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Impacts of mulch on prairie seedling establishment: Facilitative to inhibitory effects

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ABSTRACT

Seedling establishment in semiarid prairie sites under reclamation can be facilitated by mulch due to its effects on seedbed conditions. Effects on plant recruitment can also be inhibitory, as mulch can filter out or attenuate environmental signals that break seed dormancy and can negatively affect early seedling performance. A manipulative field experiment was established to determine if straw and hay mulch facilitate seedling emergence and establishment. The reclamation site is an abandoned irrigation area in the mixed grass prairie of southern Alberta, Canada. Soil was tilled and the seedbed prepared through manual harrowing, then plots were broadcast seeded with *Elymus trachycaulus*, *Bouteloua gracilis*, *Hesperostipa comata*, *Astragalus canadensis* and *Linum lewisii*. Hay and straw mulch were applied at two rates (300 and 600 g m^{-2}). Seedling emergence and survival were assessed through the first growing season. Both hay mulch rates increased *E. trachycaulus* and *L. lewisii* seedling emergence relative to bare ground. *A. canadensis* seedling emergence was more than ten times higher with low straw and both hay rates than with bare ground. Straw mulch facilitated seedling emergence at a low rate but had a neutral effect at high rates. Effects of low straw and both hay mulch rates on seedling establishment were facilitative for *E. trachycaulus* and *L. lewisii* and neutral for *B. gracilis*. Effects of high straw rates were neutral for *E. trachycaulus* and *L. lewisii* and hindered *B. gracilis* seedling establishment. These results clearly show that low mulch rates can increase native plant establishment during the critical first year of prairie reclamation as they were able to overcome microsite limitations.

1. Introduction

Seedling establishment in semiarid grasslands is limited by climate and soil factors that jointly affect available soil water for germination and early seedling growth (Chambers, 2000; Lauenroth et al., 1994; Munson and Lauenroth, 2012; Wilson et al., 2004). Microclimate conditions in bare soil are seldom favorable for recruitment; evaporation depletes water from the soil surface, sub and supra optimal temperatures negatively affect seed germination rates and seedling survival, and a poorly covered soil can lead to erosion and crust formation (Hadas, 2004). In arid and semiarid sites, with such unfavorable and unstable seedbeds, mulch may be used to conserve soil water, improve seedbed microclimate conditions and consequently increase seedling emergence and establishment.

Establishment of native grasses and forbs during prairie reclamation can be facilitated by surface application of plant material amendments (Biederman and Whisenant, 2009). Dead plant material, as natural litter or applied mulch at the soil surface, can intercept incident light and affect the transfer of heat and water vapour between the soil and atmosphere (Donath et al., 2007; Donath and Eckstein, 2010; Facelli and Pickett, 1991; Suding and Goldberg, 1999). Consequently, this plant material can increase soil water availability by reducing soil temperature and evaporation and by increasing resistance to water vapour diffusion (Facelli and Pickett, 1991). Mulching may be positive for the seedbed, yet thick layers may prevent germination of seeds that positively respond to light and to temperature fluctuations (Fenner and Thompson, 2005) and can deter establishment and performance of shaded emerged seedlings (Facelli and Pickett, 1991; Suding and Goldberg, 1999). Thus, mulch has three main possible effects on plant recruitment: facilitative (Biederman and Whisenant, 2009; Chambers, 2000; Desserud and Naeth, 2013; Eckstein and Donath, 2005; Fehmi and

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Kong, 2012; Loydi et al., 2013), neutral (Chambers, 2000; Eckstein and Donath, 2005; Loydi et al., 2013; Wilson et al., 2004) and inhibitory (Eckstein and Donath, 2005; Fehmi and Kong, 2012; Loydi et al., 2013).

Although it is not clear in which situations mulch can facilitate or inhibit plant recruitment, straw mulch and seed-containing hay are convenient methods to expedite prairie reclamation. Both techniques are effective and practical for practitioners even for large scale reclamation endeavors (Desserud and Naeth, 2013; Kiehl et al., 2010; Török et al., 2011). While most of the success of native hay mulching is ascribed to allocation of viable seeds to a site where the soil seed bank was already depleted (Coiffait-Gombault et al., 2010; Donath et al., 2007; Kiehl et al., 2010), the physical inhibitory effects at different transfer rates should be understood to better develop reclamation practices.

The first growing season of any reclamation project is critical to seedling emergence and establishment. Hence, facilitating these processes may enhance reclamation success. The objective of this research was to determine if straw and hay mulch at different rates facilitate seedling emergence and establishment of select plant species, broadcast seeded for grassland reclamation.

2. Materials and methods

2.1. Study site

The study site is situated on the Rangelands Research Institute of the University of Alberta in the Dry Mixed Grass Prairie Ecozone of southern Alberta (50°53′30.7″ N, 111°56′52.1″ W), Canada. Natural vegetation is dominated by *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths, *Hesperostipa comata* Trin. & Rupr. and *Koeleria macrantha* (Ledeb.) Schultes (Strong and Leggat, 1992). The climate is continental, sub-humid, characterized by long cold winters and short summers. Mean July and January daily temperatures of the region are 18.3 and −11.3 °C, respectively (Environment Canada, 2013). Mean annual precipitation in the region is 348 mm, two thirds occurring during the growing season (Environment Canada, 2013; Kjearsgaard et al., 1983). Potential evapotranspiration deficit during the growing season exceeds 100 mm (Strong and Leggat, 1992). Elevation is 720 m above sea level. The landscape is rolling with fluvial-eolian loamy sand surficial deposits (Kjearsgaard et al., 1983). Topsoil is well-drained, sandy to loamy sand texture, with a sand content of 87% and organic matter content of 2.3%.

Research was conducted in an abandoned old irrigation field. Established vegetation after agricultural use was dominated by *Bromus inermis* Leyss., *Calamovilfa longifolia* (Hook.) Scribn. and *Artemisia frigida* Willd. The land is used as cattle range on a rotational grazing basis.

2.2. Soil preparation, seeding and mulch treatments

A 0.36 ha (65 m × 55 m) site was sprayed with glyphosate (Roundup Transorb, Monsanto, St. Louis, MO, USA) at a rate of 8 l/ha in mid-May, rototilled to a depth of 15 cm 10 days later, and fenced to prevent cattle and wildlife grazing. Six replicate plots per treatment were hand raked to remove dead plant material, then further raked to prepare the seedbed. Certified seeds were purchased from local suppliers. Pure seed units were selected by diaphanoscopy. Seeded species were: *Hesperostipa comata* (Trin. & Rupr.) Barkworth (Syn = *Stipa comata* Trin. & Rupr., needle and thread grass), *Elymus trachycaulus* (Link) Gould ex Shinners ssp. *trachycaulus* (Syn = *Agropyron trachycaulus* (Link) Malt., slender wheat grass), *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths var. Bad River (blue grama grass), *Astragalus canadensis* L. var. ARC Aspen (Canada milkvetch) and *Linum lewisii* Pursh (wild blue flax). Plots were hand seeded on June 8. Fifty seeds (caryopsis, 1-seeded florets or seeds) per species were carefully spread in 1 m × 1 m areas centered in a 2 m × 2 m treatment plot, creating a buffer area for soil monitoring, sampling and additional plant measures. Before seeding the buffer area, seeds were weighted to get a target rate of 50 PLS per m^2 and species.

The experiment tested two different mulching materials commonly used for reclamation: wheat straw and rangeland hay. We expected to find different mulching properties between these two materials due to the coarser texture of straw and finer (similar to native litter) texture of hay. The experiment used a randomized single factor design with a bare ground control. Mulch treatments were: hay high rate, hay low rate, straw high rate, straw low rate and bare ground (control). Hay and straw were applied at rates of 300 (low) and 600 (high) $g\,m^{-2}$, considered appropriate for reclamation based on previous research (Kiehl et al., 2006; Kiehl and Wagner, 2006). In early spring, fresh native hay was mechanically mowed in a nearby field and harvested after two days. Hay was composed of grasses and forbs (green and dead leaves, vegetative stems with no previous year standing inflorescences). The surface layers of one-year-old wheat straw bales were used for straw mulch. Water content of the native hay and wheat straw was 8 and 7%, respectively, determined after oven drying at 90 °C to constant weight. Plots were covered with open mesh plastic (used to wrap bales) to prevent wind blowing the straw and hay material.

Surface soil temperature of three replicates per treatment were measured with S-TMB-M002 (Onset Computer Corporation, Cape Cod, MA, USA) installed in HOBO Micro Stations (Onset Computer Corporation, Cape Cod, MA, USA). During each monitoring date, soil volumetric water content of the upper 5 cm of soil was measured in all replicates with an ML2x ThetaProbe (Delta-T devices, Cambridge, UK). Transmitted daily photosynthetically active radiation (PAR) was measured below mulches with a Li-Cor LI-191 Line Quantum sensor (Li-Cor Biosciences, Lincoln, NB, USA).

2.3. Seedling emergence and establishment monitoring

Emergence and seedling survival were assessed every two weeks: July 3–5, July 23–26, August 13–15 and September 3–4. Individual seedlings were identified to species, marked with different colored sticks and tracked as cohorts. New emerged seedlings in subsequent monitoring dates were marked as different cohorts. A seedling was considered emerged when it could be seen without disturbing the mulch. Weeds and other unseeded species were removed from the plots by hand pulling. Since the seeded species were absent or had very low frequency and density at the site, all emerged seedlings were assumed to have originated from planted seed.

Seedling survival was calculated as the percentage of emerged seedlings that survived at the end of the growing season. *A. canadensis* and *H. comata* survival was not studied due to their low emergence. Establishment and reproductive indices (transition probability to establish seedlings and develop to a reproductive stage) were studied for *E. trachycaulus*, *B. gracilis* and *L. lewisii.* Establishment index per species and experimental unit was calculated as the fraction of initial broadcasted seeds that established seedlings at the end of the growing season, equivalent to the product of the fraction of emerged seedlings times the fraction of emerged seedlings that survived at the end of the summer (Herrera and Laterra, 2008). Emergence and survival data of the first three cohorts, those that were monitored for survival, were combined for analyses. The reproductive index was equal to establishment probability times the fraction of established seedlings that reached the reproductive stage at the end of the growing season (produced flowers or inflorescences).

Plant morphological measurements were taken at the end of the growing season on September 4. Seven plants per plot and species were randomly selected for morphological measurements. For *Elymus trachycaulus* and *B. gracilis*, tiller number per individual and length of the most recently fully-expanded leaf of one vegetative tiller per plant were determined. For *L. lewisii*, length of the longest leaf per stem and stem number per plant were determined.

2.4. Data analyses

Cumulative seedling emergence was evaluated in combination and separately for each of the species by repeated measures analysis of variance (rmANOVA), with mulch as the between subject main effect and time as the within subject factor (Von Ende, 1993). Significance of time and the interaction mulch × time were determined through Wilks' Lambda multivariate tests. Contrasts between mulches were performed with a posteriori Tukey tests. Emergence percentages were transformed using the arc sine formula $\sqrt{x}$ to satisfy the assumption of homogeneity of variances. The significance of the comparison of establishment and reproductive indices among treatments was studied through Kruskal–Wallis non-parametric tests followed by post hoc Dunn's comparisons.

Plant morphological features and soil volumetric water content from each monitoring date were analyzed with one-way ANOVAs followed by a posteriori Tukey tests ($p < 0.05$; Sokal and Rohlf, 1995). PAR radiation transmitted through the mulch treatments was analyzed with Kruskal–Wallis tests. All statistical analyses were conducted using STATISTICA version 10 (StatSoft Inc. Tulsa, OK). All results are presented as untransformed means of six replicates ± standard error.

3. Results

3.1. Mulch effects on seedbed and soil conditions

Mulch treatments had main effects on seedbed and soil physical conditions. Mulch significantly filtered PAR light ($H = 19$, $p < 0.001$) and lowered photon flux densities that reached the soil surface by more than 70% (Fig. 1). High straw mulch rates provided the most shaded conditions and reduced transmitted light close to 100% in most of the areas where it was measured (Fig. 1). Mulch, especially at high rates, lowered weekly average and maximum soil temperatures (Fig. 2a and b) and attenuated daily soil temperature amplitudes (Fig. 2c). Soil volumetric water content was significantly affected by mulch treatments (Fig. 3). Pairwise comparisons showed that straw mulch, especially at high rates, most effectively increased soil water content relative to bare ground ($p < 0.05$, in three out of four sampling dates, Fig. 3), while hay mulch values were intermediate between high straw and control treatments (Fig. 3).

3.2. Mulch effects on seedling emergence

Seedlings of all sown species emerged; however, results are focused on *E. trachycaulus*, *B. gracilis*, *L. lewisii* and *A. canadensis* due to lack of consistency and low emergence *of H. comata* seedlings. All seeded species were included in total emergence (Fig. 4a). Total seedling emergence varied significantly with mulch treatments ($p < 0.001$, Table 1), with time (but not mulch × time interaction) having an overall significant effect on seedling density ($p < 0.001$, Table 1). Seedling density was significantly higher with low straw and both hay mulch rates relative to the control ($p < 0.05$, Fig. 4a).

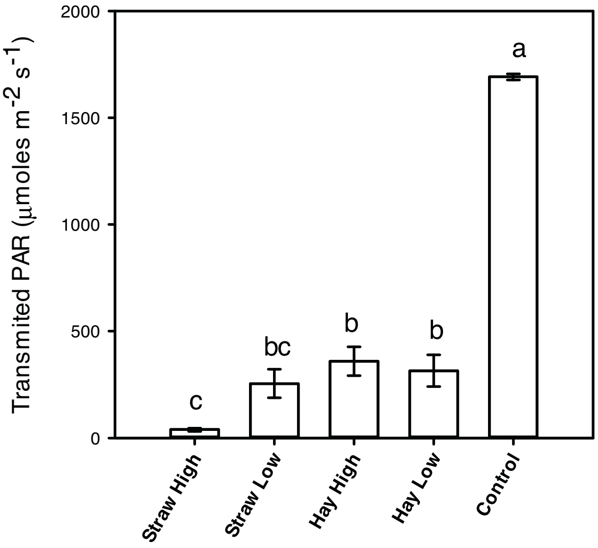

Fig. 1. Noon photosynthetically active radiation (PAR) transmitted through mulch treatments. Data are presented as means ± SE of six plots per treatment. Bars not sharing the same letter are significantly different ($p < 0.05$).

Relative to the bare gorund control, the high straw rate had no significant effect on total seedling emergence ($p > 0.05$, Fig. 4a).

Cumulative emergence analysis per species indicated species specific effects of mulch (Fig. 4b–d). Low straw and both hay mulch rates provided the best conditions for increasing *E. trachycaulus* emergence just after seeding and throughout the growing season (mulch and time effects: $p < 0.001$, Table 1, Fig. 4b). The control treatment had the worst conditions for *E. trachycaulus* seedling emergence as most sown seeds failed to produce seedlings (Fig. 4b). High straw application rates hindered *B. gracilis* emergence (Fig. 4c). Other mulch treatments did not significantly improve *B. gracilis* emergence relative to bare ground (Fig. 4c). All mulch treatments increased *L. lewisii* emergence relative to the control treatment, immediately after seeding and with subsequent cohorts (mulch and time effects: $p < 0.001$, Table 1, Fig. 4d). Mulch × time interaction was not significant for the above mentioned cases ($p > 0.05$, Table 1). *Astragalus canadensis* data could not be analyzed through rmANOVA due to failures in normalizing data after transformations. Non-parametric Kruskal–Wallis tests and

Table 1
Results of rmANOVA analysis of the effects of mulch type and rate (between subject factor), time and their interaction (within subject factors) on cumulative seedling emergence.

Factors	df	*F*-value	*p*
Total			
Mulch	4	11.4	<0.001
Time	3	22.6	<0.001
Time × mulch	12	0.94	0.514
E. trachycaulus			
Mulch	4	10.9	<0.001
Time	3	8.30	<0.001
Time × mulch	12	1.69	0.091
B. gracilis			
Mulch	4	5.46	0.003
Time	3	7.04	0.001
Time × mulch	12	0.90	0.549
L. lewisii			
Mulch	4	11.1	<0.001
Time	3	9.52	<0.001
Time × mulch	12	1.53	0.135

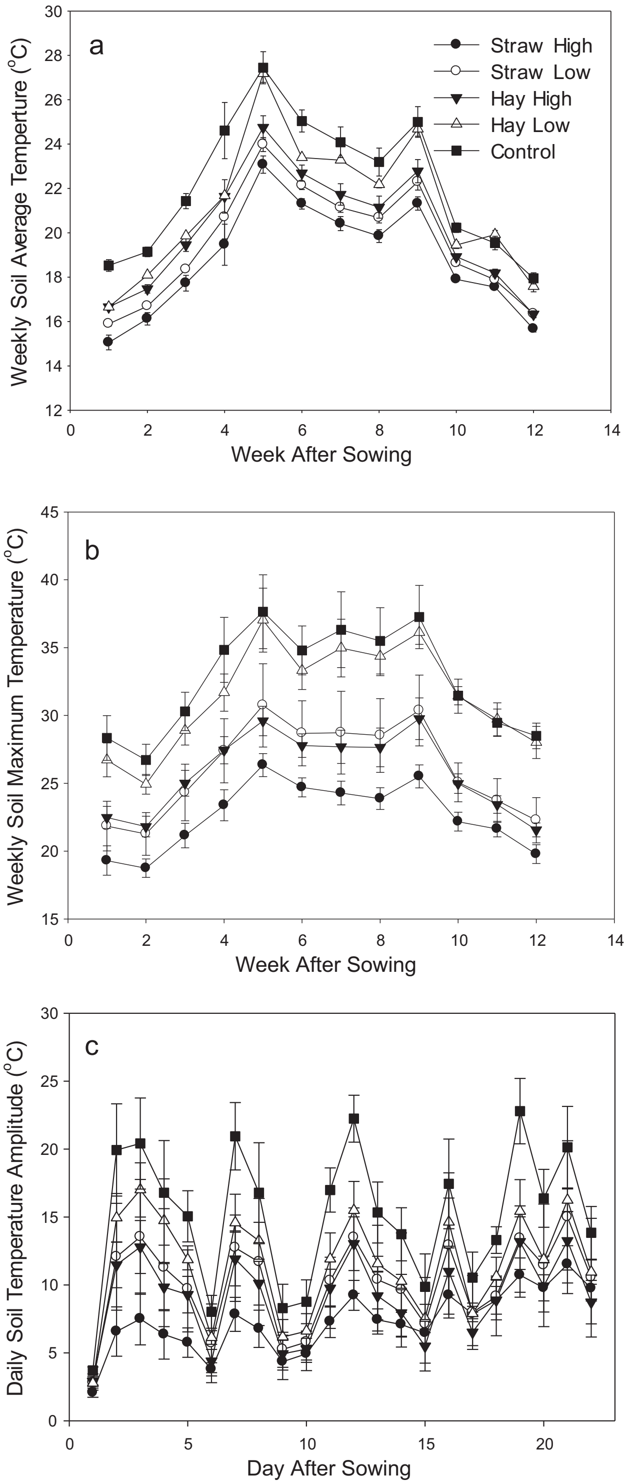

Fig. 2. Soil temperature time courses in the seedbed with mulch treatments. Weekly soil average temperature (a), weekly soil maximum temperature (b), and daily soil temperature amplitude (c). Data are presented as means ± SE ($n = 3$).

pairwise comparisons indicated density of *A. canadensis* emerged seedlings was higher with low straw and both hay mulch rates relative to bare ground controls ($H = 9.32$, $p = 0.04$). Average density of *A. canadensis* was 1.7 (low straw and hay rates) or 2.7 (high hay) seedlings m^{-2} for mulch treatments while that of the control treatment was 0.16 seedlings m^{-2} (data not shown).

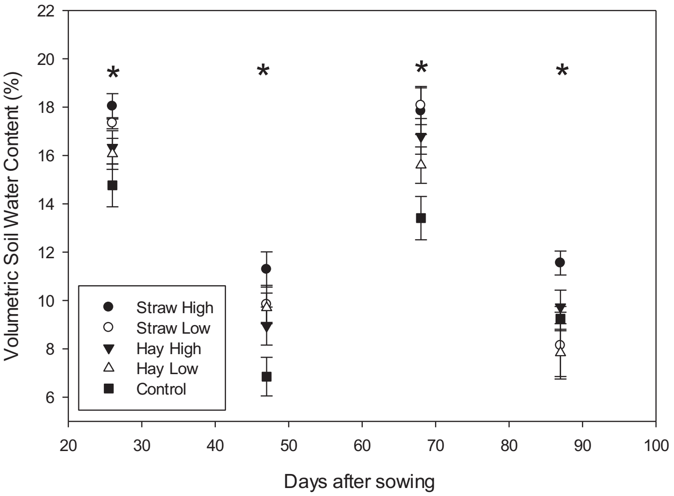

Fig. 3. Volumetric soil water content (mean ± SE, $n = 6$) of different treatments. Asterisks indicate significant differences among treatments for each date ($p < 0.05$).

3.3. Mulch effects on seedling survival, establishment and reproductive stage

There were no statistically significant differences in seedling survival of emerged seedlings among mulch treatments for *E. trachycaulus* and *L. lewisii* at the end of the growing season ($p > 0.05$ both cases, data not shown). Average survival was 80% for *E. trachycaulus* and 88% for *L. lewisii* (pooled treatments, data not shown); control plot data were not considered for survival statistical analysis or overall survival percentages due to poor seedling emergence. *B. gracilis* seedling emergence was similar with low hay mulch and the control ($p > 0.05$) but seedling survival was higher than with high hay rates ($p < 0.05$). *B. gracilis* seedling survival of pooled low hay rates and bare ground control treatments was 92% (data not shown).

Low straw and both hay mulch rates improved establishment indices (transition probability of emergence of total seeded individuals times emerged seedling survival) relative to bare ground ($p < 0.05$, Fig. 5a). Low straw mulch rate was as beneficial as both hay rates and more advantageous for *E. trachycaulus* establishment than high straw mulch rate ($p < 0.05$, Fig. 5b). Mulch with low straw and high hay mulch rates improved the fraction of seeded *E. trachycaulus* individuals that reached the reproductive stage relative to bare ground ($p < 0.05$, Fig. 5c). The fraction of *E. trachycaulus* seeded individuals that reached the reproductive stage showed that a high straw mulch rate is neutral relative to bare ground ($p > 0.05$, Fig. 5c). Mulch did not increase *B. gracilis* establishment index over the bare ground control (Fig. 5d) and high straw application voided *B. gracilis* establishment (Fig. 5d). Compared to all other treatments, a higher fraction of *B. gracilis* individuals established in bare ground and produced inflorescences ($p < 0.01$, data not shown) with 9% of broadcasted seeds developing to the reproductive stage at the end of the growing season (Fig. 5e). *L. lewisii* establishment indices were improved by low straw and both hay mulch rates relative to bare ground ($p < 0.05$, Fig. 5f). No established *L. lewisii* plants flowered during the first growing season.

3.4. Mulch effects on plant morphology

Straw mulch treatments increased leaf length in *E. trachycaulus* plants relative to the bare ground control ($p < 0.05$, Fig. 6a); however, amendments did not significantly change *E. trachycaulus* tiller number ($p > 0.05$, Fig. 6b). Mulch had no statistically significant

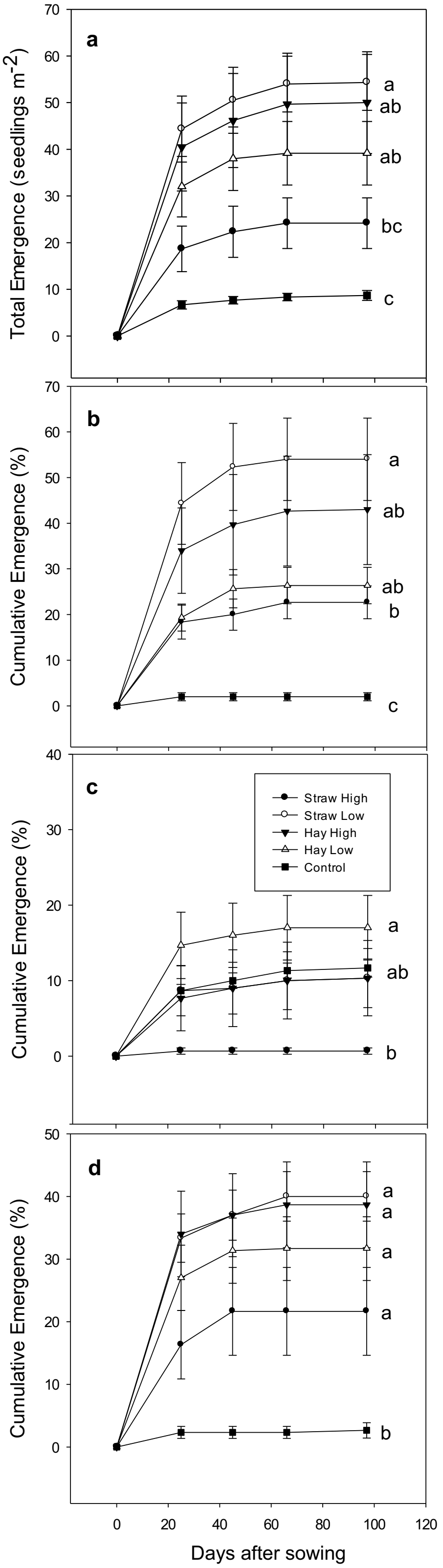

Fig. 4. Cumulative seedling emergence under mulch treatments. Total seedling emergence, all species pooled (a), *Elymus trachycaulus* cumulative seedling emergence (b), *Bouteloua gracilis* cumulative seedling emergence (c), and *Linum lewisii* cumulative seedling emergence (d). Seedling emergence is represented as percentages out of 50 seeds per replication and species in (b), (c) and (d). Data are presented as means ± SE ($n = 6$). Time-courses not sharing the same letter are significantly different according to rmANOVA between subject main effects ($p < 0.05$).

effect on *B. gracilis* leaf length ($p > 0.05$, Fig. 6c) but significantly lowered tiller number more than two times that of plants established on bare ground ($p < 0.05$, Fig. 6d). There was no effect of mulch on *Linum lewisii* stem or leaf length ($p > 0.05$, data not shown).

4. Discussion

Our results showed that mulch affected seedbed and soil conditions through effects that can exert either facilitative or inhibitory effects on plant recruitment. The main facilitative effect was improvement of soil water regimes. This effect is especially important in soils like those of our site, where the surficial soil dries out quickly. However, while a high straw rate proved to be the most efficient treatment to conserve soil water, differences in mulch materials and rates were not clear during most of the dates for soil water. Mulch ameliorated seedbed thermal properties and significantly filtered PAR irradiance, in some treatments to levels where photosynthesis or photomorphogenesis of shaded seedlings may have been limited by light. Results also show that the micro-environmental differences between straw and hay mulch are apparent at high rates for transmitted PAR light and at low rates for maximum temperatures. Taken together, these results suggest that mulching effects are both rate and material dependent with the outcome resting on the advantage of ameliorating water stress versus the disadvantages of creating light and temperature limitations for seed germination and seedling survival.

Our research indicated that mulch at low rates improved total seedling emergence. Even high hay mulch rates were able to improve seedling emergence relative to bare ground. The 300 and 600 g of fresh cut hay per m^2 in our mulch experiment, as recommended for native hay transfer (Kiehl et al., 2006; Desserud and Naeth, 2011, 2013) overcome microsite limitations for seedling emergence. However, straw mulch yielded different outcomes, facilitating seedling emergence at a low rate but having a neutral effect at high rates. *E. trachycaulus* and *L. lewisii* seedling emergence improved with mulching relative to bare ground, even at high straw rates. Mulch facilitated *A. canadensis* seedling emergence which can have functional consequences for nitrogen cycling as it was the only legume included in the mix. Low straw mulch rates (200 g/m^2) had neutral effects on *B. gracilis* emergence (Wilson et al., 2004). Our results indicate *B. gracilis* emergence was not positively affected by straw mulch when doubling and tripling their rates, and lower mulch rates or even bare ground were better options for its establishment.

Establishment indices of total seeded species showed those treatments beneficial for seedling emergence also facilitated establishment; both hay rates and the low straw rate improved seedling establishment relative to bare ground. Quality of materials used in this research for surface amendments are highlighted by species establishment indices. While both hay mulching rates had facilitative (*E. trachycaulus*, *L. lewisii*) or neutral (*B. gracilis*) effects on establishment, high straw rates had neutral effects on *E. trachycaulus* and *L. lewisii* and prevented *B. gracilis* seedling establishment. Dense litter accumulation in grasslands can affect plant development so plants flower more sparsely, probably due to reductions in soil temperature (Facelli and Pickett, 1991; Deutsch et al., 2010), suggesting mulch may affect plant phenology. Mulch effects on *E. trachycaulus* reproductive index were positive or neutral relative to bare ground; however, the ability of *B. gracilis* plants to develop to a reproductive stage was negatively affected by mulch. Results suggest mulch changed *B. gracilis* sexual reproductive behavior, an effect that may have negative consequences for further recruitment during subsequent growing seasons.

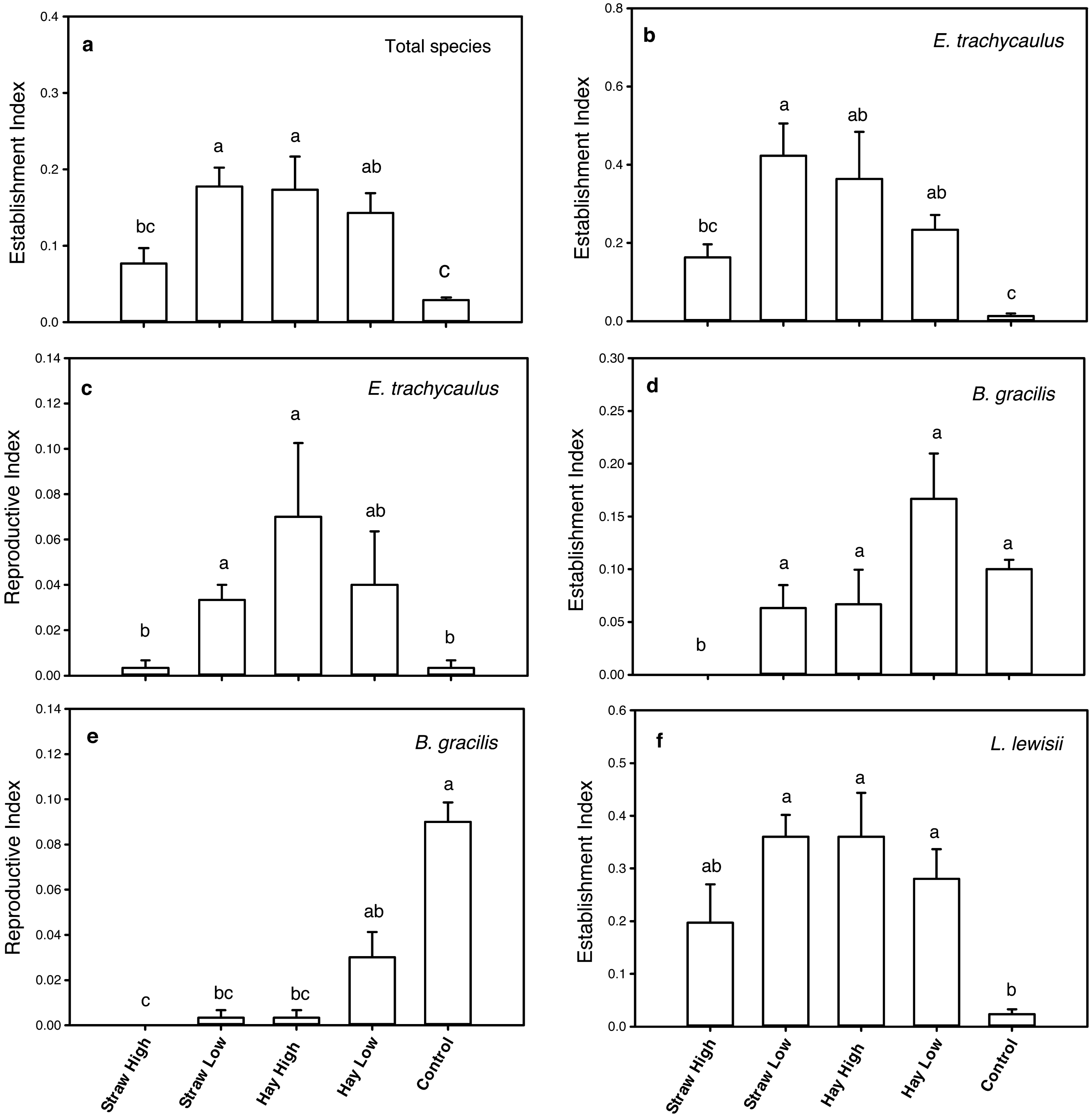

Fig. 5. Effects of mulch amendments on seedling establishment and reproduction. Total species establishment index (a), *Elymus trachicaulus* establishment index (b), *E. trachycaulus* reproductive index (c), *Bouteloua gracilis* establishment index (d), *B. gracilis* reproductive index (e), and *Linum lewisii* establishment index (f) (no. *L. lewisii* plants flowered during the first growing season). Data are presented as mean fraction (±SE, $n = 6$). Bars not sharing the same letter are significantly different ($p < 0.05$).

An important characteristic of grasses is the ability to compensate for low density by tillering. Vegetative reproduction is the principal mechanism of plant recolonization in grasslands, much more important than plant recruitment by seeds (Benson and Hartnett, 2006). In our experiment, low straw and hay mulch rates more than halved *B. gracilis* tiller number relative to bare ground, effects that may affect its early shoot demography. Plant size can affect recruiters' survival as bigger plants can strongly outcompete smaller individuals due to size asymmetric resource competition for light (Vojtech et al., 2007). Mulch significantly affected plant size in ways that can affect individual performance of late emerged seedlings; straw mulch increased *E. trachycaulus* leaf length without changing its tiller number relative to bare ground. Thus mulch can change individual plant morphology and, consequently, modify available resources for late recruiters.

5. Management implications

Our results indicate that mulch can facilitate seedling establishment of broadcast seeds in semiarid degraded grasslands. These data contrast with and support previous meta-analyses which

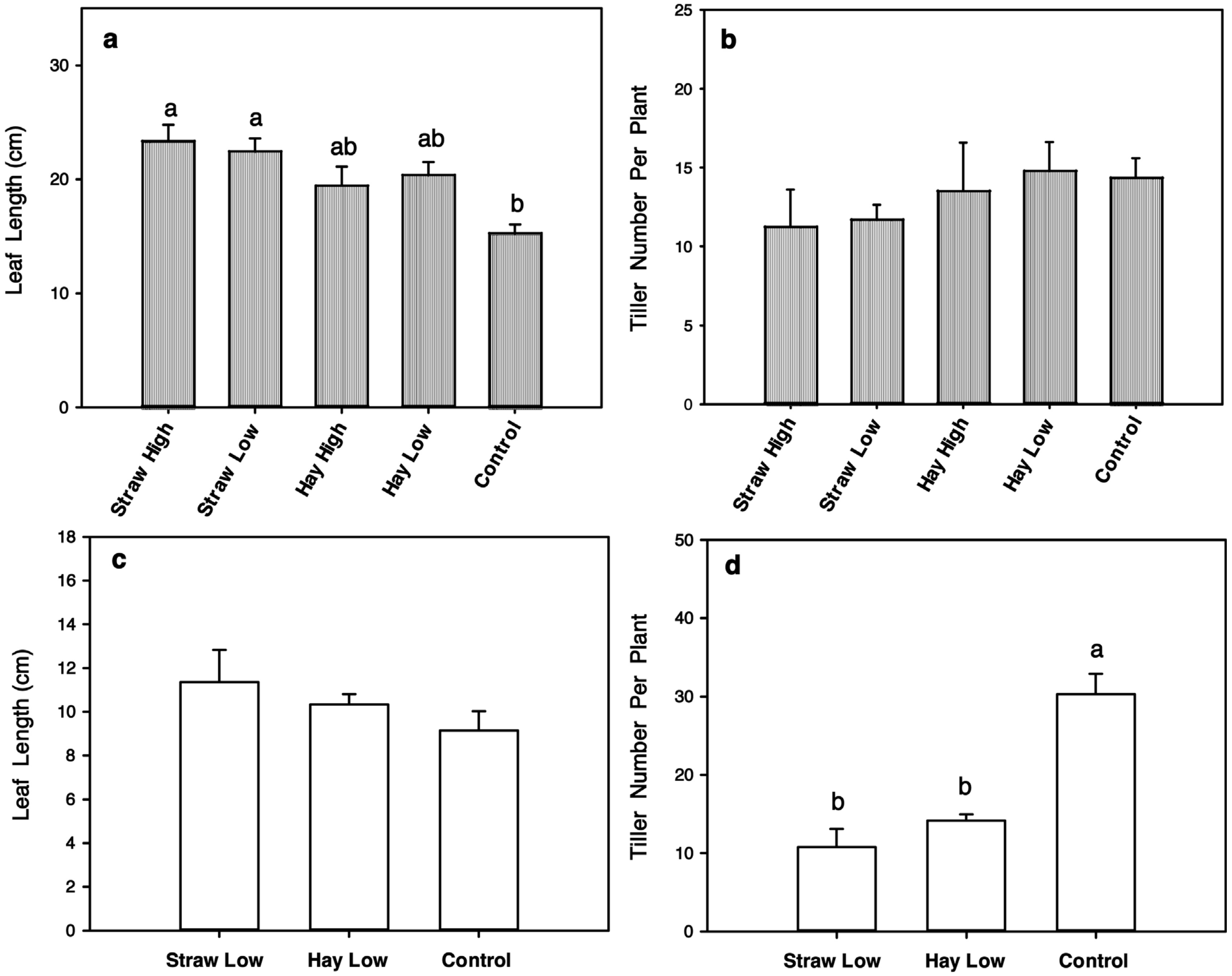

Fig. 6. Effects of mulch treatments on leaf length (a and c) and tiller numbers (b and d) of *Elymus trachycaulus* (a and b) and *Bouteloua gracilis* (c and d) plants with mulch treatments. Plant morphological traits were measured 92 days after seeding. *B. gracilis* was not measured in straw and hay high rates due to absence or scarcity of plants. Data are presented as means ± SE ($n = 6$). Bars not sharing the same letter are significantly different ($p < 0.05$).

show that litter, at similar rates to those used in our experiment, can negatively affect (cfr. Xiong and Nilsson, 1999), or have a neutral to slightly positive effects (cfr. Loydi et al., 2013) on seedling establishment in old fields and grasslands. Our results justify the use of low rates of surface applied amendments for prairie reclamation. Mulching at rates greater than 300 g m^2 should be applied with caution as it might not create a favorable regeneration niche for *B. gracilis*, one of the target species for prairie reclamation. Our results may be concern for those who use seed-bearing hay transfer for grassland reclamation as they indicate that as high as 600 g per m^2 of freshly cut hay can be used without inhibiting seedling establishment. Thus an evaluation of which species are targeted for reclamation is of high importance in using or not using mulches. This research can be of critical importance in grassland reclamation where broadcast seeding is the most cost effective revegetation technique but is often very ineffective. If individual species requirements are known, mulch rates can be adjusted to facilitate establishment of desired and hard to establish species.

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