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The Effects of Compost and Polyacrylamide Hydrogel on the Re-Vegetation of Eroded Southern Aspects in the Western Rangeland

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THE EFFECTS OF COMPOST AND POLYACRYLAMIDE HYDROGEL ON THE RE-VEGETATION OF ERODED SOUTHERN ASPECTS IN THE WESTERN RANGELAND

By

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ABSTRACT

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MPG Ranch is a conservation-oriented organization in Montana's Bitterroot valley. Since 2010, MPG has annually planted between 5,000 and 10,000 shrubs and trees with the goal of restoring native plant communities, beautifying the landscape, and providing habitat and forage for wildlife. Plant survival has been lowest on degraded south facing slopes, likely due to a combination of erosion and high solar radiation, which have left the soil with low nutrient content, soil moisture, and high soil temperatures. To resolve these issues, we partnered with MPG to test whether soil amendments can be used to increase plant establishment on degraded hillslopes. Soil amendments included a polyacrylamide hydrogel (Terra-sorb), compost, and Terra-sorb and compost combined. These amendments were tested on three different native shrub species: *Cercocarpus ledifolius* (curl leaf mountain mahogany), *Juniperus scopulorum* (Rocky Mountain juniper), and *Purshia tridentata* (antelope bitterbrush). We assessed the impact of these three soil amendments on plant growth, plant health/mortality rates, and soil chemical and physical properties. Overall results revealed few consistent patterns. Compost as a treatment resulted in the lowest levels of plant mortality whereas plants in the control plots suffered the highest. Plant growth was more dependent on the species in question rather than the amendment used. Mountain mahogany was the most successful in terms of growth both above and below ground with all living plants growing 0 – 1% throughout the course of the season. Our recommendation to MPG is that they continue to monitor these plants for multiple growing seasons in order to determine if they are more or less effective in the long run than what our experiment showed for short-term results.

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INTRODUCTION

MPG Ranch is a privately owned and operated ranch near Florence, Montana in the Bitterroot Valley committed to sustainable land stewardship and wildlife habitat enhancement. Cattle grazing, agriculture, and non-selective herbicide application from the previous owners of the ranch degraded the landscape and altered native plant communities. MPG is attempting to restore native plant communities and to create new wildlife habitat and forage. Since 2010, MPG Ranch has planted over 27,000 native trees and shrubs and has experimented with various techniques and planting amendments to improve survival numbers (McTee 2013). After the first year of re-vegetation, plant survival was limited to 38%. The ranch has made progress, and in 2014 49% of all plants from all previous years were still alive (McTee 2013).

The most significant challenge for the ranch so far has been to encourage plant survival on south-facing slopes of the ravines that run through the property. These slopes receive significant amounts of solar radiation and have lost the majority of their topsoil to erosion. This combination has led to soils that have low water holding capacity, low fertility, low nutrients, and low likelihood of plant establishment. For example, 77% of plantings on north facing slopes in Upper Partridge Alley survived at least two years after planting in 2011. In the same gulley, only 23% of plants planted on corresponding south-facing slopes survived until the following fall (McTee 2013). MPG has determined three species – *Cercocarpus ledifolius* (curl leaf mountain mahogany), *Juniperus scopulorum* (Rocky Mountain juniper), and *Purshia tridentata* (bitterbrush) – are the best suited for these degraded slopes and has experimented with different irrigation regimes with little overall effect (McTee 2013). To address these challenges that MPG is facing we devised an experiment to determine the efficacy of two different soil amendments on plant growth and survival.

Terra-sorb, the first amendment chosen by MPG, is used to increase water-holding capacity. This product has been shown to promote plant survival by increasing plant-available water thus reducing the stressful effects of drought (Arbona et al 2005, Hűttermann et al 1999, Verschoor and Rethman 2010). Terra-sorb has been shown to hold up to 150 times its weight in water, increasing the amount of water available for plants to use (Akhter et al. 2004). A main ingredient in Terra-sorb is potassium, which is also linked to improved drought tolerance (Pearson Learning Solutions, 747; 2015). In addition, polyacrylamide gels have shown to be effective at mitigating erosion when applied to soils that have recently been disturbed (Inbar et al. 2015). These studies occurred on sites degraded by either wildfire or drought-affected soils, meaning that no information exists yet to suggest Terra-sorb would have the same effects on agriculturally degraded slopes (Alm and Stanton 1993).

Other studies using polyacrylamide hydrogel have indicated that its effectiveness in holding soil moisture is lessened with exposure to high levels of temperature and sunlight, such as those seen on MPG Ranch (Rowe et al. 2005). Despite this issue, we believed that the potential benefits of Terra-sorb to the soil were worth the effort and costs of including it in the experiment.

To combat the low fertility and nutrition on these slopes, compost was chosen as the second soil amendment. Compost has been shown to stimulate plant growth and development and increase plant biomass; these effects are due to the increase in nutrient content and cation-exchange-capacity (Chen and Aviad 1990). Other research has shown that compost increases soil organic carbon, available phosphorous, iron, manganese, zinc, copper, potassium, and pH meaning that compost is a good way to supplement nutrients to unhealthy soils (Soumare et al. 2003).

To assist MPG in determining the efficacy of using these soil amendments and in identifying potential limitations to plant survival and growth, we addressed the question: how does the use of soil amendments (Terra-sorb, compost, and Terra-sorb + compost) affect transplant growth, survival and soil properties for new plantings on harshly degraded and drought-affected soils? We expected that the addition of Terra-sorb would reduce plant stress and result in greater growth than plants in untreated soil because Terra-sorb would increase the soil's water holding capacity and moderate its temperature. We did not expect a significant change of soil chemistry due to the addition of Terra-sorb because it is primarily made up of only potassium and no other nutrients. We also predicted that the addition of compost to eroded, nutrient poor, south-facing slopes would lead to successful plant establishment. We did not predict that the addition of compost would make any significant changes in terms of soil moisture or temperature.

This research was meant to add widely applicable knowledge to the field of restoration on the use of these two particular soil amendments. Many of the aforementioned studies have experimented with compost or polyacrylamide hydrogels in soils affected by a variety of disturbances, but none have specifically dealt with the issues that MPG faces in attempting to restore their land. In addition few studies have experimented on the potential benefits of using a polyacrylamide hydrogel in conjunction with compost (Böhlenius et al 2014).

METHODS

Terra-sorb and Compost

To assess the impact of soil amendments on transplant growth and survival, we used four treatments: Terra-sorb only, compost only, both amendments combined, and a no amendment control. Three ravines (Sheep Camp, Middle Draw, and Tongue Creek) were chosen at MPG Ranch (Florence, MT) that were consistent in soil properties and microclimate. Mountain mahogany, Rocky Mountain juniper, and antelope bitterbrush were planted randomly on south-facing slopes of the ravines. These three species were chosen by MPG for this and previous plantings due to their high forage and cover value (McTee 2013).

For each draw, there were 15 replicates per treatment and control; this totaled to 180 plants per draw (N = 540). MPG technicians dug holes that were the volume of one gallon. Excavated soils were then mixed with amendments on site. For treatments that received compost, they added compost to the soil at a 10% rate. For treatments that received Terra-sorb, they added one ounce. Soils were mixed and deposited back in the hole with the plant.

To assess the impact of treatments and differences among species in growth and survival, initial plant height was measured as the length of the plant's tallest growth leader immediately after transplant. Plant growth and survival was assessed mid-growing season (July) and at the end of the season (September). Percent growth was determined by subtracting the initial plant height from plant height at each time point, then dividing the difference by the initial size and multiplying by 100%. For plants that died before the third measurement, percent growth was recorded as zero. Mortality rates were calculated by taking the number of dead plants per treatment per species per location divided by total number of plants of each treatment per species per location. To assess the mortality rates by treatments, locations were combined and mortality rates of each species were calculated separately and then averaged. In addition, final total biomass was measured at the end of the season. Biomass was measured by taking a subsample of 36 plants from the Sheep-Camp draw and harvesting both the soil and plant. We used a ratio estimator that uses the height and biomass data from our subsample to calculate the root:shoot ratio of plants that were not harvested. The plants were dug out, washed, dried at 65 °C, and weighed.

To assess the impact of Terra-sorb and compost addition on soil temperature and moisture, we used soil temperature buttons and a soil moisture sensor to measure changes in both throughout the season. Soil temperature buttons were inserted into the ground to a depth of 10 cm adjacent to a plant at the time of planting and collected continuous temperature data throughout the season. One temperature button was placed in the soil for one replicate for each treatment for each species ($N = 12$). Soil moisture was measured manually every two weeks from two replicates of each combination of species and treatment ($N= 24$). To keep soil moisture levels consistent on each draw, drip irrigation was installed and all ravines were watered once every two weeks. Soil moisture was measured on weeks between irrigation weeks.

To assess the impact of Terra-sorb and compost on soil nutrient levels, one replicate of each treatment and species combination was chosen at random for soil chemical analysis (Ward Laboratories, Inc, Kearney, NE) at the Sheep Camp site. Analysis included: pH, soluble salts, organic matter, cation exchange capacity, and nutrient content (N, Zn, K, Ca, Mg, Na, S, Fe, Mn, and Cu). Samples were taken at the beginning of the season from sites chosen for plantings and again at the end of the season from the amended soils. Samples were collected with a standard hand shovel to a depth of 20 cm and were sent to the laboratory in paper bags provided by Ward Laboratories.

STATISTICAL ANALYSIS

In order to determine if our data was normally distributed we created histograms for each independent variable and found that no transformations were needed. We tested for among-soil amendment treatment and species differences in plant growth and survival using repeated measures ANOVA models, with separate tests for each response variable (plant growth rate, survival, soil temperature, and soil moisture levels). Soil amendment treatment (Terra-sorb, compost, combination, and control), species, draw, and time of data collection (July or September) were included as independent variables in the model. We also included a species x treatment interaction term to assess if the three species showed differences in their response to soil amendments.

We tested for among-treatment and species differences in final total biomass using a two-way ANOVA model. Soil amendment treatment and species were included as independent variables in the model, and we included a treatment x species interaction term.

RESULTS

Growth

In a three-way ANOVA, species was found to be the only significant individual factor ($P < 0.000$), while location and treatment were not significant for growth. The interaction between plant species and soil amendment was the only significant interaction in its effect on percent growth ($P = .006$). When followed up with a post-hoc test it was found that any differences in the impacts of the interactions were due to species and not treatment. Growth of plants in terms of height are shown in Figure 1 according to species and treatment.

A two-way ANOVA test indicated that species was a significant factor for root:shoot ratio ($P = .000$); there was no significant effect of amendment, and none of the tested interactions were significant. For root:shoot ratio mountain mahogany greatly exceeded the other two species with mean root growth being equal to 80% of above ground growth. Bitterbrush experienced a mean root growth equal to 29% of its shoot growth, and Juniper 31%.

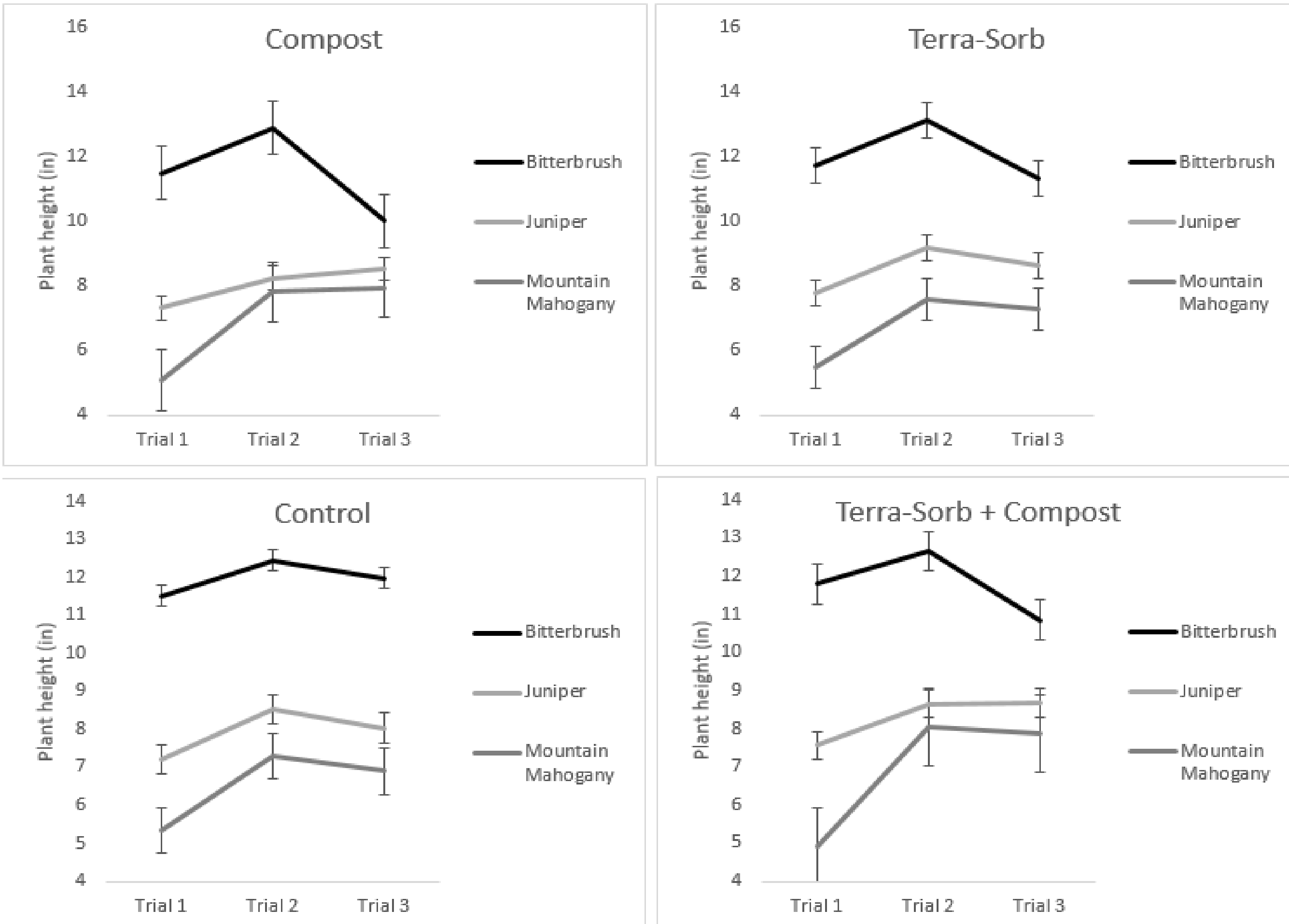


Figure 1. Mean plant species height between measurement trials separated by amendments. Mountain mahogany had highest mean percent growth (Compost, .0489%; Control, 0.207%; Terra-Sorb, 0.349%; Terra-Sorb + Compost, 0.55%) comparatively to all other species with each amendment, followed by juniper and then bitterbrush.

Mortality

All three variables (location, species, and treatment) influenced the variability of mortality among the plants. Plants in the control treatment had the highest rate of mortality (45%), while plants in all other treatments suffered around 36% mortality (Table 1). More noteworthy were the differences in mortality between the three species. Bitterbrush experienced the highest rate of mortality, which was greater than those of the other two species combined (Table 1). Also interesting were the differences in mortality rates between the three locations. Sheep camp notably had a much higher mortality rate than either of the other two locations (Table 1).

Table 1: Total mortality rates across the experiment by treatment, location, mortality

Table 1: Mortality Rates	
Treatment	Mortality Rate:
Control	45%
Compost	35%
Terra-sorb	37%
Terra-sorb + Compost	36%
Species	Mortality Rate:
Juniper	30%
Mountain Mahogany	20%
Bitterbrush	64%
Location	Mortality Rate:
Sheep Camp	52%
Tongue Creek	29%
Middle Draw	25%

Moisture

Soil moisture showed little variation overall, with the average moisture content throughout the season ranging from .08% to .2 % soil water volume (Figure 2). A three-way ANOVA test revealed that none of the factors (treatment, location, species) were significant in driving soil moisture (all P-values > .05). A univariate ANOVA test between amendment and average soil temperatures of June (P=0.497), July (P= 0.518), and August (P=0.435) showed there were no significant differences between amendments on soil temperature.

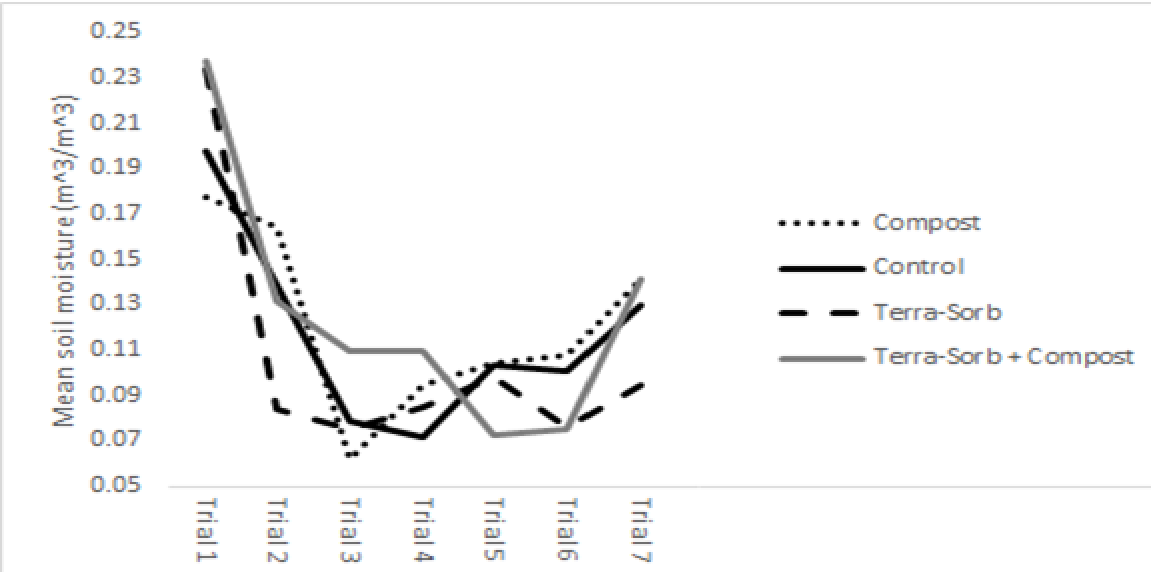


Figure 2. Mean soil moisture content for all samples of the same treatment across the seven measurements. All treatments followed a clear pattern of losing most moisture by trial 3 (mid-July) and then regaining some by the final measurement in September.

Chemistry

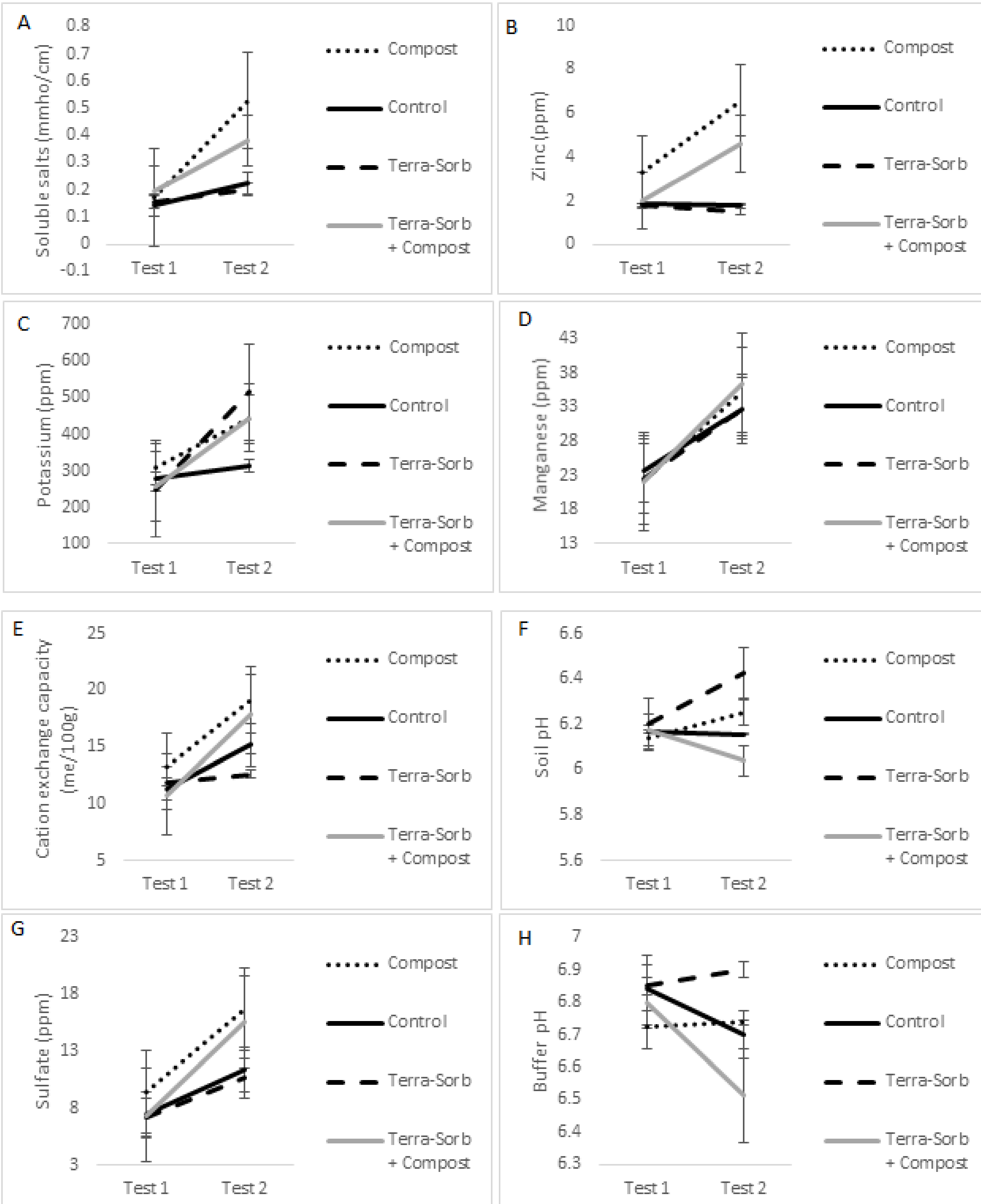
Out of the 15 soil properties and nutrients that were tested, it was found that organic matter and concentrations of copper, iron, magnesium, nitrate and calcium did not significantly change with any of the treatments.

For plants treated with only Terra-sorb, there were five significant changes in soil chemistry. Sulfate (p=0.006), potassium (p=0.01), and sodium (p=0.02) all increased; soil treated with Terra-Sorb also became less acidic (p=0.03) and showed an increased cation exchange capacity (P= .024) (Fig. 3).

For plants treated with only compost the only significant change in soil chemistry was an increase in cation exchange capacity (P=.028) (Fig. 3).

Soil in the control plots showed significant increases in CEC (P=.000), sulfate (P=.003) and sodium (P=.003) over the course of the season (Fig. 3).

The soil from the Terra-Sorb + compost treatment impacted the largest number of nutrient concentrations. Soluble salts (P=.049), zinc (P=.027), potassium (P=.009), manganese (P=.027), CEC (P=.012), sulfate (P=.003) and sodium (P=.002) all increased over the course of the season, while soil pH decreased (P=.023).


A
Soluble salts (mmho/cm)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
Test 1
Test 2
Compost
Control
Terra-Sorb
Terra-Sorb + Compost
B
Zinc (ppm)
10
8
6
4
2
0
Test 1
Test 2
Compost
Control
Terra-Sorb
Terra-Sorb + Compost
C
Potassium (ppm)
700
600
500
400
300
200
100
Test 1
Test 2
Compost
Control
Terra-Sorb
Terra-Sorb + Compost
D
Manganese (ppm)
43
38
33
28
23
18
13
Test 1
Test 2
Compost
Control
Terra-Sorb
Terra-Sorb + Compost
E
Cation exchange capacity (me/100g)
25
20
15
10
5
Test 1
Test 2
Compost
Control
Terra-Sorb
Terra-Sorb + Compost
F
Soil pH
6.6
6.4
6.2
6
5.8
5.6
Test 1
Test 2
Compost
Control
Terra-Sorb
Terra-Sorb + Compost
G
Sulfate (ppm)
23
18
13
8
3
Test 1
Test 2
Compost
Control
Terra-Sorb
Terra-Sorb + Compost
H
Buffer pH
7
6.9
6.8
6.7
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Test 1
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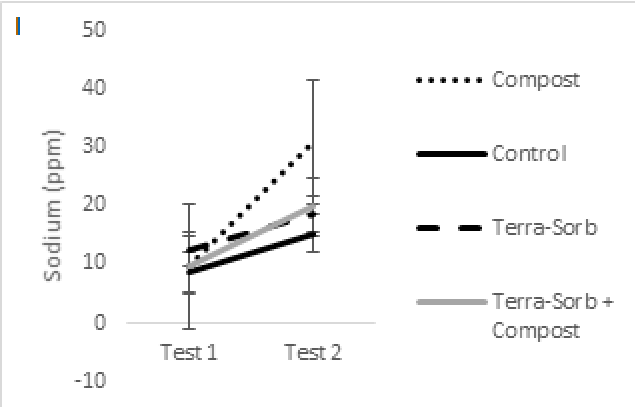

Figure 3. Changes in soil chemistry from experiment start (6/7/15) to end (9/6/15) among treatments (compost, control, Terra-sorb, Terra-sorb + compost): a) soluble salts, b) zinc, c) potassium, d) manganese, e) cation-exchange capacity, f) soil

DISCUSSION

In the field of ecological restoration many practitioners have experimented with soil amendments to counteract the effects of erosion and nutrient leaching. MPG is one organization that is interested in seeing if soil amendments can help repair the degradation left behind by the ranch's previous owners, especially on the steep southern aspects. The primary defects in the soil on these southern aspects have been the lack of moisture and nutrients required to support anything beyond the occasional invasive weed. Because moisture and nutrients are the main limiting factors, we chose to apply Terra-Sorb and compost as our experimental soil amendments to improve soil water holding capacity and nutrient levels. There is however conflicting information in the scientific literature about the effectiveness of both of these treatments and most of the data was not collected in field settings (Apostol and Jacobs, 2008, Rowe et al 2005, Böhlenius et al 2014, Orikiriza et al 2009, Oliveira et al 2011). Our research therefore will provide a novel contribution to the available literature pertaining to the use of these amendments for revegetation purposes.

One success of this experiment was that the overall survival rate of plants was higher than in previous year's attempts by MPG to revegetate their south-facing slopes (McTee 2013). Overall mortality for our experiment was 35% while in MPG's first year of plantings plants suffered as much as 62% mortality (McTee 2013). Antelope bitterbrush suffered the greatest level of mortality for any individual species (64%). While we can find no clear explanation for why bitterbrush died at more than double the rate of the other two species we expect that it may have something to do with its low root – shoot growth ratio. Mountain mahogany had the greatest amount of root growth and also survived in the greatest numbers. This seems to indicate a clear relationship between root growth and plant survival except for the fact that juniper plants had a root – shoot ratio nearly as low as bitterbrush but with survival rates nearly as high as mahogany. Apparently whatever the cause of bitterbrush's high mortality rate was it was not something we were able to infer based on the measurements taken during this experiment.

Our most accurate prediction was that the plants treated with soil amendments would survive in greater numbers than those with no amendments added. It was interesting; however, that no other differences in our measurements were present to explain this increased survival. Soils treated with amendments showed no greater levels of soil moisture, no less harsh soil temperatures and only a few small differences in the changes in soil chemistry compared to the control plants. This overall success in terms of survival for plants treated with these soil amendments, as opposed to control plants, means that they provide a greater benefit than plain soil. However the lack of explanation for why treated plants have higher survival rates indicates that MPG or others with similar objectives should continue to experiment with these amendments while adding in others for further comparison. Doing similar experiments in the same location in the future with additional treatments may shed light on whether it really was the amendments which caused this increased survival in our experiment. We also acknowledge that continued monitoring of these plants may show greater benefits in future years as the amendment materials, especially compost are given a chance to breakdown.

Our expectation that soil amendments would have an effect on plant growth was incorrect. Instead, the only significant variance in plant growth was due to differences between the species. Mountain mahogany had the greatest mean growth throughout the season while bitterbrush had the lowest. Other studies have found similar results with different species. For example, previous work by Böhlenius et al (2014) found no increase in growth or survival of poplar cuttings planted with hydrogel and fertilizers. These authors offered two potential explanations for why neither of the amendments were effective at stimulating plant growth:1) that the water holding capacity of the hydrogel was so great that it decreased the availability of water for the plant, or 2) that the expansion of the hydrogel forced the plantings upwards, damaging the newly formed roots. Either of these theories could help to explain the results of our experiment. Even with the bi-weekly watering regime, the hydrogel (Terra-sorb in our case) may have prevented the plant from accessing the limited amount of water in the soil. This could explain the lack of difference in soil moisture content between plants treated with Terra-sorb and those in the control. If this is the case then increasing irrigation frequency might make the Terra-sorb more effective at providing the plant with usable water throughout the season. Since we did not observe any plants being actively forced out of the ground, it seems unlikely that hydrogel expansion caused damage to plants. Overall we feel that for MPG ranch water is the main factor limiting the growth and survival of plants, especially on the harsher aspects. Lack of water may have even prevented some of the nutrient content in the soil from being usable by the plants (Taiz 2015).

Results of this experiment were unfortunately influenced by human error multiple times. Only a portion of the temperature buttons placed into the soil were recovered. Those buttons that were recovered only represented three of the treatments (compost, Terra-sorb and control). There also seemed to be experimenter error in measuring height of some plants, especially bitterbrush. Confusion among data collectors about the specific method for measuring these plants may be why the results show many of the plants shrinking throughout the season.

We found that our initial expectations that compost would have the most effect on soil chemistry and Terra-sorb would have very little effect on soil chemistry were incorrect. Soil in compost treatments experienced fewer changes over the season in soil properties, macronutrients, and micronutrients compared to the other three treatments. The only significant change in soil with the compost treatment was an increase in cation exchange capacity, but an increase was shown in all of the treatments. Cation exchange capacity influences the soil's ability to hold onto essential nutrients, and soils with organic matter have a higher CEC (Soil Quality Pty Ltd 2016). Because CEC changed in the control as well as the treatments, we believe that the increase was due to the addition of the plants to these soils. Soil amended with compost may show more significant changes if monitored for a period longer than one growing season because with further decomposition the soil will have a higher concentration of organic matter and available nutrients. Contrary to our prediction, changes were observed in soils that contained Terra-sorb. All soil properties, macronutrients, or micronutrients that had a significant change were in soils containing Terra-sorb. No research exists on the effects of Terra-sorb on soil chemistry, properties, macronutrients, or micronutrients. We can only speculate about the possible effects Terra-sorb has had on the soil chemistry in this experiment and why these changes might be either statistically or biologically significant.

The contents of Terra-sorb likely explain the increases we saw in soil potassium in both the Terra-sorb and Terra-sorb + compost treatments. In both of these treatments the potassium concentrations of the soil went from about 250 ppm to about 500 ppm. Terra-sorb is composed of 93% potassium polyacrylamide/acrylate copolymer and 7% the inert ingredient of water (Forestry Suppliers, 2015). The advertisements for Terra-sorb explain that the product will leave potassium as a fertilizer once it biodegrades after several years (Forestry Suppliers, 2015). This increase in soil potassium may lead to an increase in growth eventually, but no difference in growth was seen in this experiment.

Soil in the control, Terra-sorb only, and Terra-sorb + compost treatments all experienced an increase in sodium concentrations. Because Terra-sorb does not contain sodium and sodium rose in the control as well as Terra-sorb only and Terra-sorb + compost treatments, we do not feel this change is due to Terra-sorb. The only amendment that did not experience a statistically significant rise in soil was the compost treatment. Generally, an increase is sodium does not bring a positive change to soil chemistry. Increasing salts in a soil may lead to less water uptake by plant roots. We believe it is possible that compost may have been acting as a buffering agent in the soil to a rise in sodium. There is a possibility that the irrigation water may have been adding extra sodium to the soil, and the addition of compost was preventing a build-up of sodium around the plant roots.

While changes in cation exchange capacity, buffer pH, and soil pH were all statistically significant, we are not able to make conclusions that these factors are biologically significant or any treatments changed the soil to a degree that would be useful to the plants. When cation exchange capacity is high in soils, the buffering pH is generally higher; however, buffering pH showed a significant decrease in the Terra-sorb + compost treatment (Pearson Learning Solutions, 528; 2015). Because buffering pH did not consistently decrease across all treatments, we do not believe the change in the Terra-sorb + compost treatment was biologically significant and may be due to variation spatially across the soil. It is also difficult to assume that the decrease of soil pH in the Terra-sorb treatment was biologically significant, especially when soil pH can vary dramatically over very small distances (Pearson Learning Solutions, 527; 2015). Sulfate, soluble salt, zinc, and manganese concentrations all had significant increases, but concentration changes did not show any patterns across treatments to draw any specific conclusions about whether these changes were caused by the amendments or was due to spatial variation of soil.

Conclusions

Our experiment has yielded some potentially useful results for MPG as well as any others doing similar revegetation projects. Arguably the most interesting result for MPG specifically was the rate of plant survival in our experiment. This rate was much greater than many of their previous attempts to re-vegetate these southern aspects. This alone is enough, in our opinion, to justify MPG continuing to monitor these plants to see if any further patterns emerge.

Another suggestion we would have for MPG specifically would be to increase either the amount of water that they irrigate these plants with or to irrigate more frequently (or both). We don't believe that Terra-sorb showed its actual potential to benefit the plants and the most plausible explanation seems to be that water was just too limited and what water was absorbed by the hydrogel was held onto too strongly for the plant to access any of it.

While we are interested to know if any patterns will emerge with more time it is also important to consider cost effectiveness. With such a low growth rate for all plants in the experiment it may make more sense to move on and consider other soil amendments or other strategies entirely depending on their management objectives. If in the future the mortality rate of these plants remains low and the growth rate increases for surviving plants then that would justify continuing to use and experiment with these amendments. If however mortality rates increase to the same level of MPG's other revegetation attempts and/or the growth rates of these plants remain very low then it would make more sense for MPG to try other treatments. Any other land managers interested in the use of polyacrylamide hydrogels and compost should follow MPG's continued research to see the long term effects of these treatments.

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LITERATURE CITED

Akhter, J., K. Mahmood, K. Malik, A. Mardan, M. Ahmad, and M. Iqbal. 2004. Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. Plant Soil and Environment 50:463-469.

Alm, A., and J. Stanton. 1993. Polymer root dip increases survival of stressed bareroot seedlings. Northern Journal of Applied Forestry 10:90-92.

Apostol, K. G., D. F. Jacobs, and R. K. Dumroese. 2009. Root desiccation and drought stress responses of bareroot Quercus rubra seedlings treated with a hydrophilic polymer root dip. Plant and Soil 315:229-240.

Arbona, V., D. J. Iglesias, J. Jacas, E. Primo-Millo, M. Talon, and A. Gómez-Cadenas. 2005. Hydrogel substrate amendment alleviates drought effects on young citrus plants. Plant and Soil 270:73-82.

Böhlenius, H., and R. Övergaard. 2014. Effects of direct application of fertilizers and hydrogel on the establishment of poplar cuttings. Forests 5:2967-2979.

Chen, Y., and T. Aviad. 1990. Effects of humic substances on plant growth. Humic substances in soil and crop sciences: Selected readings :161-186.

Forestry Suppliers. 2015. Fine Grade Roots® Terra-Sorb® Synthetic Super Absorbent. http://www.forestry-suppliers.com/product_pages/Products.asp?mi=16131.

Hüttermann, A., M. Zommorodi, and K. Reise. 1999. Addition of hydrogels to soil for prolonging the survival of Pinus halepensis seedlings subjected to drought. Soil and Tillage Research 50:295-304.

Inbar, A., M. Ben-Hur, M. Sternberg, and M. Lado. 2015. Using polyacrylamide to mitigate post-fire soil erosion. Geoderma 239:107-114.

McTee, M. 2013. Planted Shrub and Tree Report.

Oliveira, G., A. Nunes, A. Clemente, and O. Correia. 2011. Effect of substrate treatments on survival and growth of Mediterranean shrubs in a revegetated quarry: an eight-year study. Ecological Engineering 37:255-259.

Orikiriza, L. J., H. Agaba, M. Tweheyo, G. Eilu, J. D. Kabasa, and A. Huttermann. 2009. Amending soils with hydrogels increases the biomass of nine tree species under non-water stress conditions. Clean-Soil, Air, Water 37:615.

Pearson Learning Solutions. 2015. *A Custom Edition for Soils, Water, and Climate; College of Forestry and Conservation; University of Montana*. 527, 528, 747

Rowe, E., J. Williamson, D. Jones, P. Holliman, and J. Healey. 2005. Initial tree establishment on blocky quarry waste ameliorated with hydrogel or slate processing fines. Journal of environmental quality 34:994-1003.

Soil Quality Propriety Limited Company. 2016. Fact Sheet: Cation Exchange Capacity. http://www.soilquality.org.au/factsheets/cation-exchange-capacity.

Soumare, M., F. Tack, and M. Verloo. 2003. Effects of a municipal solid waste compost and mineral fertilization on plant growth in two tropical agricultural soils of Mali. Bioresource technology 86:15-20.

Taiz, L., E. Zeiger, I. Møller, and A. Murphy. 2015. *Plant Physiology and Development.* 6:131.

Verschoor, A., and N. Rethman. 1992. The possibilities of a super absorbent polymer (Terrasorb) for improved establishment, growth and development of Oldman saltbush (Atriplex nummularia) seedlings. South African Forestry Journal 162:39-42.