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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.

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.

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}.

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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