.04	0.01
P, V, P*V interaction	1469.6	10.46	0.01	0.00

Results

Ambient cheatgrass propagule pressure varied from 6.3 ± 5.0 seeds/m^2 at WRR to 1676 ± 261 seeds/m^2 at SKH (Figure 3).

The creation of the simulate pipeline disturbances increased soil bulk density by an average of 0.13 ± 0.5 g/cm^3 across depth fractions. The increase in bulk density was evident at all depth fractions except the 5-10 cm depth fraction ($p < 0.01$, Figure 4). Bulk density also varied significantly across study sites with the discrepancy between the two most disparate sites, RYG and SKH, being 0.29 ± 0.8 g/cm^3.

The soil tillage treatments significantly affected soil penetration resistance (Figure 5). These differences were most evident for the shallowest depth fraction measured, 4-9 cm. At that depth, the soil had 99 ± 34 N greater resistance in the V treatment than in the control, 134 ± 29 N less resistance in the D treatment than in the control, and 74 ± 29 N less resistance in the DR treatment than in the control (Figure

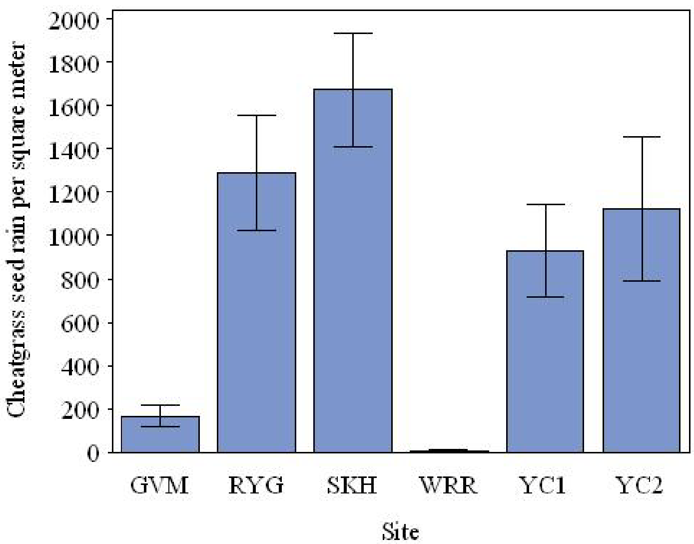


Figure 3. Ambient cheatgrass propagule pressure in undisturbed areas adjacent to each of six study sites. Error bars = SE.

5). For the 9-14 cm depth fraction, the V treatment had 163 ± 64 N more resistance than the control, and the D treatment had 171 ± 56 N less resistance than the control. For the 14-19 cm depth fraction, penetration resistance was 230 ± 107 N greater in the V treatment than in the control. Differences were not evident for any treatment at depths greater than 19 cm, and the R treatment was not significantly different from the control at any depth.

We detected no differences in volumetric soil water due to any of the tillage treatments, and the power analysis found that we had 70% power to detect differences.

The model with the most explanatory power to predict cheatgrass seedling density included the Plateau treatment, Disking, and their interaction (Table 2). In this model, an interaction occurred by which Disking reduced cheatgrass seedling density by 65.5 ± 23.4 seedlings/m^2 when Plateau was not used (Figure 6a), but had no discernable effect when Plateau was used. The Plateau itself was not significantly effective in this cross-site analysis. The next best model included PR, the Plateau treatment, and their interaction. In this model, PR had no detected effect on cheatgrass seedling density when Plateau was present, but when Plateau was absent, cheatgrass seedling density increased by 0.32 ± 0.12 seedlings for every 1 N increase in penetration resistance. Models including rolling and vibration but not disking did not perform well (Table 2).

The model with the most explanatory power to predict native seedling density was a simple model including Disking (Table 3). This model found native density to be 1.5 ± 0.8 seedlings/m^2 higher in disked plots than in undisked plots (p = 0.06, Figure 6b).

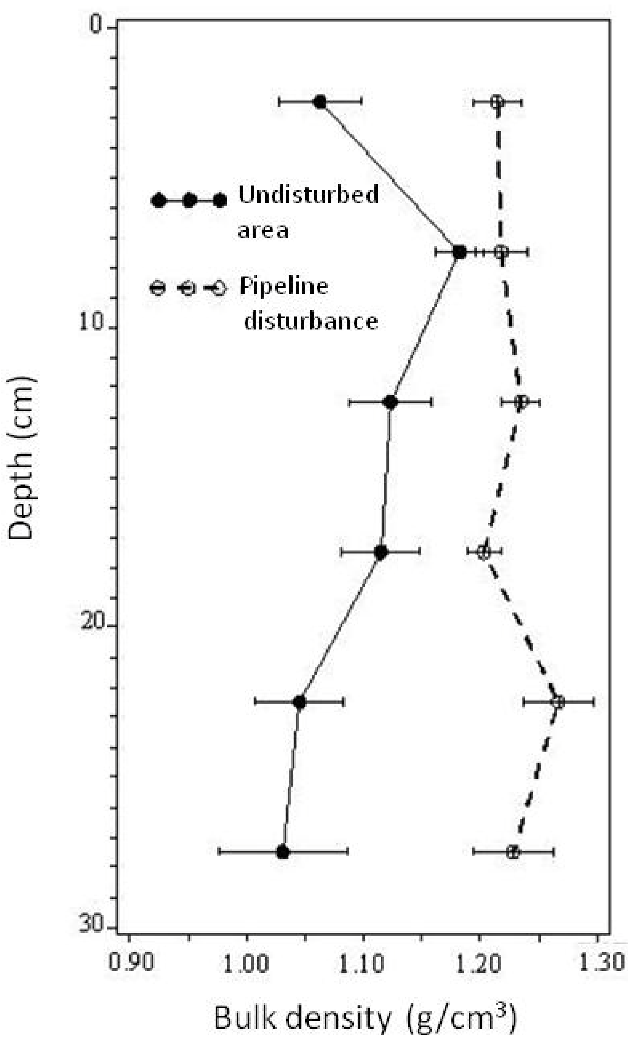


Figure 4. Effect of creating pipeline disturbances on soil bulk density profile. Error bars= SE.

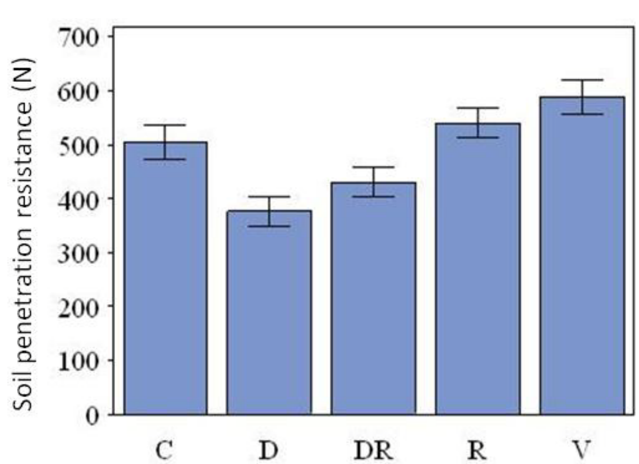


Figure 5. Effect of Disking (D), Rolling (R), and Vibratory drum rolling (V) on soil penetration resistance at a depth of 4-9 cm. Error bars = SE. C = Control.

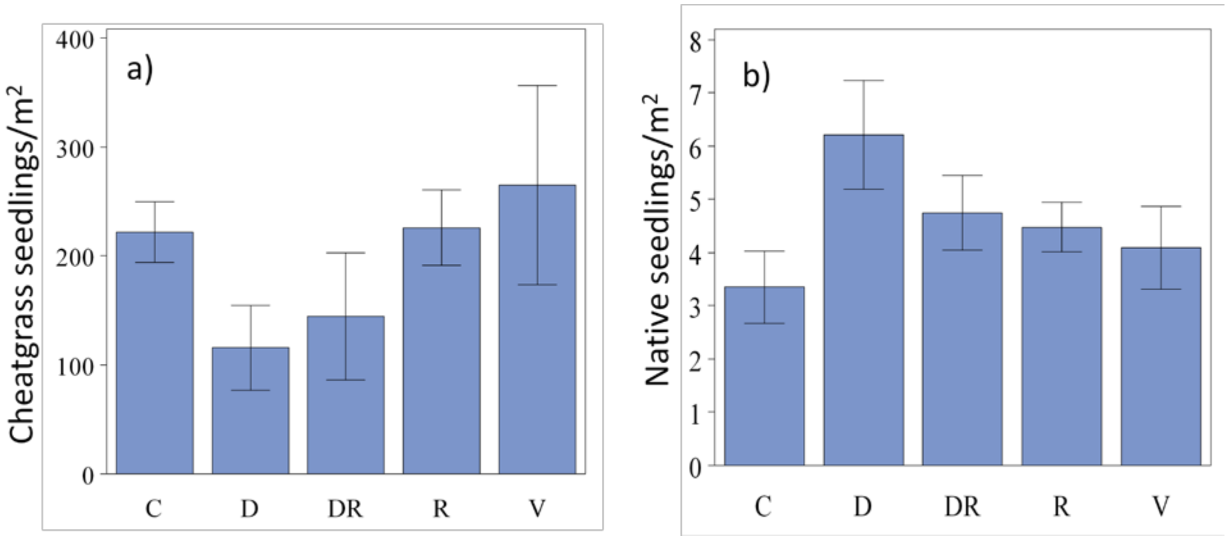


Figure 6. Response of cheatgrass seedlings (a) and native seedlings (b) to soil tillage treatments. D= Disked, R= Rolled, DR= Disked and Rolled, V= rolled with Vibration, C= Control. For cheatgrass, averages include only plots without Plateau. Error bars are SE for data normalized for site differences by subtracting the site mean and adding the overall mean to each value. Note differing Y-axis scales.

Table 3. Results of model selection for competing models of native seedling density. W_r values can be interpreted as the probability that a given model would prevail if tested again against the other models in the set. D=Disked, P=Plateau, PR= penetration resistance, R= Rolled, V= rolled with Vibration.

Parameter(s) in Model	AIC_c	ΔR	Likelihood	W_r
D	331.7	0.00	1.00	**0.27**
PR	333.3	1.64	0.44	0.12
D, P, and P*D interaction	333.6	1.94	0.38	0.10
D, P	334.0	2.32	0.31	0.08
D, R	334.1	2.47	0.29	0.08
D, R, D*R interaction	334.2	2.55	0.28	0.07
D	335.0	3.33	0.19	0.05
R	335.0	3.34	0.19	0.05
V	335.0	3.36	0.19	0.05
PR	335.5	3.87	0.14	0.04
D, P, P*D interaction, R	336.3	4.60	0.10	0.03
D, P, R	336.5	4.88	0.09	0.02
D, P, V, P*V interaction	338.2	6.57	0.04	0.01
D, P, R, P*R interaction	338.3	6.61	0.04	0.01
P, R, P*R interaction	339.0	7.35	0.03	0.01
D, P, R, V	339.1	7.46	0.02	0.01
P, R, P*R interaction	341.4	9.75	0.01	0.00
P, V, P*V interaction	341.4	9.75	0.01	0.00

In the analysis of the Plateau treatment separately by site, the Plateau treatment reduced cheatgrass seedling density by 572 ± 104 seedlings/m^2 at RYG, and 439 ± 24 seedlings/m^2 at YC2. There was no detected effect of Plateau on cheatgrass seedling density at GVM, SKH, WRR, or YC1 (Figure 7a). The Plateau treatment increased native seedling density at RYG by 13.7 ± 2.7 seedlings/m^2 (Figure 7b). There was no detected effect of the Plateau treatment at GVM, SKH, WRR, YC1, or YC2.

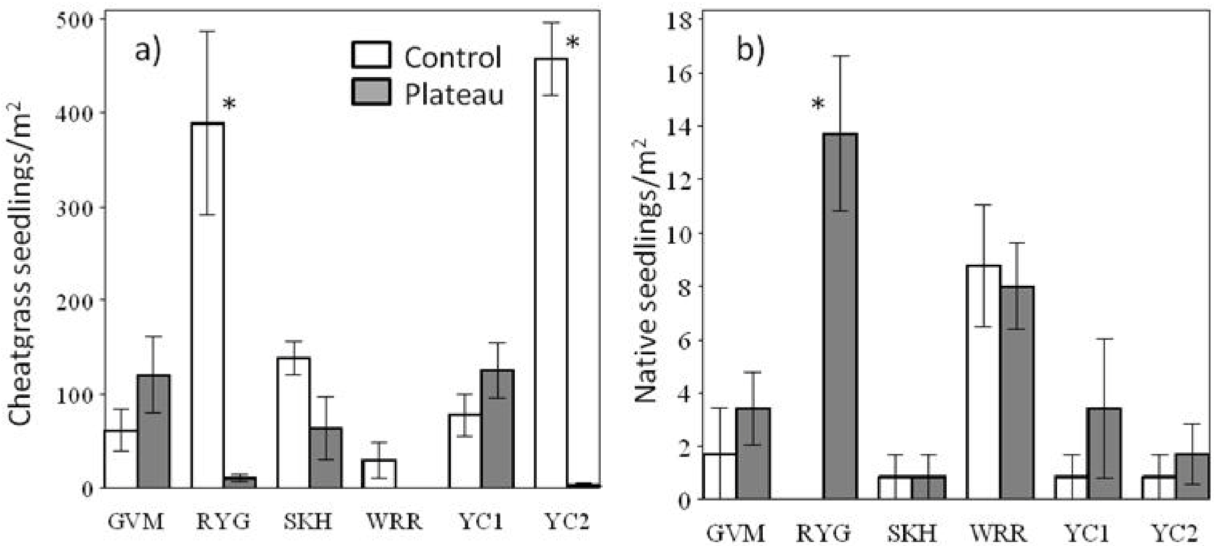


Figure 7. Response of cheatgrass seedings (a) and native seedlings (b) in late June 2009 to Plateau herbicide at six study sites. Data are counts from plots receiving the C soil tillage treatment. Error bars are SE. Stars denote significantly different means for Control vs. Plateau plots within a site at the α = 0.05 level.

DISCUSSION

The soil tillage treatment of disking proved helpful in controlling cheatgrass and improving native seedling density (Figure 6). The soil tillage treatment of rolling did not discernibly affect either native or cheatgrass seedling density. There was no evidence of interaction between the rolling and disking treatments.

Both disking and rolling altered the density of the soil, as evidenced by the soil penetration resistance measurements (Figure 5). However, a model substituting soil penetration resistance for soil tillage variables did not perform as well as a model including the disking variable. Although these results are preliminary, the most likely interpretation at this time is that the benefit of the disking treatment is primarily due to the action of turning the soil and thereby burying cheatgrass seeds, rather than by altering soil density.

There was no consistent effect of the Plateau treatment in this study. In a site-by-site analysis, Plateau was effective at reducing cheatgrass density at 2 of 6 sites, and effective at increasing native density at 1 of 6 sites (Figure 7). The reason for the discrepancy in effectiveness between sites is not entirely clear. At WRR, a lack of sufficient cheatgrass propagule pressure to test the herbicide is the most likely explanation (Figure 3). Lower cheatgrass propagule could be a factor in the lack of effectiveness at GVM, but it does not seem able to completely explain the results, as cheatgrass did establish in both Control and Plateau plots (Figure 7a). The four remaining sites certainly had high enough cheatgrass propagule pressure to present a fair test of the herbicide (Figure 3). The two of these where Plateau was ineffective, SKH and YC1, had Sodium Absorption Ratios (SAR) six to nine times higher than any of the other sites (Appendix 1). SAR is related to the ratio of Sodium to Calcium + Magnesium ions in the soil, has a large effect on soil structure. An excess of sodium causes soil aggregates to break down, reducing the ability of soil to absorb water and causing the formation of hard-pan crusts. These crusts were evident at YC1 and SKH, but not at any other sites. It is possible that these crusts prevented the herbicide from penetrating the soil. It is also possible that these crusts reduced cheatgrass establishment, as the density of cheatgrass seedlings at YC1 and SKH in the non-Plateau plots was not as high as the other sites with comparable cheatgrass propagule pressure (Compare Figures 3 and 7a). Biological soil crusts have been shown to prevent cheatgrass establishment (Shinneman and Baker 2009)

The lack of effect or possible negative effect of increasing soil density on cheatgrass establishment was not what was anticipated. In other work, cheatgrass has been shown to be a poorer competitor in compacted soils (Beckstead and Augspurger 2004). A possible explanation for this discrepancy involves how the treatments affected density at different depths. An ideal tillage treatment for hindering cheatgrass while favoring native plants would have created a dense surface crust with less dense soil through the rooting zone. None of the tested tillage treatments created this density profile. The disking + rolling treatment was the most direct attempt to do so, but rolling compacted deeper soil layers in addition to shallower ones; the reduction in resistance at the 9-14 cm depth with disking was negated when rolling was added. In this study, the detriment of soil compaction in the rooting zone for perennial plants may have outweighed any benefit of rolling in controlling cheatgrass. To achieve a soil density profile suitable for cheatgrass control, it may be necessary to add products such as soil binding agents to the soil surface.

FUTURE WORK

The Pipeline experiment will continue to be monitored for at least one more growing season. The data here, particularly the results for native plants, are preliminary, as perennial plants may take 3 years or more to respond to reclamation treatments. Percent cover of natives and cheatgrass will be measured in the reclamation plots, and percent cover and cheatgrass propagule pressure will be measured in the adjacent undisturbed community each year. Future results will be combined with those presented here in a repeated-measures analysis. A final report will be produced by February 2012, and recommendations about treatments for controlling cheatgrass and promoting native plants will be provided.

MOUNTAIN TOP EXPERIMENT

Conducted at 4 sites: Scandard (SCD), Sprague (SPG; formerly called Snowpile), The Girls' Claims (TGC) and SQS.

Background

Even after decades of recovery, reclamation areas may not resemble undisturbed habitat. A common outcome is domination by grasses, even if the surrounding undisturbed area contains a desirable mixture of grasses, forbs, and shrubs (Newman and Redente 2001). Explanations for grass dominance include a loss of variability in soil resources when topsoil is redistributed, and a disproportionate influence of the grasses included in the reclamation seed mix (Redente et al. 1984). If the surrounding undisturbed area is diverse and desirable, then creating treatments which re-establish resource heterogeneity, encourage native seed dispersal, and avoid undue competition from seeded grasses may result in more satisfactory reclamation. In this study, we examine two treatments designed to create variability in soil resources and maximize establishment of seeds from the surrounding plant community: creating large holes, and using brush scraped from the well pad surface as mulch. Large holes create variability in soil depth and microsites of higher moisture availability, and have recently been shown to improve the establishment of native species in reclamation areas (Eldridge 2008). Large holes have also been shown to entrap and retain dispersing seeds (Chambers 2000). Similarly, brush mulch creates favorable microsites by causing snow to drift and creating shade, entraps dispersing seeds (Kelrick 1991), and also likely contains some viable native seed. These two treatments are applied with and without seeding in order to address the question: If the adjacent undisturbed area is desirable, how important is seeding versus creating heterogeneity and encouraging natural seed dispersal? The treatments examined include:

1) Seeding [Seeded or Not Seeded]
2) Soil Surface [Holes or Flat]
3) Brush mulch [Mulched or Not Mulched]

These treatments were implemented in a completely randomized, factorial design with 3 replications per location (Figure 8).

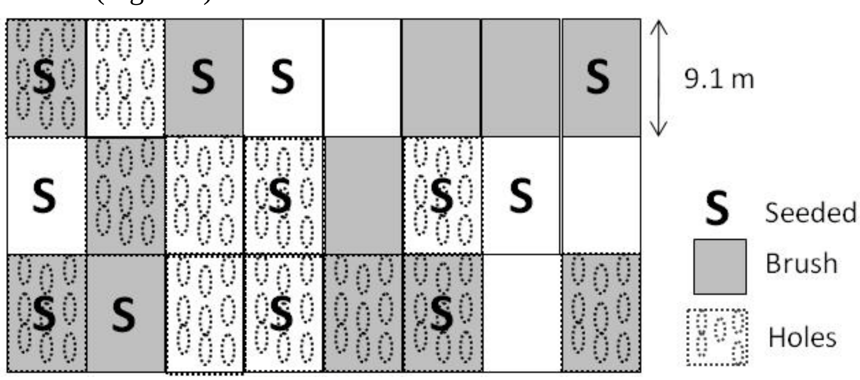


Figure 8. Layout of the Mountain Top experiment at the TGC site.

Study sites

The four study sites used in this experiment had predominately native plant communities and ranged in elevation from 2342 m (7681 ft) to 2676m (8777 ft) in elevation (Table 1). Species common to all study sites included Mountain Big Sagebrush, Saskatoon Serviceberry (*Amelanchier alnifolia*), Snowberry (*Symphoicarpos rotundifolius*), Prairie Junegrass (*Koeleria macrantha*), and Western Wheatgrass *Pascopyrum smithii*). The SCD site was further characterized by Bitterbrush (*Purshia tridentata*), Yellow rabbitbrush (*Chrysothamnus viscidiflorus*), Needle-and-thread grass (*Hesperostipa comata*), the non-native pasture grass Smooth Brome (*B. inermis*), Sulfurflower buckwheat (*Eriogonum umbellatum*), and the non-native Desert Madwort (*Alyssum desertorum*). The SPG site contained Yellow Rabbitbrush, Indian Ricegrass (*Achnatherum hymenoides*), Sandberg Bluegrass (*Poa secunda*), Arrowleaf balsamroot (*Balsamorhiza sagittata*), and the non-native Redstem filaree (*Erodium cicutarium*). The TGC site contained Bitterbrush, Sandberg Bluegrass, Sulfurflower buckwheat, Tailcup Lupine (*Lupinus caudatus ssp. caudatus*) and Purple Locoweed (*Oxytropis lambertii*). The SQS site was contained Rubber Rabbitbrush (*Ericameria nauseaosa*), the non-native pasture grass Bulbous Bluegrass (*Poa bulbosa*), Pearly Pussytoes (*Antennaria anaphaloides*), the non-native Flixweed (*Descurainia sophia*), and Silky Lupine (*Lupinus sericeus*).

Objectives for 2009

2009 was the first year for the Mountain Top Experiment. The goal for 2009 was to implement the treatments.

Treatment implementation

Treatments were implemented between 8/13/09 and 9/23/09. The large holes treatment (H) was created using a mini excavator to dig holes approximately 100 cm X 60 cm X 50 cm deep (Figure 9). Material removed was mounded next to each hole, and approximately 18 holes were dug per plot. This resulted in approximately 20% of the ground being allocated to holes, 30% to mounded soil, and 50% to interspaces.

Figure 9. Implementing the Holes treatment in the Mountain Top Experiment at the TGC site.

The seed mix given in Table 4 was planting in all plots receiving the seeded treatment. On Flat plots, seed was drilled approximately 1 cm deep using a Plotmaster™ 400 with a hunter grain drill attachment. On Holes plots, seed was broadcast and then lightly raked to incorporate the seed into the soil. Seeding rates were the same for both seeding methods. Seed was mixed 1:1 by volume with rice hulls to help ensure even distribution of species when seeding.

The Brush mulch treatment was achieved by distributing approximately 1.2 m^3 of stockpiled woody debris to each plot receiving the brush treatment. This resulted in approximately 5% of the plot are being covered by brush. Because some topsoil was mixed with stockpiled brush, and this likely contained viable seed, an effort was made to distribute equal amounts of this topsoil to each plot. Approximately 4 liters of topsoil from brush stockpiles was scattered over each plot receiving the brush treatment.

Sagebrush seed was collected within 10 miles of each study site in November 2009 and broadcast seeded between 11/11/09 and 12/15/09.

Expected products

The Mountain Top Experiment will be monitored for at least 3 additional growing seasons. The performance of the treatments will be assessed by quantifying density, cover, and diversity of desirable vegetation in the study plots. Vegetation in adjacent, undisturbed areas will also continue to be monitored at each site. Data will be analyzed using a repeated measures analysis with treatments and their interactions as fixed effects. If the effectiveness of treatments differs across study sites, a site-by-site analysis will be done. The cost and value of large holes, brush mulching, and seeding in areas with desirable surrounding habitat will be compared and discussed.

Table 4. Seed mix used in Seeded plots of the Mountain Top experiment.

Common Name	Variety	Scientific Name	Life Form	Seeds/ m^2	PLS (kg/ha)	Seeds/ ft^2	PLS (lbs/ac)
Mountain Brome	Garnet	*Bromus marginatus*	grass	54	3.8	5	3.4
Thickspike Wheatgrass	Critana	*Elymus lanceolatus spp. lanceolatus*	grass	22	0.6	2	0.6
Slender Wheatgrass	San Luis	*Elymus trachycaulus spp. trachycaulus*	grass	65	2.2	6	1.9
Green Needlegrass	Lowdorm	*Nassella viridula*	grass	43	1.2	4	1.0
Muttongrass	VNS	*Poa fendleriana*	grass	215	0.5	20	0.4
Bluebunch Wheatgrass	Anatone	*Pseudoroegneria spicata spp. spicata*	grass	65	2.3	6	2.1
Western Yarrow	Eagle Mtn.	*Achillia millefolium*	forb	161	0.3	15	0.2
Utah Sweetvetch	Timp	*Hedysarum boreale*	forb	15	1.5	1	1.3
Palmer Penstemon	Cedar	*Penstemon palmeri*	forb	215	1.7	20	1.5
Rocky Mtn. Penstemon	Bandera	*Penstemon strictus*	forb	108	1.7	10	1.5
Silver Sage	VNS	*Artemisia cana*	shrub	323	1.3	30	1.2
Mtn. Big Sagebrush	VNS	*Artemisia tridentata spp. vaseyana*	shrub	250	0.6	23	0.5
Rubber Rabbitbrush	VNS	*Ericameria nauseosa*	shrub	22	0.2	2	0.2
			TOTAL=	**1556**	**17.8**	**145**	**15.9**

STRATEGY CHOICE EXPERIMENT

Conducted at 4 sites: WRR , Sagebrush (SGE), GVM, and Mountain Shrub (MTN)

Background

The goal if the Strategy Choice Experiment is to compare two mutually exclusive reclamation strategies. A "conservative" strategy is the obvious choice in areas where weed pressure is very high: plant a highly competitive seed mix, use aggressive weed control measures, and avoid contaminating the site with seed from the surrounding area. The benefit of a conservative strategy is in minimizing weed invasion and soil loss, and the cost is in a loss of plant diversity: highly competitive seed mixes, weed control, and lack of natural seed dispersal all reduce the diversity of the resulting plant stand (Marlette and Anderson 1986, Chambers 2000, Krzic et al. 2000, Baker et al. 2007). The opposite strategy, dubbed here "optimistic", emphasizes maximizing the diversity of the plant stand but allows a higher risk of weed invasion and/or soil loss. An optimistic strategy uses highly diverse seed mixes with a minimal fraction of highly competitive grasses, avoids herbicides (many of which have a detrimental effect on forbs), and makes use of brush mulch, holes, or other mechanisms to entrap seed dispersing from the surrounding area. An optimistic strategy is the obvious choice when the surrounding plant community is desirable, and the risks of soil erosion and weed invasion are low. This study compares the results of these two strategies in situations where the choice is not clear: the risk of weed invasion is moderate, and the surrounding plant community contains both some desirable and some undesirable species. The goal of the study is to shed light on the question: What conditions mandate a conservative approach to reclamation? Treatments include:

1) Seed Mix Competition Level [High Competition (HC) or Low Competition (LC)]
2) Soil surface/mulch type [Flat/Straw or Holes/Brush]
3) Herbicide application [Plateau applied or no Plateau]

Treatments were implemented in a completely randomized, factorial design, with 3 replications in each location (Figure 10).

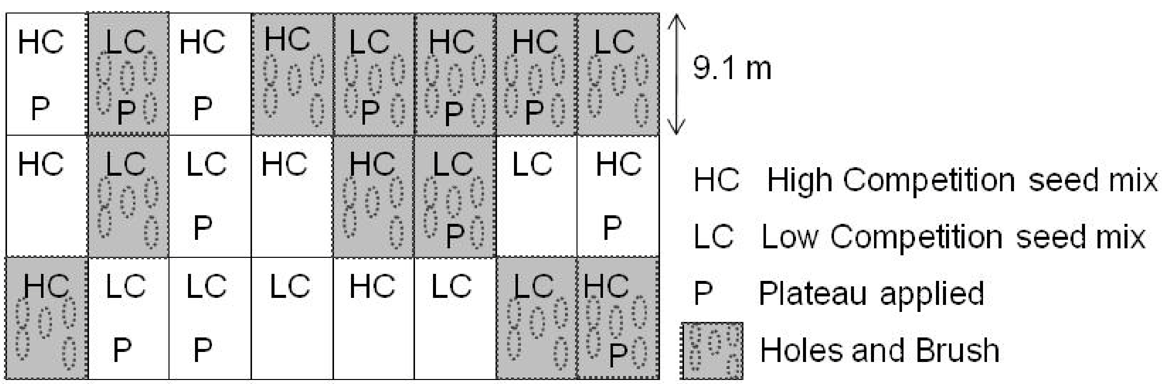


Figure 10. Layout of the Strategy Choice experiment at the GVM site.

Study sites

We selected four study sites with light to moderate weed dominance for this experiment (Table 1). The GVM site was at 5451 ft and was dominated by Wyoming Big Sagebrush, Indian Ricegrass, Utah Juniper (*Juniperus osteosperma*), shadscale saltbush (*Atriplex contertifolia*), Tall tumble mustard (*Sisymbrium altissimum*), and cheatgrass. The SGE was at 6573 ft as was dominated by Wyoming Big Sagebrush, Sandberg Bluegrass, Western Wheatgrass, Needle-and-Thread grass, Prairie Junegrass, and Scarlet Globemallow (*Sphaeralcea coccinea*). The MTN site was 7160 ft was dominated by Wyoming Big Sagebrush, Sandberg Bluegrass, Western Wheatgrass, Needle-and-Thread grass (*Hesperostipa comata*), Prairie Junegrass, Indian Ricegrass, Bulbous Bluegrass, Spreading Phlox (*Phlox diffusa*), and

Saskatoon Serviceberry. The WRR site was at 7268 ft. and was dominated by similar species to the MTN site, with the addition of a wider diversity of native forbs, including Hawksbeard (*Psilochenia acuminate*).

Objectives for 2009

2009 was the first year for the Strategy Choice Experiment. The goal for 2009 was to implement the treatments.

Treatment implementation

At GVM and MTN, the full experiment with all three treatments was implemented. At WRR and SGE, space constraints mandated implementing an abbreviated form of the experiment, and the Herbicide treatment was omitted.

Seed mixes for the HC and LC treatments are shown in Table 6. A key difference between the mixes is in the number and type of grass seeds used. In the HC mix, 344 grass seeds/ m^2 (32 seeds/ sq. ft.) were used, and these were mostly wheatgrasses, which tend to be good competitors. In the LC mix, 156 grass seeds/m^2 (15 seeds/ sq. ft.) were used, and the majority of these were less competitive species (Table 6).

On Holes/Brush plots, all species were hand-broadcast and raked, after creation of the holes but before the application of brush. On Flat/Straw plots, some seed was hand broadcast and then lightly raked, and the remained was drill seeded approximately 1 cm deep using a Plotmaster™ 400 with a hunter grain drill attachment (Table 6). Seed was mixed 1:1 by volume with rice hulls to aid in an even distribution of species.

Certified weed-free straw was applied by hand at a rate of 4.0 Mg/ha (1.8 tons/ac) to plots receiving the Flat/Straw treatment. Straw was crimped in place using a custom-built mini crimper. The Holes/Brush treatment was created using a 331 Bobcat® compact excavator to dig holes approximately 130 cm X 80 cm X 50 cm deep. Material removed was mounded next to each hole, and 18 holes were dug per plot. This resulted in approximately 1/3 of the ground being allocated to each of holes, mounds, and interspaces (Figure 11).

Figure 11. The Strategy Choice Experiment at GVM, showing Flat/Straw mulch plots and Holes/Brush mulch plots.

Plots receiving the Plateau treatment were sprayed with 140 g ai/ha of Plateau (8 oz. /acre) applied with 655 li/ha of water (70 gal. /acre) with a backpack sprayer. Dye indicator was used to ensure even application. In Plateau plots also receiving the Flat/Straw treatment, the amount of water used in the application was tripled to aid the product in penetrating the straw mulch.

After Plateau application, brush which had been cleared and stockpiled next to each site was used for plots receiving the Holes/Brush treatment. Approximately 5 m^3 of brush was applied evenly to each plot.

Sagebrush was hand-broadcast on top of snow in all plots in December of 2009.

Expected products

The Strategy Choice Experiment will be monitored for at least 3 additional growing seasons. The performance of the treatments will be assessed by quantifying density, cover, and diversity of desirable vegetation in the study plots. Vegetation in adjacent, undisturbed areas and cheatgrass propagule pressure will also continue to be monitored at each site. Data will be analyzed using a repeated measures analysis with treatments and their interactions as fixed effects. If the effectiveness of treatments differs across study sites, a site-by-site analysis will be done, and the results interpreted with respect to surrounding vegetation and cheatgrass propagule pressure. Conditions under which an optimistic strategy may be successfully employed, vs. those mandating a conservative strategy, will be discussed.

Table 5. High Competition and Low Competition seed mixes used in the Strategy Choice Experiment. On Holes/Brush plots, all seed was broadcast. On Flat/Straw plots, seed was either broadcast or drill seeded as indicated.

					High Comp. Mix		Low Comp. Mix	
	Common Name	**Variety**	**Scientific Name**	**type**	**seeds/ m^2**	**PLS (kg/ha)**	**seeds/ m^2**	**PLS (kg/ha)**
drill seeded	Bluebunch Wheatgrass	Anatone	*Pseudoroegneria spicata spp. spicata*	grass			22	0.8
	Galleta Grass	Viva	*Pleuraphis jamesii*	grass	75	2.2		
	Indian Ricegrass	Rimrock	*Achnatherum hymenoides*	grass	65	1.8	11	0.3
	Muttongrass	VNS	*Poa fendleriana*	grass			54	0.1
	Slender Wheatgrass	San Luis	*Elymus trachycaulus spp. trachycaulus*	grass	75	2.5	11	0.4
	Thickspike Wheatgrass	Critana	*Elymus lanceolatus spp. lanceolatus*	grass	65	1.9		
	Western Wheatgrass	Rosana	*Pascopyrum smithii*	grass	65	2.5	5	0.2
	Utah Sweetvetch	Timp	*Hedysarum boreale*	forb	22	2.1	22	2.1
	Fourwing Saltbush	VNS CO	*Atriplex canescens*	shrub	11	1.1	11	1.1
broadcast seeded	Prarie Junegrass	VNS	*Koeleria macrantha*	grass			54	0.1
	Bluestem Penstemon	VNS	*Penstemon cyanocaulis*	forb	108	0.7	108	0.7
	Hairy Golden Aster	VNS	*Heterotheca villosa*	forb			215	1.3
	Lewis Flax	Maple Gr.	*Linum lewisii*	forb	54	0.8	54	0.8
	Many-lobed grounsel	VNS	*Packera multilobata*	forb			215	1.3
	Oregon Daisy	VNS	*Erigeron speciosis*	forb			323	0.9
	Sulphur flower buckwheat	VNS	*Eriogonum umbellatum*	forb	108	2.3	108	2.3
	Western Yarrow	VNS	*Achillia millefolium*	forb	129	0.2	129	0.2
	Winterfat	VNS	*Kraschenínnikovia lanata*	shrub	22	0.8	22	0.8
	Wyoming Big Sagebrush	VNS	*Artemesia tridentat spp. Wyomingensis*	shrub	253	0.6	253	0.6
				GRASS TOT	**344**	**9.8**	**156**	**1.7**
				FORB TOT	420	5.6	1173	8.7
				SHRUB TOT	285	2.2	285	2.2
				TOTAL	**1049**	**17.6**	**1614**	**12.6**

GULLEY EXPERIMENT

Conducted at 4 sites: RYG , SKH, YC1, and YC2

Background

The goal of the Gulley Experiment is to address reclamation strategies in a difficult circumstance: when weed pressure from the surrounding plant community is very high. Achieving successful reclamation in this case is difficult because most weed control strategies are short-lived. For instance, tilling soil to bury weed seeds does nothing to prevent germination of new seeds landing on the soil surface. In the Piceance Basin, input of cheatgrass seeds dispersing from the surrounding plant community is a potential problem (please see Appendix 2, "Seed Dispersal Study"). An additional problem is that most herbicides are not completely effective, or are effective for only a short time. The best available selective herbicide for cheatgrass, Plateau, does not completely control cheatgrass when applied at rates which allow germination of desirable species (Bekedam 2004) A recent study has shown that even when Plateau is successfully employed, it can fail to prevent cheatgrass from regaining dominance within 2 years (Morris et al. 2009). It is clear that more thorough and continually effective strategies for controlling cheatgrass and other weeds are needed to allow a resistant, fully developed perennial plant community to develop.

In this study, we compare the effectiveness of two additional weed control strategies with that of Plateau application in reclamation areas surrounded by highly weedy plant communities. The first strategy is fallowing for one year with the herbicide Pendulum® AquaCap™ (pendimethalin, BASF Corporation, Research Triangle Park, NC; hereafter *Pendulum*). Pendulum is a broad-spectrum, pre-emergent herbicide, is effective for about 6 months, and is often used in orchards to maintain bare soils. Pendulum application is a drastic measure designed to eliminate as much of the existing seed bank as possible. The second strategy is surrounding the reclamation area with seed dispersal barriers to prevent weed seeds from blowing in. Seed dispersal barriers were constructed of aluminum windowscreen using a design that had been effective in a Utah seed bank study (Smith et al. 2008). Each of these treatments is tested alone and in combination with each other as well as with Plateau (Figure 12). In summary, the treatments are:

1) Fallowing [Fallowing with Pendulum for one year or No Fallowing]
2) Plateau application [Plateau applied just prior to planting or No Plateau]
3) Seed Barriers [Barriers or No Barriers]

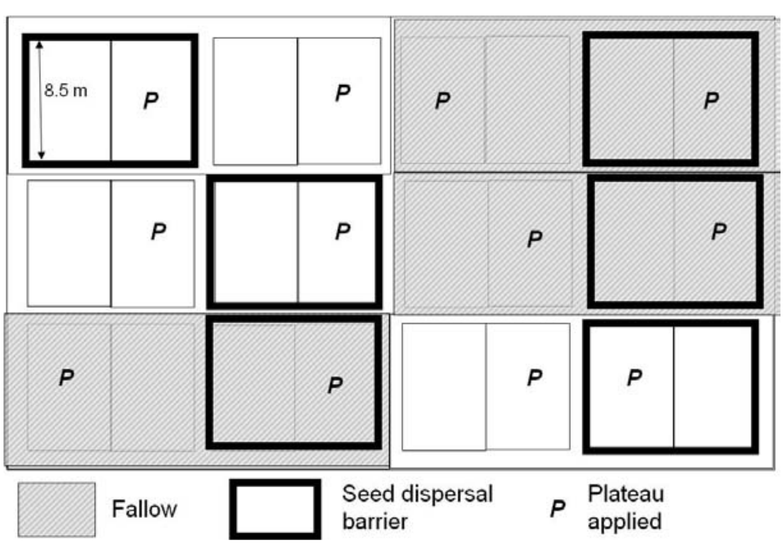


Figure 12. Layout of the Gulley Experiment at the SKH site.

Study sites

We selected four study sites with heavy cover of non-natives in the adjacent plant community: YC1, YC2, RYG, and SKH (Table 1). All sites were characterized by Wyoming Big sagebrush and cheatgrass, and most contained Tall Tumblemustard (*Sisymbrium altissimum*), Western Wheatgrass, Needle-and-Thread grass, Prairie Junegrass, Yellow Rabbitbrush, Desert Madwort, and Scarlet Globemallow. At RYG, Basin Wildrye (*Leymus cinereus*), Rubber Rabbitbrush, Winterfat

(*Krascheninnikovis lanata*), and Netseed Lambsquarters (*Chenopodium berlandieri*) were also found. At YC1, Indian Ricegrass, Sandberg bluegrass, and Winterfat were found. YC2 contained Squirreltail (*Elymus elymoides*). SKH contained Greasewood (*Sarcobatus vermiculatus*), Redstem Filaree, and Western Salsify (*Tragopogon dubius*).

Objectives for 2009

2009 was the first year for the Gulley Experiment. The goal for 2009 was to implement the Barrier and Fallowing treatments, and to apply Plateau and plant seed in the non-fallowed plots. Plateau application and seeding in Fallowed plots will occur in 2010.

Quantifying cheatgrass propagule pressure

The degree of cheatgrass seed input from the surrounding plant community is an important covariate for this study. Cheatgrass seed input was quantified at all study locations using the techniques described in the section “Pipeline Experiment”.

Treatment implementation

These treatments were implemented in a factorial, split-split plot design with three replications in each location (Figure 12). The whole-plot factor is Fallowing (assigned randomly), the sub-plot factor is Barriers (assigned randomly within Fallow designations), and the sub-subplot factor is Plateau is (assigned randomly within Barrier designations). This design allows less power to detect differences for the Fallowing and Barrier treatments than for the Plateau treatment. This was unavoidable because of the difficulty of implementing the Fallowing and Barrier treatments at small scales.

Fallowed whole plots were treated with Pendulum at 3200 g ai/ha (3 qt/ac), applied with a boom sprayer with 330 li/ha (35 gal/ac) of water between 8/26/09 and 9/2/09. At the time of application, no germinated plants of any kind were evident at any of the sites. Once dry, the product was immediately incorporated into the soil with light disking to 5 cm (2 in) to prevent breakdown due to UV radiation.

Unfallowed whole plots were seeded by hand-broadcasting a mixture of native grasses, forbs and shrubs (Table 6). Even seed distribution was ensured by preparing batches of the seed mix for each sub-subplot and seeding plots individually. Seed was mixed 1:1 by volume with rice hulls to aid in even distribution of species. Seed was lightly raked to incorporate it into the soil after broadcasting.

Plateau sub-subplots not receiving the Fallowing treatment were treated with 140 g ai/ha (8 oz/ac) applied with 655 li/ha (70 gal/ac) of water with a backpack sprayer. Dye indicator was used to ensure even application. Plateau was applied between 8/26/09 and 9/2/09, and no cheatgrass germination was evident at the time of application.

To prevent wind and water erosion, a light tackifier was applied to all plots following Plateau application. The tackifier used was DirtGlue® (DirtGlue® Enterprises, Amesbury, MA), a water-based polymer emulsion which permits water infiltration. DirtGlue was applied with a boom sprayer at 190 li/ha (50 gal/ac) diluted 10:1 with water.

Next, Barrier subplots were surrounded by aluminum windowscreen seed dispersal barriers. Barriers were 0.6 m high and were secured to oak stakes with staples (Figures 13 and 14). One meter wide buffer strips separated Barrier subplots (Figure 12).

Figure 13. The Barrier treatment at the SKH site.

A difficulty with constructing a fair test of the barriers is that subplots on the edge of the experiment area are likely be subject to more seed blowing in from the edge than are subplots in the interior. We moderated this effect by hand-broadcasting cheatgrass seed within the buffer strips separating subplots. To determine how much seed to scatter, we used data on ambient cheatgrass seed rain known from our Tanglefoot seed rain traps. Because the traps were sticky and did not allow the seeds to redistribute, we scattered only half as much seed per unit area as these traps had caught. This compensated for the fact that under normal conditions roughly half of cheatgrass seeds landing in a particular location move again (Kelrick 1991); therefore our traps likely overestimated by a factor of 2. The scattered cheatgrass seed had been collected from near-monocultures within 100 m of each site between 6/15/09 and 7/10/09, when the seed was dry and nearly ready to fall. Seed was collected using a lawnmower with a bagging attachment. Viable cheatgrass seed content was estimated for each collection by gathering 5 5g subsamples, and then counting and weighing all of the fully developed, hard-coated cheatgrass seeds for each subsample.

At two of the sites, RYG and SKH, barriers were badly damaged by cow trampling after the cheatgrass seed had been broadcast. The barriers were rebuilt, and lath secured with wood screws was added to the oak stakes at all sites to better secure the windowscreen. The barrier treatments at RYG and SKH are best viewed as being functionally implemented in 2010, while those at YC1 and YC2 were effective for 2009 growing season. All of the sites were fenced to prevent damage in the future.

Locally collected sagebrush was hand-broadcast in the non-fallowed plots in December of 2009.

Expected Products

The Gulley Experiment will be monitored for at least 3 additional growing seasons. The performance of the treatments will be assessed by quantifying density, cover, and diversity of desirable vegetation in the study plots. Vegetation in adjacent, undisturbed areas and cheatgrass propagule pressure will also continue to be monitored at each site. Data will be analyzed using a repeated measures analysis with treatments and their interactions as fixed effects. If the effectiveness of treatments differs across study sites, a site-by-site analysis will be done, and the results interpreted with respect to surrounding vegetation and cheatgrass propagule pressure. The costs and benefits of the three weed control measures tested will be compared and discussed.

Figure 14. A closeup of the Barrier treatment showing trapped cheatgrass seed.

Table 6. Seed mix used in the Gulley Experiment.

Common Name	Variety	Scientific name	Life Form	Seeds/ m2	PLS (kg/ ha)	Seeds/ ft2	PLS (lbs/ ac)
Basin Wild Rye	Trailhead	*Leymus cinereus*	grass	43	1.3	4	1.2
Bluebunch Wheatgrass	Anatone	*Pseudoroegneria spicata spp. spicata*	grass	108	3.9	10	3.5
Galleta Grass	Viva	*Pleuraphis jamesii*	grass	54	1.6	5	1.4
Indian Ricegrass	Rimrock	*Achnatherum hymenoides*	grass	108	3.0	10	2.7
Muttongrass	VNS	*Poa fendleriana*	grass	323	0.7	30	0.7
Slender Wheatgrass	San Luis	*Elymus trachycaulus spp. trachycaulus*	grass	65	2.2	6	1.9
Squirreltail	Toe Jam Ck.	*Elymus elymoides*	grass	108	2.5	10	2.3
Thickspike Wheatgrass	Critana	*Elymus lanceolatus spp. lanceolatus*	grass	65	1.9	6	1.7
Western Wheatgrass	Rosana	*Pascopyrum smithii*	grass	65	2.5	6	2.2
Lewis Flax	Maple Gr.	*Linum lewisii*	forb	54	0.8	5	0.7
Utah Sweetvetch	Timp	*Hedysarum boreale*	forb	22	2.1	2	1.9
Western Yarrow	VNS	*Achillia millefolium*	forb	183	0.3	17	0.3
Fourwing Saltbush	VNS	*Atriplex canescens*	shrub	32	3.3	3	3.0
Rubber Rabbitbrush	VNS	*Ericameria nauseosa*	shrub	22	0.2	2	0.2
Winterfat	VNS	*Krascheninnikovia lanata*	shrub	16	0.6	1.5	0.5
Wyo. Big Sagebrush	VNS	*Artemesia tridentat spp. Wyomingensis*	shrub	250	0.6	23	0.5
			TOTAL=	**1514**	**28**	**141**	**25**

COMPETITION EXPERIMENT

Conducted at 2 sites: WRR and SGE

Background

The Competition Experiment is a small-scale study to evaluate how soil additives may affect the competitive balance between native wheatgrasses and cheatgrass. Known quantities of cheatgrass seed and wheatgrass seed were planted within a simulated well pad disturbance. Two soil additives were added, with or without soil compaction.

The first soil additive is a super-absorbant polymer (SAP). SAPs have been used for many years in baby diapers and potting soil because of their ability to retain up to 400 times their weight in water. When added to degraded soils, SAPs will absorb and then gradually release water, reducing the effects of water stress (Huttermann et al. 2009). If addition of SAP reduces annual variability in soil moisture, then cheatgrass establishment may be hindered, because cheatgrass has been shown to be a more effective invader when soil moisture is more variable (Chambers et al. 2007). The SAP we are investigating is Luquasorb®, a cross-linked copolymer of Potassium acrylate and acrylic acid in granulated form (BASF, Ludwigshafen, Germany).

Another type of soil additive common in reclamation settings is soil binding agent, or tacifier, which is used to stabilize soil and facilitate binding of seed to the soil surface. The effect of tacifiers on competitive interactions is unknown. We are investigating the effects of DirtGlue® (DirtGlue® Enterprises, Amesbury, MA) because of its claimed ability to bind soil particles without reducing water infiltration.

Finally, we are examining the effects of both Luquasorb® and DirtGlue® in combination with with rolling with a heavy lawn roller. The goal of the heavy roller treatment is to determine if combining rolling with a binding agent would create a soil density profile useful in preventing cheatgrass germination. In summary, treatments include:

1) Binding agent (BA; low, high, or no addition of BA)
2) Super-absorbant polymer (SAP; Addition of SAP or no addition)
3) Rolling (Rolled or Not Rolled)

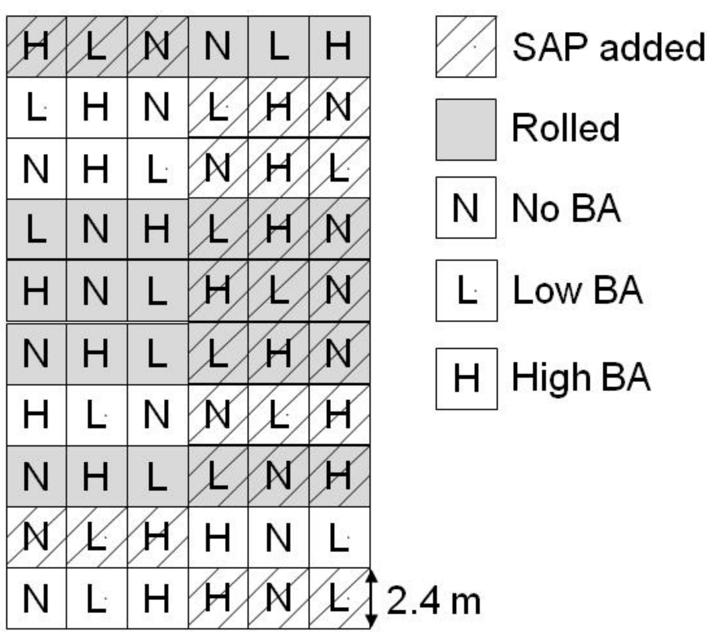


Figure 15. Layout of the Competition Experiment at the WRR site.

Treatments were implemented in a factorial split-split plot design, with completely randomized whole plots (Figure 15). The subplot factor was BA, the split plot factor was SAP, and the whole plot factor was Rolling. Three replicates were implemented at each site.

Study sites

Because we wanted to control the degree of competition in this experiment, we desired study sites which were free of cheatgrass at the initiation of the experiment, but which were capable of being invaded by cheatgrass. The two study sites selected, SGE and WRR, had no apparent cheatgrass, but cheatgrass was well established on nearby roads and disturbed areas. Both

SGE and WRR were within the Piceance fine sandy loam soil type (USDA Natural Resources Conservation Service Survey version 2/4/08) and had slopes of approximately 5%. For a full description, please see the section "Strategy Choice Experiment."

Objectives for 2009

2009 was the first year for the Competition Experiment. The goal for 2009 was to implement the treatments.

Cheatgrass seed collection and dispersal

Cheatgrass seed was collected using a lawnmower with a bagging attachment from monocultures or near-monocultures in 4 locations, each within 50 miles of the study sites. Collections were made in late June or early July when most or all of the cheatgrass in a location had fully ripened seed heads. Seed was allowed to dry and after-ripen in shallow containers in a dry, warm location for approximately 3 months. The density of apparently viable cheatgrass seeds was determined by gathering five 5g subsamples from each collection, and then counting and weighing all of the fully developed, hard-coated cheatgrass seeds for each subsample. Equal quantities of seeds from each location were mixed together, and then quantities of seed sufficient to supply 300 seeds/m^2 were prepared for each 17.8m^2 subplot. Seed was hand-broadcast in early October, 2009, and immediately lightly raked to incorporate seed into the soil. The 300 seeds/m^2 seeding rate is about 25% of the 2009 cheatgrass seed rain at heavily cheatgrass-infested sites quantified for the Pipeline Experiment, and therefore thought to be a reasonable value of cheatgrass seed density for a Piceance Basin site in the initial phases of invasion.

Treatment implementation

A mixture of native wheatgrasses was drill-seeded using a Plotmaster 400 (Table 7). Seed was mixed 1:1 by volume with rice hulls to maintain suspension of the seed mixture. For subplots receiving the SAP treatment, granulated SAP was added to the seed/rice hull mixture. At SGE, 6.7 g/m^2 of SAP was added, and at WRR, 30.8 g/m^2 was added. These rates span are near the lower and upper limits, respectively, of recommended application rates for different agricultural purposes. Next, whole plots receiving the Rolling treatment were rolled ten times with a static roller supplying a linear load of 20.8 lbs/in (36.5 N/cm). Next, BA subplots were treated by sprinkling plots using hand watering cans (Figure 16). High BA plots received 4100 li/ha (440 gal/ac) of BA, diluted 6:1 with water. Low BA plots received 1600 li/ha (175 gal/ac) of BA, diluted 17:1 with water. No BA plots received 21000 li/ha (3200 gal/ac) of plain water, an amount equivalent to the total amount of liquid applied to other plots.

Following implementation, the entire treatment area was surrounded by a barrier to prevent dispersal of cheatgrass seed out of the experiment area. A physical barrier of aluminum window screen was constructed adjacent to the plots. This barrier was 0.6 m high and supported by oak stakes. Outside of this, we applied a chemical barrier of pendimethalin herbicide (Pendulum® AquaCap™, BASF Corporation, Research Triangle Park, NC) at 3200 g a.i./ha (0.75 gal/ac) a broad spectrum pre-emergent herbicide, to a 1m- wide strip of bare ground.

Figure 16. Implementing the Competition Experiment at the WRR site.

Expected products

The competition experiment will be monitored for at least two additional growing seasons. The performance of the treatments will be assessed by quantifying density and cover of weeds vs. desirable vegetation. Data will be analyzed using a split-split plot, repeated measures analysis, with treatments and their interactions as fixed effects. The control over cheatgrass seed in this experiment should allow more power to detect effects than that afforded by typical reclamation trials. Costs and recommended application procedures will be discussed for any treatments promoting dominance of desirable vegetation under competition from cheatgrass.

Table 7. Seed mix used in the Competition Experiment.

Common Name	Variety	Scientific Name	Life Form	Seeds/ m2	PLS (kg/ha)	Seeds/ ft2	PLS (lbs/ac)
Slender Wheatgrass	San Luis	*Elymus trachycaulus spp. trachycaulus*	grass	150.7	5.1	14	4.5
Thickspike Wheatgrass	Critana	*Elymus lanceolatus spp. lanceolatus*	grass	150.7	4.5	14	4.0
Western Wheatgrass	Rosana	*Pascopyrum smithii*	grass	150.7	5.8	14	5.2
			TOTAL	**452.1**	**15.3**	**42**	**13.7**

CONCLUSIONS

In 2009, we obtained and analyzed the first year of data from the Phase I of the project, an experiment on weed control techniques on simulated pipelines. Plateau herbicide was effective at 2 of 6 study sites, and disking was also useful in controlling cheatgrass.

2009 was the initial year for Phase II of the project, which included 4 experiments conducted on simulated well pad disturbances. These experiments were tailored to particular zones of the landscape, and had overlapping treatments, which will allow inference over as broad a range of conditions as possible. Questions posed by the new experiments include: How important is facilitating natural seed dispersal vs. planting seed? What conditions mandate a conservative approach to reclamation? What new weed control techniques might be effective in improving establishment of desirable plants in weedy areas? How do soil additives affect the competitive balance between weeds and desirable plants? All four experiments were successfully implemented.

Future work will include monitoring cover of desirable and undesirable vegetation in all 5 experiments through 2012. The effectiveness of all treatments, their costs, their limitations, and the conditions under which they should be employed will be summarized in annual reports and in a final report for each experiment, which will be made available by February 2013. Recommendations about the best combinations of treatments for promoting diverse, complete plant communities in each climatic zone will be provided.

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Appendix 1. Soil test results.

					ppm						
SITE	**pH**	**EC (mmhos/cm)**	**Lime Estimate**	**OM (%)**	**NO_3-N**	**P**	**K**	**Zn**	**Fe**	**Mn**	**Cu**
GVM	8.1	0.2	Very High	1.8	0.7	1.8	125	0.417	4.58	4.25	4.35
MTN	7.7	0.2	Low	1.3	2.6	2.5	155	0.333	7.76	2.61	2.42
RYG	7.8	0.2	Medium	2.2	4.5	4.9	238	0.469	17.0	4.03	3.66
SCD	7.3	0.2	Low	2.5	3.0	1.8	113	0.390	17.3	2.57	2.29
SGE	7.9	0.3	High	1.4	4.6	1.5	77.1	0.146	4.05	3.56	1.80
SKH	8.3	0.3	Very High	0.9	3.4	3.1	213	0.308	2.68	0.79	3.00
SPG	7.8	0.3	High	2.5	12.0	2.1	79.7	0.340	12.3	0.82	2.87
SQS	6.5	0.2	Low	1.9	11.6	3.4	336	1.280	68.3	1.89	2.23
TGC	7.0	0.1	Low	2.8	6.8	4.6	166	0.618	36.2	0.60	2.04
WRR	7.3	0.3	Low	1.8	2.4	2.8	93.2	0.269	7.27	3.27	2.19
YC1	8.1	0.3	Very High	1.8	5.8	2.5	166	0.699	6.52	3.15	2.61
YC 2	7.8	0.3	Very High	3.2	11.3	6.2	200	0.526	12.8	6.55	3.10

	meq/L					%			
SITE	**Ca**	**Mg**	**Na**	**K**	**SAR**	**Sand**	**Silt**	**Clay**	**Texture**
GVM	2.1	0.5	0.4	0.1	0.3	50	30	20	Loam
MTN	2.1	0.6	0.4	0.1	0.3	52	26	22	Sandy Clay Loam
RYG	2.6	0.3	0.4	0.5	0.3	68	16	16	Sandy Loam
SCD	1.8	0.6	0.3	0.1	0.3	66	14	20	Sandy Loam
SGE	2.8	0.6	0.5	0.2	0.4	60	22	18	Sandy Loam
SKH	1.4	0.2	1.8	0.3	**2.0**	52	22	26	Sandy Clay Loam
SPG	3.1	0.7	0.4	<0.1	0.3	70	12	18	Sandy Loam
SQS	1.2	0.3	0.3	0.4	0.4	68	20	12	Sandy Loam
TGC	0.5	0.1	0.4	0.1	0.6	72	12	16	Sandy Loam
WRR	3.7	0.8	0.4	<0.1	0.3	56	26	18	Sandy Loam
YC1	1.7	0.1	2.6	0.2	**2.8**	62	24	14	Sandy Loam
YC 2	3.9	0.5	0.4	0.5	0.3	70	16	14	Sandy Loam