EFFECT OF SOIL AMENDMENTS (MATS AND HYDROSEEDING) ON ESTBALISHMENT SUCCESS OF FOUR NATIVE GRASSLAND SPECIES

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ABSTRACT

Restoration of grassland ecosystems is challenging due to moisture limitation, competition from non-native invasive plants, and difficulty in establishing native grassland species. A manipulative experiment was designed to study the establishment for four native grassland species using combinations of two soil amendments in the lower grasslands of Kamloops, BC. The treatments included the use of a straw germination mat with seed placed either on top or underneath, hydroseeding, a combination of the straw matting with the hydro-seeding either below or on top, seeding without any soil amendment and a control with no seeding or amendment. Treatments were each replicated 6 times in a randomized complete block design. Approximately 150 seeds of each bluebunch wheatgrass (*Pseudoroegneria spicata*), rough fescue (*Festuca campestris*), brown-eyed Susan (*Gaillardia aristata*) and long-leaved daisy (*Erigeron filifolius*) were broadcast seeded per plot. Soil moisture and temperature, and cover of functional groups on each treatment were recorded and statistically analyzed. The highest cover by functional group was undesirables, none of which were seeded species, indicating the presence of plant propagules at this site. It was found that mat treatments, with seeding below, resulted in the greatest cover of seeded species and the most desirable ratio of grass, forbs and undesirable species.

KEY WORDS

Grassland restoration, straw mats, functional groups, invasive species

INTRODUCTION

The goal of ecological restoration is to restore damaged ecosystems to a functioning and sustainable state (Cook and Suski 2008). This can be difficult as there are still barriers to using native seeds (Oliveira *et al*. 2013, Oliveira *et al*. 2012). There is uncertainty that natives will not establish or compete well with agronomic or non-native species and are at higher risk of weed invasion (Oliveira *et al.* 2013; Thompson *et al.* 2006). Disturbance may have changed the nutrient availability, soil structure, and overall growing conditions making the location unsuitable for native vegetation (Bradshaw 1983). Native seeding is also associated with higher costs that may come from having to artificially recreate favorable conditions for native seedlings and increased seeding rates (Bradshaw 1983, Richards *et al*. 1998, Thompson *et al.* 2006). There are also reports of poor success initially, but this could be attributed to the fact we have little research on the performance and germination requirements for native seed (Oliveira *et al*. 2013, Oliveira *et al.*2012, Peterson *et al.* 2004). In many cases there is also a lack of accessibility to native seeds because of limited stockpiling, low productivity, lack of policy and poor political support (Richards *et al.* 1998).

Restoration of grassland ecosystems in western North America presents even larger challenges. Moisture availability is one of the most important challenges to overcome in native grassland restoration (Oliveira *et al.* 2013). Annual precipitation in these regions tends to have high temporal variability and a narrow window in which seedlings can take advantage of moisture, making the growing seasons unpredictable (Bakker *et al.* 2003). As well, non-native invasive species introduced from other continents are of great concern in grassland ecosystems across western North America (DiTomaso 2000). Invasive species flourish in disturbed sites which causes major problems in trying to establish native vegetation when these invasive species are already present (Young and Clements 2005). In general, interspecific competition for soil resources between native and invasive species results in different plant community outcomes which may deviate from the goals of restoration (Bakker *et al.* 2003).

There are different approaches for dealing with moisture limitations and invasive species in grassland restoration. It is common for treatments such as irrigation and fertilizers to be used to support seed germination and growth (Bakker *et al.* 2003, Peterson *et al.* 2004) but these methods also cause increases in undesirable species (Abraham and Corbin 2009). To deal with increased weed species, herbicides can be used. To collectively address these problems many amendments have been developed including mats and hydroseeding. Operationally, mats and hydroseeding have become increasingly popular due to claims of their ability to increase soil moisture and reduce weedy species, among other benefits (Steinfeld *et al.* 2007).

Although there is a move towards using native species in grassland restoration situations, there are challenges to successfully establish these species in arid to semi-arid environments. The current knowledge on methods to increase germination and establishment success of grassland native species is often limited to a few of the more dominant species such as the key grasses. There is also limited information available on the impact of using common operational techniques such as mats and hydroseeding in these dry systems. Although previous studies suggest that these types of soil amendments may increase soil moisture and germination success this has not been well documented with native species in a grassland environment. Therefore this study was designed to address some of these knowledge gaps.

This study utilized two common forms of soil amendments, a straw germination mat and hydroseeding, and four native grassland species. The overall objective of this study was to determine how different restoration treatments impact seeded native species establishment and growth of undesired agronomics and noxious weeds. The specific objectives were focused on how the seven treatments impacted:

(i) soil moisture and temperature; and
(ii) the canopy cover of different functional groups (grasses, forbs and undesirable species).

These results can be applied to many situations where grassland restoration may be necessary, including in mine reclamation, oil sands reclamation, habitat restoration and disturbances from other industries. The data will provide information on functional groups and their response to different site treatments.

METHODS

<u>Study Area</u>

The study area was located within a lower grassland region of Kamloops BC. McLean and Marchland (1968) describes this lower grassland region as a big sagebrush-blue bunch wheatgrass site. These types of sites are characterized as being between 335 m and 610 m in elevation, with 23-25 cm of rain a year with over half falling between April and October (McLean and Marchland 1968). The dominant species found in undisturbed areas are bluebunch wheatgrass (*Pseudoroegneria spicata*), Sandberg's bluegrass (*Poa secunda*), needle-and-thread grass (*Stipa comata*) and big sagebrush (*Artemesia tridentata*) (McLean and Marchland 1968).

The specific location of the experiment was 50° 40' 17'' N 120°22'18'' W at an elevation of 544 m. The site was a fenced compound at Thompson Rivers University. The vegetation surrounding the study site consisted of native and introduced lower grasslands species. Dominant species included bluebunch wheatgrass (*Pseudoroegneria spicata*), big sagebrush (*Artemesia tridentata*), Kentucky bluegrass (*Poa pratensis*), crested wheatgrass (*Agropyron cristatum*), and knapweed (*Centaurea* spp.). On the study site all above ground vegetation was removed using the bucket of a tractor on May 3rd, 2013. The site was then raked and large remnants of plant material were removed. The existing seed bed and some rootstock still remained and no herbicide was applied to the site.

<u>Experimental Design</u>

The experiment was set up as a randomized block design consisting of 7 treatments each replicated 6 times for a total of 42 plots (Table 1). The treatments were control (no seeding), seeding only, hydroseeding, straw matting with seed above the mat, straw matting with seed below the mat, hydroseeding under the straw mat and hydroseeding above the straw mat (Table 1). The design lay out had three plots along the width and 14 plots along the length. Each plot was a half meter square with 20 cm between plots width wise and 50 cm between plots length wise, creating a totally rectangle that was 1.9 m by 13.5 m. Blocking was applied due to a slope gradient and an increase in gravel content in the south plot which may affect soil moisture.

Table 1. The seven treamtents used in the study and the associated codes.

Definition	**Code**
Control, sand only	Cont
Seeded only	S
Hydroseeded	H-S
Straw matting with seed placed underneath the mat	M-SB
Straw matting with seed placed on top of the mat	M-ST
Hydroseeding underneath a straw mat	HM-SB
Hydroseeding on top of a straw mat	HM-ST

Four species were selected for seeding, 2 native grasses, *Festuca campestris* and *Pseudoroegneria spicata*, and 2 native forbs, *Gaillardia aristata*, and *Erigeron filifolius*. The grasses were selected because they are the dominant native species found in surrounding grasslands. The native forbs were selected based on unpublished data that showing that these two forbs had a relatively high germination success (K. Baethke, personal communications, 2013). *F. campestris, P. spicata* and *G. aristata* seeds were purchased from Purity Feeds, a local seed supplier. *E. filifolius* was hand-picked from a Lac du Bois Park at an elevation of 550 m. Seed packets consisting of approximately 150 seeds for each species, based on weight, were prepared for each seeded plot for a total of 600 seeds per half meter plot. Two tablespoons of sand was added to act as a carrier; the control seed packets contained sand, no seed Broadcast seeding occurred on May 3rd 2013, a windless day, on raked plots. Special care was taken to keep the package contents low to the ground to reduce seed drift.

The straw matting used, *Dewitt Straw Guard 200*, was designated as a seed germination blanket with some erosion control. The mat was cut into 0.5 m^2 squares for the specified plots. The edges were nailed into place to prevent the wind from blowing it away. To determine if placement of seed impacted establishment six replicate treatments had the seed placed on top of the matting and six replicate treatments had the seed placed underneath the matting.

The hydro-mulch used was *EcoFibre Premium Wood Fibre* produced by *Profile Products*. The hydroseeding slurry was mixed in one large batch and separated for each specified plot. The entire hydroseeding slurry contained 97.5 L of water, 3105.5 g of wood fibre, and three tablespoon of tackifier, a chemical binder which was provided with the wood fibre. Three litres of the slurry were taken at a time and the designated seed package was mixed in before it was placed on the plot. Special care was taken to make sure seeds did not settle to the bottom of this container before the slurry was poured onto the plot. The three litre mixture was then smoothed out over the plot using a plastic spatula.

On the day of seeding and for the 2 days directly after, the study site was watered for half an hour with an oscillating lawn sprinkler. After that plots received 2 litres of water twice a week until July 29th with the goal of assisting seed establishment. If soil moisture was above 10% water fraction by volume, the soil was at field holding capacity and no watering was done, which was the case through the month of May.

Precipitation and ambient temperature was recorded at a weather station located at 50°44'20.66"N, 120°25'58.14"W, 691 m in elevation, in another lower grassland region within Kamloops. This weather station was chosen because it was located at the most similar elevation compared to other weather station options in the area. The precipitation, maximum monthly temperature and minimum monthly temperature for 2013 were compared to the long term normal calculated from data from 1979 to 2013. Precipitation in April and May was above the 34 year average, but was then was drastically lower in June, July and August. The average monthly maximum air temperature throughout the growing season was consistently lower than the 34 year average and the average monthly minimum air temperature was higher than the 34 year average.

Data Collection

Soil moisture and temperature were taken twice a week during the time period of May 17 2013 to August 30 2013 using a *POGO Portable Soil Sensor* equipped with a *Stevens Hydra Probe Soil Moisture Sensor* with 6 cm probes used in conjunction with Windows *HydraMon 1.4* software program. The sensor probes were placed in the centre of each plot until the reading became steady, then the values were recorded. This was repeated for each plot starting from the north end of the plots to the south end of the plots. One plot, the sixth hydro-seeded replicate, was found to have too much gravel in the soil which prevented any soil moisture readings through the season.

At the end of the growing season, on September 9 and September 10 2013, canopy cover of all species present was recorded. Percent canopy cover by layer of individual species in the entire 0.5 m^2 plot was recorded. Plants that were rooted outside of the plot but hanging in were not included because their establishment would not have been from the treatment. To reduce bias data collection was done by a single observer.

Plant cover data was organized into three functional groups, grasses (seeded and other native grasses), forbs (seeded and other native), and undesirables (weedy species) (Table 2). Undesirable species consisted of any non-native grasses or forbs. This included noxious weeds and agronomic species.

Table 2. A list of the individual species that made up the three functional groups: grasses, forbs and undesirables. This table includes all species found in the lower grassland study site based on plant data sampling conducted September 9th and 10th, 2014.

Grass	Forb	Undesirable
Festuca campestris	*Erigeron filifolius*	*Kochia scoparia*
Sporobolus cryptandrus	*Gaillardia aristata*	*Centaurea spp.*
	Artemisia tridentata	*Agropyron cristatum*
	Grindelia squarrosa	*Sisymbrium spp.*
		Bromus tectorum
		Linaria vulgaris

Statistical Analysis

Soil moisture and temperature data was pooled by treatment to give an average temperature (degrees Celsius) and moisture content (percent water by fraction) for each date. Values for each treatment were averaged throughout the growing season and plotted to see if treatment impacted these variables. No statistical analysis was conducted on this data.

Statistics were analyzed using *IBM SPSS Statistics 20.* Data were tested against the assumptions of analysis of variance (ANOVA). Raw data did not fit the assumption of normality and was transformed by adding one and taking the log (10) value. Transformed data was deemed as normally distributed based on using a normal Q-Q plot and values for skewdness and kurtosis. The Levene's test was run on the transformed data and indicated that equality of variance was not met. However, the effect of inequality of variance is mitigated when the sample sizes are equal which was the case for our study. Therefore ANOVA was used for all data analysis.

To determine treatment impact on canopy cover a two-way ANOVA was run for each seeded species. If treatment effect was significant post hoc analysis was conducted using a Tukey's test. To determine treatment impact on functional groups a two-way ANOVA was run. If a significant effect was found then a Bonferroni adjustment was used to determine differences between the treatments. This adjustment is recognized as being a conservative post hoc test which allows a lot of confidence to be placed in significant outcomes.

RESULTS

Soil Temperature and Moisture

No differences in soil moisture or temperature were detected between different treatments in the top six centimeters of soil. Soil temperature was increasing and decreasing with changes in ambient temperature.

Canopy Cover of Functional Plant Groups

Blocking had no significant effect on canopy cover of the functional groups, but canopy cover was significantly impacted by both functional group ($p<0.001$) and treatment (P*p*0.001). For functional groups the post hoc testing determined all comparisons were significantly different from each other (grass and forb $p = .01$, grass and undesirables $p < .001$, forb and undesirables $p < .001$) (Figure 1).

For treatment the post hoc testing detected a significantly higher total plant cover, of all species, in the mat seeded on top and mat seeded below treatments compared to hydroseeding on top of mat. There were no significant differences of total plant cover between the control and any treatment (Figure 2).

The highest mean cover of undesirable species was found in the control (μ=70.5%) and seeded only (μ=68.7%) treatments but decreased in the mat seeded below (μ=41.7%) and mat seeded on top treatments (μ=43.5%), and was lowest in the hydroseeding on top of mat (μ=26.8%) and hydroseeding below mat (μ=28.8%) treatments (Figure 7). The highest mean of grasses and forbs was found in the mat seeded on top (μ=32.6%, μ=14.1%) and mat seeded below (μ=49.5%, μ=12.8%) treatments. The control, seeded only and hydroseeding treatments had the highest undesirable cover. The hydroseeding on top of mat and hydroseeding below mat plots had the lowest cover of undesirables but also lowered the cover of grasses and forbs. The mat (both seeded on top and seeded below) treatments had the most desirable ratio of grass, forbs and undesirables (Figure 3).

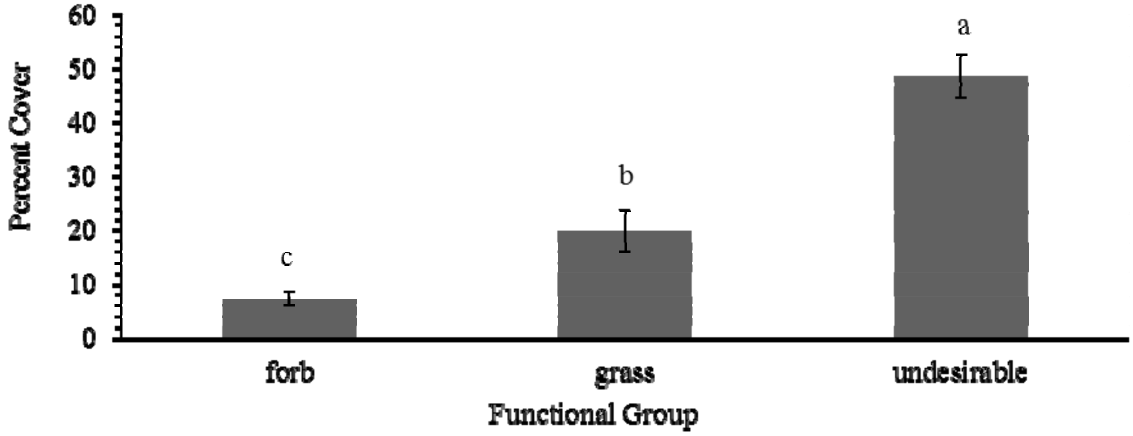

Figure 1. The average canopy covers of each functional group. The data represented as the bars and the error bars show the actual raw data cover data. Means with different letters represent significantly different results with a 0.05 *p* value. Post hoc groupings are based on transformed data.

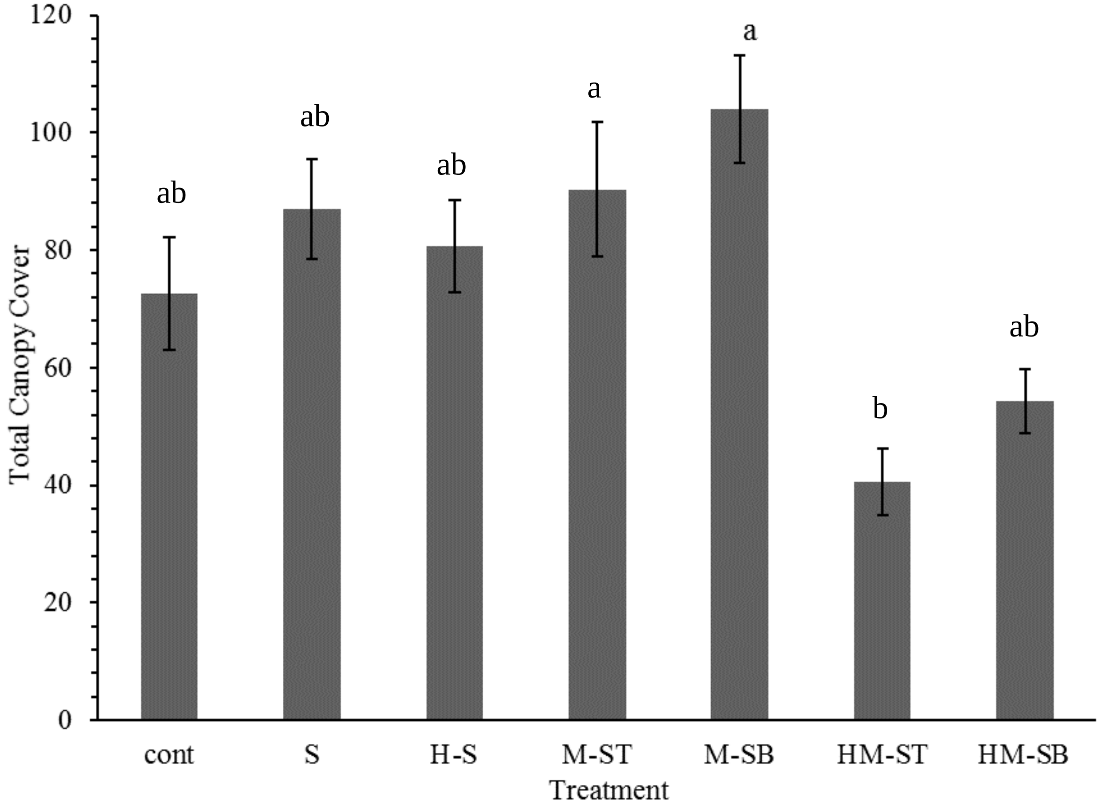

Figure 2. The average total combined cover of all species (all functional groups combined) by treatment type. The data represented as the bars and the error bars show the actual raw data cover data. Means with different letters represent significantly different results with a 0.05 *p* value. Post hoc groupings are based on transformed data.

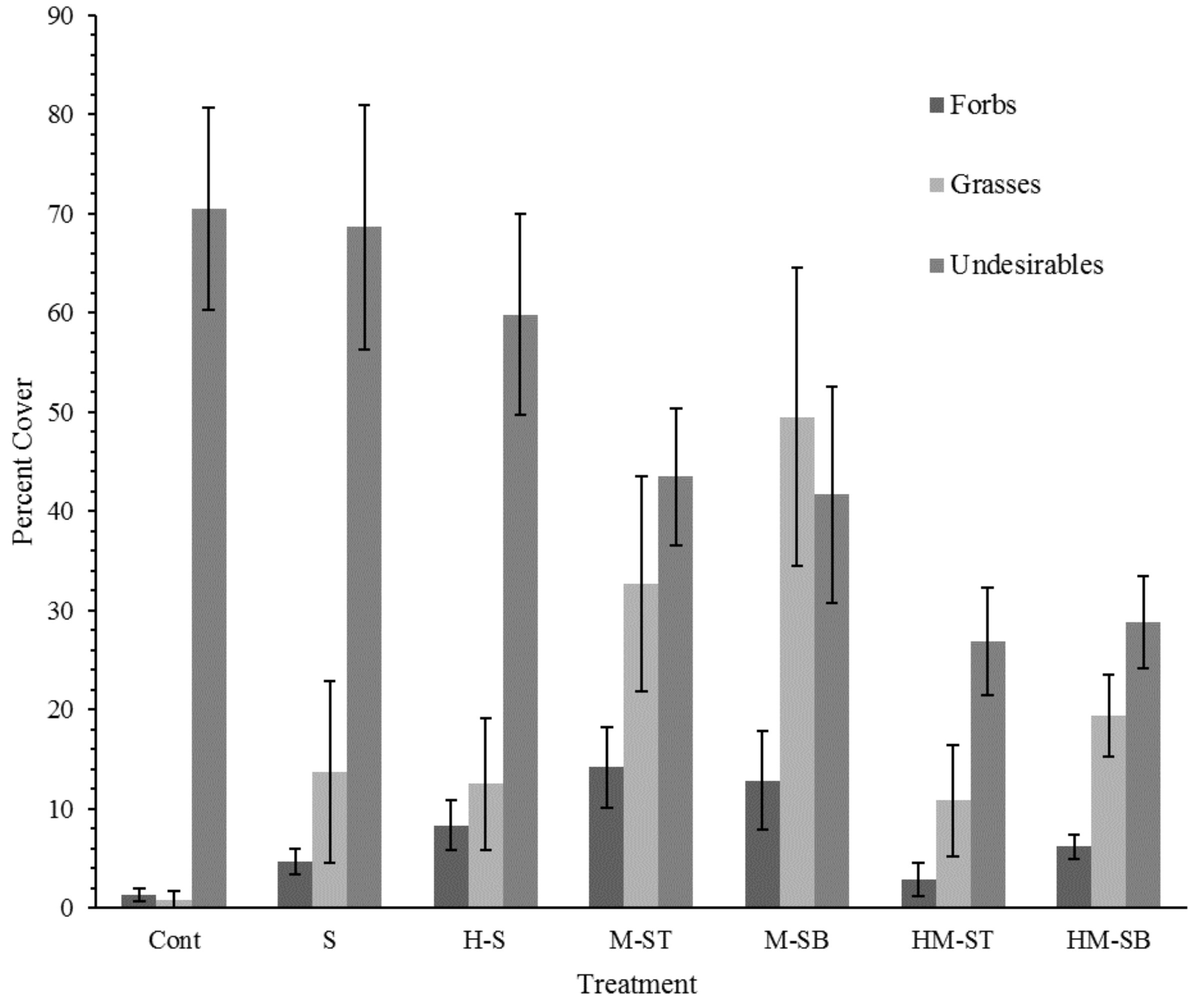

Figure 3. The average percent cover of each functional group, being grasses, forbs and undesirables, by treatment. The data represented as the bars and the error bars show the actual raw data cover data.

DISCUSSION

Soil Temperature and Moisture

The results show that treatments did not impact soil moisture and temperature. This outcome was most likely due to the methodology used to determine these variables. The *POGO Portable Soil Sensor* used to measure soil moisture and temperature had a 6 cm deep probe. The probe tracked soil moisture a few centimeters under the soil surface but was not able to capture differences on the surface of the soil. Other experiments have been able to detect differences in soil moisture using the gravimetric method and other types of soil probes for similar depths (Deutsch *et* al. 2010, Wicks *et al.* 1994). During the experiment, differences in moisture were observed, particularly if rain events had occurred within a few days prior. Matting amendments appeared to have more moisture present between the soil surface and the straw matting, while the top of the straw was dry. The hydroseeding slurry was also observed to be moist on some of these occasions as well. These indications of moisture were observed when the control and seeded only treatments were dry on the surface. The observations of the site are more consistent with the literature in terms of soil moisture than what was actually recorded (Deutsch *et al*. 2010, Wicks *et al.* 1994). Using different instrumentation may have captured these differences more accurately, for example the use of iButton data loggers on the soil surface as they can continuously log temperature and humidity.

<u>Canopy Cover of Functional Groups</u>

Our results show that undesirable species had a significantly higher cover than forbs and grasses. This may have been a result of the site location and the type of disturbance that was used to create this experiment. While the top few centimeters of soil were removed to create this experiment, the seed bank and roots in the soil were not eradicated and no herbicides were used to eradicate any live plant material present. The plant material and seed bank that would most likely be present would be similar to the vegetation surrounding the experiment. This mostly included *A. cristatum*, *Centaurea* spp., and *Sisymbrium* spp. which are all grouped in the undesirable functional group. Therefore, in this case, regardless of treatment these species were already going to be well established on the site and seeded species were going to have to compete. These conditions likely hindered the full ability of seeded species (Skousen and Venable 2008).

Regardless of species or functional group, treatments had statistically similar plant cover, ranging from 45% to 105% cover. The control had 73% cover and was not significantly different from any of the other treatments. This is because there was already a seed bank and live root mass on this recently disturbed site. This may not be the case on sites where there is a longer term disturbance and a limited seedbank or source of propagules are available. Hydroseeding on top of the mat resulted in significantly lower cover when compared to the mat. This indicates that the mat created the most favorable conditions, resulting in the highest mean cover, while the combination of hydroseeding on top of the mat created the least favorable conditions, likely smothering any vegetation that did start to grow beneath the amendment. Hydroseeding below the mat had the second lowest mean, but was not significantly different from the other treatments.

Even though total cover was similar across species the amount of forbs, grasses and undesirable species cover changed between treatments. The matted treatment resulted in the most desirable outcome having high levels of forb and grass cover (μ= 62%) while lowering undesirable cover to 40-50% versus the 70% found in the control and 68% in the seeded only. This is much higher for first year establishment seen in other seeding only studies (Skousen and Venable 2007). The straw mat may have reduced evaporation, increased water infiltration by preventing soil surface sealing due to rain drop splash, and reduced soil surface temperatures which over all created better growing conditions for seeded species (Cole 2007, Roberts and Bradshaw 1985). These components may have created the most favorable microsite for germination that was not captured in the temperature and moisture recordings (Peterson *et al* 2004, Simmons *et al.* 2011). The mat with seeding below had over three times the cover of grass and forbs compared to seeding alone and hydroseeding treatments. Mat treatments have previously been shown to significantly improve survivorship (Mallik and Karmin 2008). The decrease in the cover of undesirables in the mat treatments may have been due to increased competition from the seeded species. In many other cases straw mulch decreased weed species significantly, but this may be partially due to smothering from thick applications (Anzalone *et al.* 2010, Wicks *et al.*1994). In our study the straw matting created a relatively thin single layer with many openings to the soil surface. In a practical application of using mats some form of an herbicide would likely be used that would have reduced the cover of desirables further (Wicks *et al.* 1994).

The seeded only treatments had a very high cover of undesirables and lower cover of grasses and forbs. The undesirable species would have been quicker taking advantage of the conditions through earlier emergence (Oliveira *et al*. 2013). They would have also benefited from the springtime watering, but native species where still able to compete, reaching a mean cover of 26%. Undesirable species such as *A. cristatum* are quick to grow in the springtime to use available soil resources, restricting their use by desirable species (Oliveira *et al*. 2013). Other species, like *Centaura* spp., may have used their deep rooting to reach soil resources as a competitive advantage (Oliveira *et al*. 2013). The restricted growth of the grasses and forbs in the seeding and hydroseeding treatments is most likely due to competition with undesirables (Oliveira *et al*. 2013). There are many instances recorded in the literature that show that the weed species, grouped in this study as undesirables, benefit and compete better in disturbed locations and with watering (Banerjee *et al*. 2006).

The hydroseeding treatment had very similar results in its proportions of functional groups as seeding alone. Previous concerns that hydroseeding may inhibit seed establishment do not appear to be occurring in this case. However, without the watering in the spring there might not be the amount of cover of native species on this treatment (Andrés and Jorba 2000).When the hydroseeding and matting was combined the result was a low cover of all functional groups. The combination of the treatments likely acted as a barrier to all plants, regardless of functional group. The thickness and hardness of the combined treatment may have created an impermeable barrier.

The control had the highest mean of undesirables and the lowest amount of grasses and forbs, as would be expected. The reason we found an occurrence of the grass functional groups is because one of the control replicates had one occurrence of *Sporobolus cryptandrus* and one occurrence of *F. campestris*. The forbs that occurred on the control included one occurrence of each seeded forb and two occurrences of A*rtemisia tridentata.* The occurrence of the seeded species was likely due to drift off of plots from wind or water or human mishap during the time of seeding.

In general there was a decreased trend of cover of undesirables from the control to the mat. This trend reflects first the addition of the seeded species (seeded and hydroseeded) and then the increase in favorable conditions for seeded species (mat treatments) along with increased competition for the undesirables (Cole 2007, Mallik and Karmin 2008, Peterson *et al.* 2004, Roberts and Bradshaw 1985). Overall the use of mats provided the best ratio of desirable grasses and forbs to undesirable species while hydroseeding was similar to seeding alone.

<u>Study Limitations</u>

This study was short term, capturing only one growing season. Natives are often slow to emerge and other studies have found large increases in the second year (Oliveira *et al.* 2013). Seeding was also done in the spring and the following year may give seeded species an opportunity to take advantage of early spring moisture and snow melt resulting. Also the blocking effect with low replication may have made it more difficult to detect significant differences, specifically in the case of species with low cover. The use of herbicide before seeding may have helped to reduce competition and resulted in better establishment of the seeded species. Finally, the use of sensors that can capture temperature and moisture in smaller depth increments and more continuously over time would be beneficial to understanding the relationship between these different treatments and microclimate.

CONCLUSION

This study has added to the limited knowledge of native grasslands species and their ability to establish with the use of soil amendments. The results indicate that hydroseeding was similar to seeding alone, making this a viable option for use in grassland restoration where erosion control may be an issue, or over large areas at risk of wind and seed predation. However the use of straw matting resulted in the most favorable outcome, increasing the establishment of native seeded species and also decreasing the cover of undesirables. These results suggest that the use of matting is helping to address some of the site limitations. This is most likely because moisture is a limiting factor in these environments and mat treatments alter the moisture stress, although this study was not able to capture changes in soil moisture.

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