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Enriched Topographic Microsites for Improved Native Grass and Forb Establishment in Reclamation☆

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ABSTRACT

Low seed germination and seedling establishment are the greatest challenges for revegetation success. Topographic microsites are known to enhance seed germination and seedling establishment due to their unique soil properties and provision of shelter from elements and herbivores; soil amendments can supply organic matter and nutrients for plant establishment and growth when limited. We investigated the effect of three topographic microsites and six soil amendments and their additive effects on three disturbed grasslands in central and southern Alberta, Canada. Treatments were topographic microsites of mounds, pits, and flats, with and without amendments (erosion control blanket, hay, straw, manure, hydrogel, control) and were seeded with four native grasses and three native forb species. Seedling emergence and survival and soil temperature and water content were assessed over two seasons and plant cover over three seasons. The effect of microsites and amendments was not additive. The addition of erosion control blanket, hay, and straw to flat sites was just as productive as on topographic microsites. These amendments increased grass and forb emergence and buffered soil temperature. Mounds increased first year forb emergence and reduced over winter survival rates for grasses and forbs. Pits were not beneficial for revegetation. The effect of topographic microsites and amendments was influenced by site conditions.

Introduction

Temperate grasslands are one of the world's most threatened biomes (Hoekstra et al., 2005). Among their environmental services, they support a diversity of vegetation and wildlife including rare and protected species, produce high-quality forage for livestock grazing, and are important for carbon cycling and storage. Canadian grasslands have been reduced by 70% since the 1930s (Government of Canada, 2010); urban development, cultivation, livestock overgrazing, and energy industry activities threaten and continue to decrease their area and health. Efforts to restore native grass and forb diversity after disturbance through seeding often result in poor establishment of a few native species (Baer et al., 2002; Bakker et al., 2003; Kiehl et al., 2010), with low seed germination and seedling establishment a main impediment to reclamation success (James et al., 2011; Merritt and Dixon, 2011; Kildisheva et al., 2016).

Seed-based reclamation requires germination, emergence, and survival of seeded species, which can each be influenced by multiple factors including temperature, light, soil water availability, and seed loss due to predation and erosion (Call and Roundy, 1991; Isselstein et al., 2002; Hardegree et al., 2003). These factors can be influenced by microsites, a suite of unique biotic and abiotic conditions on a landscape. Microsites commonly include cracks, depressions, ridges, rocks, plant litter, and adjacent vegetation.

In grasslands, microsites were important for seed germination and early plant establishment (Oomes and Elberse, 1976; Call and Roundy, 1991; Laurenroth et al., 1994; Lundholm and Larson, 2003; Kiehl et al., 2010) and thus for reclamation success. The decline of microtopographic features has been directly linked to reduced native plant abundance and diversity (Werner and Zedler, 2002). Pits can increase soil water content and lower surface temperatures, enhancing seed germination and seedling emergence (Oomes and Elberse, 1976; Laurenroth et al., 1994). Mounding can affect soil water content, light

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availability, and nutrient cycling, which can drive vegetation development (Biederman and Whisenant, 2011; Hough-Snee et al., 2011).

Since various soil amendments can enhance germination and seedling growth in grasslands (Ohsowski et al., 2012), they can also serve a purpose in reclamation. In arid environments, soil becomes drier with exposure; amendments that increase soil water content and retention are thus desirable. Organic amendments such as manure and compost can improve poor-quality reclamation soils by providing organic matter and nutrients, reducing bulk density and thereby improving plant establishment (Cohen-Fernández and Naeth, 2013). Erosion control blankets, hay, or straw can reduce water loss and competitive ability of non-native species (Desserud and Naeth, 2011; Cohen-Fernández and Naeth, 2013). Erosion control blankets are associated with greater cover of seeded species and fewer weed species during early vegetation establishment (Faucette et al., 2006). Hydrophilic polymers are used on sites with low precipitation or poor water retention to increase soil water-holding capacity (Williamson et al., 2011), although their effects on plant growth and survival are inconsistent; being positive (Hüttermann et al., 1999), slightly positive (Rowe et al., 2005), and neutral (Williamson et al., 2011).

Across a landscape, diverse microtopography can provide variable soil water, light, and nutrient availability and thus specific conditions that may enhance seed germination and early seedling development of different species. Manipulation of microtopography and further enrichment of microhabitat with amendments may increase that heterogeneity, with an opportunity to create conditions favorable for hard-to-revegetate species. Understanding what components of this heterogeneity are most important for plant establishment when reclaiming temperate mixed grasslands and whether there are additive effects of microsites and amendments could enhance restoration and conservation success. The objective of this research was to determine the effects of select topographic microsites, with or without enrichment by select soil amendments, to improve the seed and seedling environment as measured by grass and forb seedling emergence, survival, and abundance in three reclaimed grass-dominated communities.

Methods

Research Sites

Research sites were established in three disturbed grasslands in Alberta, Canada. The Mattheis Ranch (Mattheis) is in mixed grass prairie, on a grazed, historical pivot irrigation site. Elk Island National Park (Elk Island) and Devonian Botanic Garden (Devonian) sites are on grass communities in aspen parkland. Elk Island was a national park landfill in the 1930s to 1970s; reclamation in 1997 included landfill material removal, recontouring, and seeding native grasses. Devonian was an oil well site, decommissioned in 1993; reclamation included soil replacement to 50 cm, straw incorporation, and seeding non-native grasses. During the study years meteorological conditions at the research sites were similar to their long-term climate normals (Jiao, 2015) (Table 1).

Herbicide and tillage were used to remove existing vegetation before plot establishment. The herbicide glyphosate (Roundup Transorb, Monsanto, St. Louis, MO) was applied in solution at 8 L Transorb ha^{-1}. Soil was rototilled to 15-cm depth a week later, and remnant surface plant debris was removed by raking. Research areas were fenced to prevent grazing, with electric and barbed wire at Mattheis and game fence at Elk Island and Devonian.

Experimental Design and Treatments

At each site a complete randomized design was used to assess topographic microsite and soil amendment factors. Topographic microsites were mounds and pits, with flats as a control. Amendments were erosion control blankets, straw, hay, manure, and hydrogel, with no amendment as a control. Amendments were selected on the basis of positive changes they could bring to the microsites and by their ability to procure and apply for large landscape-scale reclamation. Treatments were randomly assigned to 2 × 2 m plots at each site, using three topographic microsites × 6 amendments × 5 replicates = 90 plots per site.

Topographic microsites were established in the center of each plot. Pits, 10 cm deep and 25 cm wide, were excavated by shovel. Mounds were formed using soil from pits and buffer areas outside the plots. Mounds were round, 20 cm in height, with a 40-cm base width. Flats were not altered from the natural topography.

Manure and hydrogel were applied before seeding and incorporated to 10- to 15-cm depth with a trowel. Manure was applied at 0.35 kg m^{-2}; from beef cattle at Mattheis and dairy cattle at Elk Island and Devonian. Hydrogel (Soil Moist, JRM Chemical Inc., Cleveland, OH), a synthetic polyacrylamide with a potassium salt base, was used to potentially increase plant available water. Hydrogel was mixed with water and applied at 0.035 kg m^{-2} according to the manufacturer's instructions. Erosion control blankets, hay, and straw were surface applied after seeding. Erosion control blankets (Nilex Inc., Edmonton, Canada) of coconut and straw were spread and anchored with staples. One-year-old barley straw was surface applied at 0.3 kg m^{-2} at Elk Island and Devonian, and 1-year-old wheat straw was applied at 0.6 kg m^{-2} at Mattheis. Local, certified weed-free hay was surface applied at 0.3 kg m^{-2} at Elk Island and Devonian. Weed-free hay was unavailable near Mattheis; therefore fresh native hay was procured from adjacent fields and applied at 0.6 kg m^{-2}. Straw and hay were applied at rates considered appropriate for grass-dominated communities (Kiehl et al., 2006; Desserud and Naeth, 2011, 2013) and higher at Mattheis due to the arid, windy environment. Straw and hay plots were covered with a fine open mesh, often used on hay bales, to prevent wind erosion of amendments.

A mix of seven native grasses and forbs was sown. Species were native to the area with certified seed available from local seed companies. Grasses were *Hesperostipa comata* (Trin. & Rupr.) Barkworth (needle and thread grass), *Elymus trachycaulus* (Link) Gould ex Shinners (slender wheatgrass), *Bromus ciliatus* L. (fringed brome), and *Koeleria macrantha* (Ledeb.) Schult. (june grass). Forbs were *Astragalus canadensis* L. (Canada milkvetch), *Geum triflorum* Pursh (old man's whiskers), and *Linum lewisii* Pursh (wild blue flax). At Mattheis, *Koeleria macrantha* was substituted with *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths (blue grama). Seed was hand broadcast the second week of June 2012, with each species sown at 50 pure live seeds (PLS) m^{-2} for a total of 350 PLS m^{-2}.

Table 1
Research site characteristics

Sites	Devonian	Elk Island	Mattheis
Mean rainfall (mm)	269.4	328.2	266.6
Mean temperature (°C)	14.3	14.6	16.0
Soil classification	Black, dark gray chernozem	Gray, dark gray luvisol	Brown chernozem
Soil texture	Sandy loam	Sandy loam	Sand
Soil pH	7.2	7.6	6.5
Soil electrical conductivity (dS m^{-1})	0.5	0.9	0.5
Soil total organic carbon (%)	2.1	3.1	1.2
Soil total inorganic carbon (%)	0.64	0.14	0.05
Soil total nitrogen (%)	0.22	0.32	0.15

Meteorological data from 2012 and 2013 growing season (May – September).
Soil data are means across treatments within sites.

Soil Measurements

Soil volumetric water content and temperature were measured at each site with 5TE sensors and EM50 digital/analog data loggers (Decagon Devices Inc., Pullman, WA). Sensors were installed after manure

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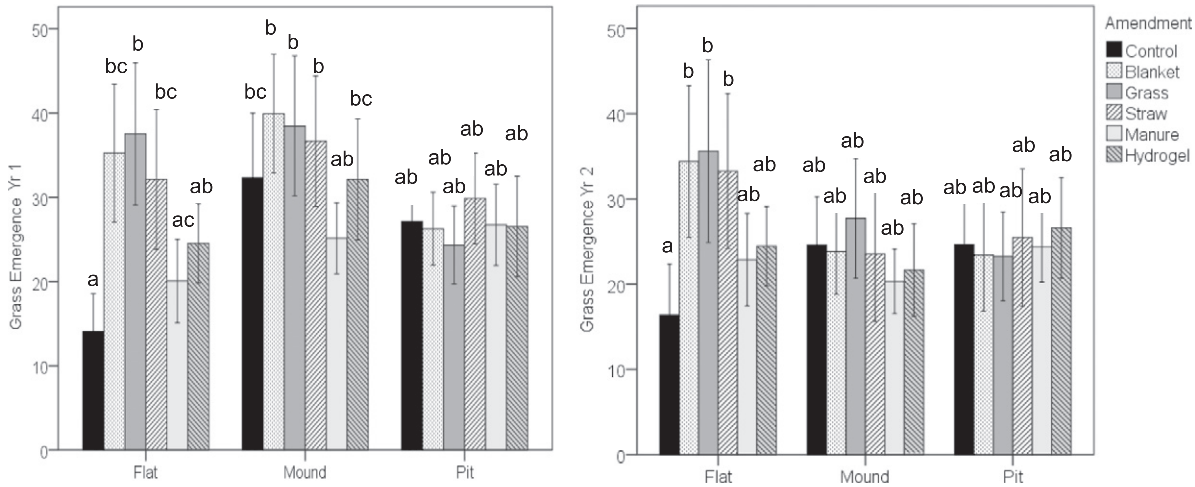

Figure 1. Effect of topographic microsites with or without amendments on native grass emergence (number of emergents per m^{-2}) in the first 2 yr following seeding.

and hydrogel were incorporated, before seeding and placement of straw, hay, and erosion control blankets. Sensors were placed horizontally in a 5-cm deep trench, anchored with staples, covered with soil, and connected to a data logger. Sensors were in the plot center for flats and pits and in each cardinal direction adjacent to mounds. Data were recorded in 30-min intervals throughout the study.

Soil was sampled to a depth of 10 cm from each of three random plots per treatment after plot preparation. Particle size distribution was determined by hydrometer; organic and inorganic carbon by gravimetric loss of CO_2; total carbon and total nitrogen by combustion with a Carbo-Erba NA 1500; electrical conductivity and pH by meter in saturated paste (Carter and Gregorich, 2008).

Vegetation Measurements

In yr 1, the number of new emergents, live plants, and dead plants were counted for each seeded species every 3 wk from seeding to late August. Yr 2 assessments were conducted in early June and late August. Vegetation data were collected on a species basis from a fixed 1 × 1 m area in the center of each plot, keeping the microsite and adjacent areas separate. Emerged seeded plants were identified and marked with species-specific colored straws. Newly emerged plants in a subsequent monitoring date were considered a different cohort and marked with a different straw identifier per species. Plant canopy cover (%) was ocularly assessed at the end of each growing season for each seeded species. In yr 3 plant cover by species was assessed in late August.

Data Analyses

Species were grouped as grasses or forbs to analyze emergence, survival, and plant cover response variables. Emergence was measured as the number of total emergents by year. Survival was calculated as percent of live emergents at the end of the first growing season, first winter, and second growing season.

Analyses were conducted in SPSS version 23 (IBM Corp., Armonk, NY) using an alpha value of 0.050. Vegetation parameters (emergence, survival, plant cover) did not meet assumptions of normality and homogeneity of variance using Shapiro-Wilk and Levene's tests, respectively. Therefore permutational three-way analysis of variance (ANOVA) was performed with PERMANOVA version 1.6. The three factors were site, microsite, and amendment; data were analyzed within each year as temporal differences were expected during plant community development. The Euclidean dissimilarity distance measure for univariate data and 10 000 permutations of raw data were used in all tests. Student's *t*-tests were conducted for posteriori pairwise comparisons following a significant permutational ANOVA. Effect of location within pits and mounds (in and out) was compared using Student's *t*-tests for each species at each site. Soil temperature and soil water content data were analyzed using two-way parametric ANOVA within sites. Tukey's post hoc pairwise comparison test was conducted following a significant ANOVA.

Results

Soil Properties

Devonian and Elk Island near surface soils were sandy loam texture, and Mattheis was sand (see Table 1). Soil pH was near neutral at all sites; total nitrogen was low, slightly higher at Elk Island and Devonian than Mattheis. According to the soil quality criteria for reclamation (Alberta Soils Advisory Committee, 1987), soils were rated good at all sites for pH and electrical conductivity. Organic carbon content was rated good at Elk Island and Devonian and fair at Mattheis. Manure increased electrical conductivity at all sites, total organic carbon and total nitrogen at Mattheis, and total organic carbon at Devonian; it slightly reduced total carbon and total nitrogen at Elk Island but did not alter reclamation ratings (Jiao, 2015).

There was no interaction between topographic microsite and amendment on near surface soil temperature. Mean monthly temperature was approximately 2.5°C higher in 2012 than 2013 (data not shown). Near surface soil temperature was significantly affected by topographic microsite, with growing season temperatures in flats and mounds 0.3 — 2.6°C higher than in pits across sites and years (data not shown). Although temperature varied slightly with mound aspect, effects were not significant. Effect of amendment was not always significant, although the trend was the same across sites and years. Treatments that provided ground cover, such as erosion control blanket and straw, generally had 0.5 — 2°C lower temperatures than the control and/or manure treatment, significantly lower with the erosion control blanket at Devonian and Elk Island and with straw at Mattheis. Temperature differences among treatments within sites were not always significant due to within treatment variability.

There was no interaction between topographic microsite and amendment on near surface soil water content, which varied little by year (data not shown). Near surface soil water content was generally highest at Elk Island and lowest at Mattheis (Jiao, 2015). During the 2013 growing season, water content of pits was significantly higher than mounds and flats at Elk Island and mounds at Mattheis. When topographic microsite effects were significant, differences were only 0.01 to 0.07 m^3 m^{-3} higher in pits than flats and mounds. 2012 differences were only significant at Devonian with pit water content slightly

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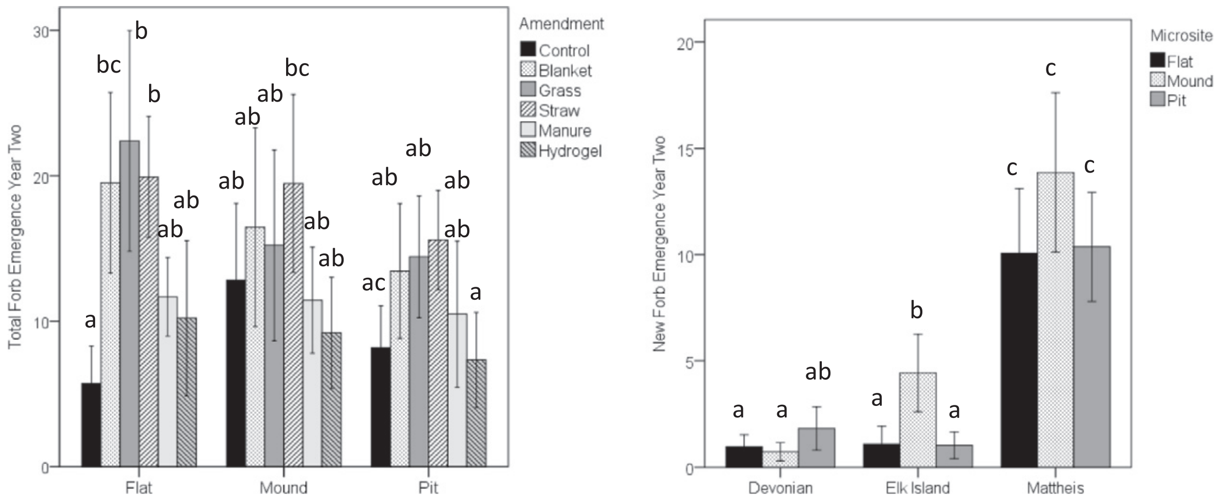

Figure 2. Effect of site, topographic microsites, and amendments on native forb emergence (number of emergents per m^{-2}) in the second yr following seeding.

lower than that of flats. Water content among amendments was only significantly greater in hydrogel than straw, manure, and control at Elk Island in June 2012 and less in hydrogel than erosion control blanket at Devonian in July 2013.

Plant Emergence

Fewer than 50 grass and 25 forb plants m^{-2} emerged across sites and treatments, < 25% of the seeds planted for both groups. Slender wheatgrass comprised the highest proportion of grass emergents (mean 71 − 84%) at Devonian and Elk Island and blue grama grass (48 − 71%) at Mattheis. Relative to yr 1, emergence of new seedlings in yr 2 was low with < 15 grass or forb emergents m^{-2}.

There were no three-way interactions among factors for emergence. Microsite and amendment had a significant interaction for grass emergence in both years and forb emergence in yr 2 (Figures 1 and 2). Amendment effects on grass and forb emergence were also dependent on site (Table 2).

Grass emergence was significantly less in the control (unamended flats) than flats or mounds amended with an erosion control blanket, hay, or straw in yr 1 (see Figure 1). In yr 2, results were the same for flats but not mounds. Amendments did not significantly improve grass emergence at Elk Island (Table 2). Erosion control blanket and hay significantly enhanced emergence at Devonian and Mattheis; straw was effective at Devonian but not Mattheis (see Table 2). At Mattheis in yr 2, grass emergence with hydrogel and manure was significantly greater than in the control. Although low in all treatments, new grass seedling emergence in yr 2 was greater at Devonian than the other sites (data not shown). At Mattheis, straw had significantly less new grass emergence than other treatments except hay and was not favorable to blue grama. Straw was applied at a higher rate at this site.

Effects of microsite and amendment on forb emergence in yr 1 were independent. Mounds resulted in 33% greater forb emergence across sites than flats and 67% more than pits (data not shown). Straw increased forb emergence relative to the control across sites and hay at Devonian and Mattheis (see Table 2). An erosion control blanket was beneficial at some sites. In yr 2, the erosion control blanket and hay added to flats or straw added to flats or mounds resulted in significantly greater forb emergence than in the control (see Figure 2). New forb emergence in yr 2 was significantly greatest at Mattheis.

Seedling emergence was greater surrounding pits or mounds than in or on them at Devonian and Elk Island in yrs 1 and 2 (Table 3). Results were the same for grass and forb densities at the end of yr 1 (data not shown). At Mattheis, results were only significant in yr 2 for all species; with delayed emergence in yr 1.

Plant Survival

Yr 1 seedling survival was > 60% for grasses and 75% for forbs across treatments. Microsite and amendment had no effect on yr 1 survival for either plant group. Grass survival in yr 1 was significantly highest at Devonian (98%) and lowest at Mattheis (73%).

Overwinter survival of grasses and forbs was lower than within-year survival and consistently lowest in mounds (see Figure 3). Grass survival was significantly lower in mounds than flats (20% less) at all sites and then pits at Elk Island (29%). Forb survival was significantly lower in mounds than flats (30%) or pits (24%) across sites and significantly lowest at Devonian (mean 48%) than other sites (both 66%).

Plants that survived yr 1 and overwintered had high survival in yr 2 (mean 89% for grasses, 88% for forbs). Grass survival was significantly lower in pits at Mattheis than all microsites at the other two sites. There was a significant three-way interaction for forb survival in yr 2.

Table 2
Emergents m^{-2} for native grasses and forbs sown in amendment treatments at three research sites. Seeding rates were 200 pure live grass seeds m^{-2} and 150 pure live forb seeds m^{-2}

Factor	Devonian				Elk Island				Mattheis			
	Grass		Forb		Grass		Forb		Grass		Forb	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Amendments												
Control	28.9^{a} (2.6)	31.5^{a} (1.9)	13.1^{a} (2.1)	7.3^{a} (1.7)	24.2 (2.9)	20.9 (3.0)	11.1^{b} (2.1)	9.7^{a} (1.2)	20.4^{a} (4.3)	13.3^{a} (1.3)	8.0^{a} (3.0)	4.3^{a} (2.8)
Erosion blanket	41.9^{b} (3.2)	40.0^{b} (3.2)	20.1^{ac} (2.7)	12.4^{b} (1.2)	27.7 (3.3)	22.3 (2.7)	13.6^{ab} (1.8)	10.6^{a} (1.4)	31.9^{b} (3.5)	19.3^{b} (1.3)	19.0^{b} (1.8)	11.5^{b} (2.8)
Hay	41.1^{b} (3.7)	42.0^{b} (3.4)	21.4^{b} (1.9)	15.1^{b} (1.9)	28.1 (2.4)	21.5 (2.3)	12.7^{ab} (2.6)	11.4^{ab} (2.4)	31.1^{bc} (4.9)	23.1^{b} (1.6)	21.1^{b} (4.4)	12.9^{b} (3.5)
Straw	45.1^{b} (1.9)	44.7^{b} (3.1)	25.0^{b} (2.6)	18.5^{b} (2.4)	32.9 (3.5)	24.7 (3.4)	22.1^{a} (3.5)	17.2^{b} (2.8)	20.6^{ac} (2.0)	12.9^{a} (1.5)	15.2^{b} (1.5)	7.5^{ab} (1.9)
Manure	24.7^{a} (2.1)	27.2^{a} (2.1)	17.8^{ab} (1.8)	6.9^{a} (1.6)	24.1 (2.5)	20.7 (2.6)	14.5^{ab} (1.7)	10.1^{a} (1.3)	23.1^{ab} (2.7)	19.7^{b} (1.4)	9.6^{a} (1.0)	7.1^{ab} (2.5)
Hydrogel	25.8^{a} (3.3)	28.3^{a} (2.9)	14.1^{ac} (2.5)	6.2^{a} (1.3)	27.3 (2.6)	24.2 (2.9)	11.1^{b} (2.1)	10.9^{a} (2.8)	30.1^{b} (3.3)	20.2^{b} (1.6)	10.2^{a} (1.6)	4.9^{a} (1.6)

Within columns, means that do not share a common letter are significantly different.

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Table 3
Emergents per m^2 for native species sown in pits and on mounds relative to adjacent areas at three research sites

	Slender wheatgrass		Fringed brome		Needle and thread grass		June grass/blue grama[1]		Canada milkvetch		Old man's whiskers		Wild blue flax	
	Pit	Mound	Pit	Mound	Pit	Mound	Pit	Mound	Pit	Mound	Pit	Mound	Pit	Mound
Devonian														
In/On	8.4^{b} (1.1)	9.1^{b} (1.0)	0.4^{b} (0.2)	1.1^{b} (0.3)	0.0 (0.0)	0.2 (0.1)	0.0^{b} (0.0)	0.0 (0.0)	0.5^{b} (0.2)	1.1^{b} (0.3)	0.0 (0.0)	1.1 (0.0)	1.7^{b} (0.4)	6.1^{b} (0.8)
Adjacent	15.0^{a} (1.6)	23.4^{a} (1.3)	1.8^{a} (0.6)	3.1^{a} (0.6)	0.0 (0.0)	0.4 (0.1)	0.4^{a} (0.0)	0.0 (0.0)	1.7^{a} (0.4)	2.5^{a} (0.4)	0.0 (0.0)	1.8 (0.1)	10.2^{a} (1.3)	14.1^{a} (1.1)
Elk Island														
In/On	6.8^{b} (0.8)	6.9^{b} (0.9)	1.4^{b} (0.3)	1.6^{b} (0.3)	0.0 (0.0)	0.0 (0.0)	0.0^{b} (0.0)	0.0 (0.0)	0.2^{b} (0.1)	0.8 (0.2)	0.0 (0.0)	0.1 (0.0)	1.9^{b} (0.5)	4.2^{b} (0.7)
Adjacent	13.6^{a} (0.7)	16.1^{a} (1.1)	5.5^{a} (0.6)	3.5^{a} (0.7)	0.1 (0.0)	0.0 (0.0)	3.7^{a} (0.6)	0.1 (0.0)	2.4^{a} (0.6)	1.5 (0.4)	1.2 (0.4)	0.5 (0.1)	7.4^{a} (0.0)	10.5^{a} (1.5)
Mattheis														
In/On	5.4 (0.5)	3.7^{b} (0.8)	0.3^{b} (0.1)	0.8^{b} (0.2)	0.3 (0.0)	0.2 (0.1)	5.4 (0.0)	2.7^{b} (0.0)	0.5 (0.2)	0.1 (0.1)	0.1 (0.0)	0.0 (0.0)	4.5 (0.8)	4.2^{b} (0.8)
Adjacent	5.9 (0.9)	12.9^{a} (0.0)	3.3^{a} (0.7)	3.9^{a} (1.0)	0.7 (0.2)	0.7 (0.2)	5.0 (0.0)	7.4^{a} (0.0)	0.1 (0.1)	0.3 (0.1)	0.1 (0.0)	0.0 (0.0)	5.7 (0.9)	9.1^{a} (1.2)

Within site and microsite, means that do not share a common letter are significantly different.
[1]June grass was sown at Devonian and Elk Island and blue grama at Mattheis.

Survival in the control was higher than in pits with hydrogel at Devonian and in pits with manure at Mattheis. Old man's whiskers did not survive at Elk Island in yr 2. Needle and thread grass only survived with hydrogel and straw.

Plant Abundance

Grass cover was less than 3% in yr 1, increasing considerably in yr 2 (mean 16%), and maintained in yr 3 (13%). A three way interaction occurred in each year for grass cover, however, there were few statistically or biologically significant differences among treatments. Compared to the control (unamended flats) no treatment significantly enhanced grass cover after three years (Figure 4). Slender wheatgrass was the most abundant grass across treatments, followed by fringed brome at Elk Island, june grass at Devonian and blue grama at Mattheis.

Forb cover was low and similar to that of grasses in yr 1 but lower than grass cover in subsequent years (mean 8% in yr 2 and 7% in yr 3). The effect of treatments on forb cover varied each year but there were few statistically or biologically significant treatment differences and no consistent trends to report. In yr 3, forb cover at Elk Island in flats and pits was significantly treatment differences and no consistent trends to report. In yr 3, forb cover at Elk Island in flats and pits was significantly lower than in any micro site treatment at the other two sites; amendment had no effect on cover (Figure 4). Wild blue flax was most abundant at all sites and similar to Canada milkvetch at Devonian.

Discussion

Fowler (1986) showed that suitable microsites can prevent soil and seed desiccation in semiarid environments. We proposed that addition of amendments to microsites could enrich them and further improve vegetation establishment. Microsites did not have the expected consistent or pronounced effect on native grasses and forbs, with effect dependent on site and plant group, and additive effects of amendment were not evident. The lack of an additive effect of amendments and microsites is not easily quantified and may be due to the small differences in all treatments that occurred and the variable responses at different sites. It would be less detectable with the low emergence on all sites. Since we broadcast seeded, our near surface soil and water data may not exactly reflect conditions for seed germination and seedling emergence, at least for treatments without mulch.

Near-surface soil water content was expected to be higher in pits and surrounding mounds and thus be a main factor to increase plant emergence, growth, and survival. The few significant differences that occurred in the growing season when it would be of most importance to plants were not the primary factors affecting plant response. Microsites that increase soil water may not have been as important at Elk Island and Devonian as in more water-limited sites such as Mattheis. Marteinsdottir et al. (2013) found higher plant mortality in pits due to sand accumulation. Although we did not measure it, deep burial of seed could have prevented germination, particularly for small seeds, and increase seedling mortality. Increased snow depth in pits could result in excess water ponding and reduced seedling emergence in spring as observed at Elk Island, although this was not reflected in significantly higher soil water contents. Although differences in soil water content among treatments were small in magnitude, they may be large enough to affect germination and seedling survival of sensitive species (Baskin and Baskin, 2014). Grant et al. (1980) found infiltration rate increased on mounds, but not soil water content, which may explain increased forb emergence in these treatments in our study.

Pits and mounds can provide shelter from temperature extremes and winds in arid environments (Umbanhower, 1992), as evidenced in our study by a significantly positive plant response to areas surrounding amended mounds. Although differences in temperature among treatments

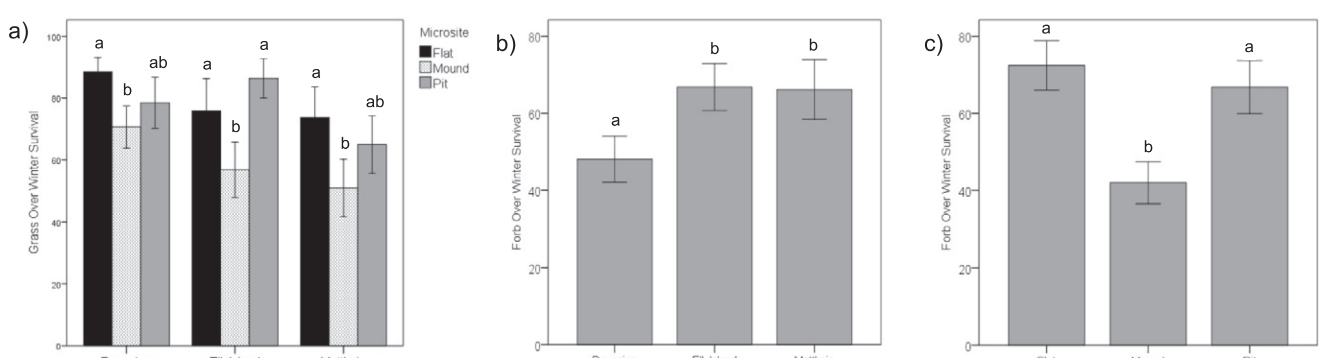

Figure 3. Effects of site and topographic microsite on native grass (**a**) and forb (**b, c**) percent overwinter survival in the first yr.

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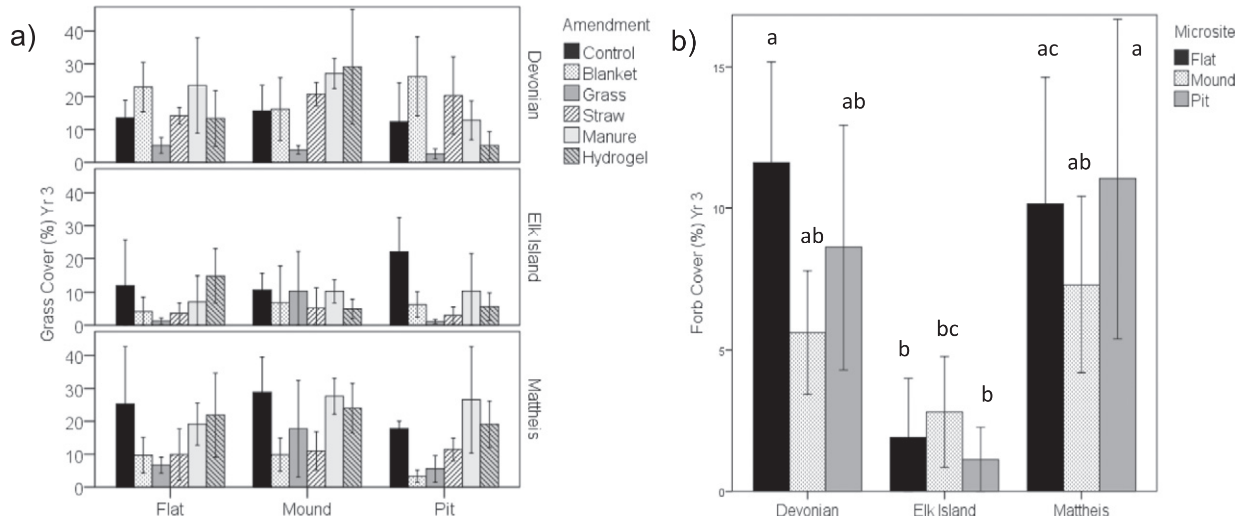

Figure 4. Effect of site, topographic microsite, and amendment on native grass (**a**) and forb (**b**) cover in the third yr following seeding.

were not always significant due to within-treatment variability, the difference we found may be large enough to be biologically significant (Baskin and Baskin, 2014). Higher temperatures in mounds can result in increased decomposition and nutrient availability (Walker and del Moral, 2003; Bruland and Richardson, 2005). Lower winter survival in mounds may be due to unfavorable microenvironments on some aspects, such as the windward side (Biederman and Whisenant, 2011). Although overwinter survival in our study was reduced with mounds, it did not negate the potential benefits, with plant abundance in the final year similar to other treatments. Some consider pit and mound size important in determining plant composition and abundance (Peterson et al., 1990; Umbanhower, 1992). Smaller mounds or pits, distributed more widely, may provide different results than what we found, emphasizing the importance of scale of microsites for reclamation.

Mulch can help conserve water (Chakraborty et al., 2008; Balwinder-Singh et al., 2011) and moderate soil surface temperatures, which can enhance germination and seedling emergence. This was evidenced with erosion control blanket, hay, and straw. Mulches also reduce seed erosion by wind and water, particularly an issue when broadcast seeding. The reduced effect of straw at Mattheis was likely due to the higher rate of application and inclusion of blue grama in the seed mix. Mollard et al. (2014) found straw applied at 0.3 kg m^{-2} facilitated seedling emergence in prairie reclamation to overcome microsite limitations. Mattheis is drier than the other sites and at higher application rates, straw may not degrade as quickly, reducing germination by photoinhibition (Mollard and Naeth, 2014) and reducing temperature fluctuations. Seedling emergence was delayed at this site and increased in the second year. Lack of the same effect on seedling emergence with native hay may be due to its finer texture facilitating greater decomposition; it also had less insulation value relative to straw or erosion control blanket. Mollard et al. (2014) found hay transmitted greater photosynthetically active radiation than straw. Native hay, only applied at Mattheis, may increase recruitment by adding grass and forb propagules, including some species seeded.

Although hydrogel has not been widely used as a soil amendment in reclamation, our study shows it is not detrimental to native species and has potential to enhance vegetation cover in disturbed, grass-dominated communities, especially at arid sites. The similar effect of manure on grass and forb establishment may be due to increased water retention; its high nutrients, electrical conductivity, and surface temperatures did not appear to negatively affect native plants in the early stages of revegetation.

The relative importance of specific site properties and year relative to other site factors, such as non-native plant species, exposure, and seed erosion, potentially plays a role in determining effect of microsites and amendments on plant response. Soils in our study were not as nutrient deficient or of poor structure relative to highly disturbed reclamation substrates, where a greater benefit of microsites and amendments may be observed. Bakker et al. (2003) also found establishment of native grasses in semiarid grasslands was highly dependent on local conditions, which varied fourfold among years and threefold between sites. Benefits of microsites may be more pronounced for naturally recruited species (Umbanhower, 1992; Laurenroth et al., 1994; Richardson et al., 2012) than those seeded.

Implications

Our research shows that topographic microsites and amendments primarily work independently of each other and are dependent largely on site conditions and plant species. Mulches and covers can be just as effective as topographic microsite creation and much easier to implement in reclamation. Straw, hay, and erosion control blankets buffer soil temperatures and likely reduce seed erosion, increasing grass and forb seedling emergence, a critical and limiting phase in restoration. Hydrogel provides similar results to manure in arid environments with low to moderately disturbed soils and with no risk of excessive nutrient loading and is worth further testing. Mounds enhanced seedling emergence but did not increase revegetation success; pits were not beneficial. While the magnitude of effects was not large in this study, further investigation of amendment application rates and size and shape of topographic microsites is warranted to improve revegetation outcomes.

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