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Germination and Seedling Emergence of Three Semiarid Western North American Legumes☆,☆☆

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ABSTRACT

Few seed sources of North American forbs are available for revegetation/restoration of degraded western rangelands adapted to annual precipitation zones less than 300 mm, and those that are available are mainly wildland collected. The amount of time and resources necessary to make wildland collections in quantity results in high seed prices and variable seed quality, such that forbs have been under-represented in rangeland seeding mixes. We have previously identified western prairie clover (*Dalea ornata* Douglas ex Hook.), Searls' prairie clover (*Dalea searlsiae* A. Gray), and basalt milkvetch (*Astragalus filipes* Torr. ex A. Gray) as native species adapted to low precipitation zones in the western United States for which field-grown seed production would potentially reduce seed costs and increase availability. A series of glasshouse experiments were conducted to determine the effects of scarification, planting depth, and soil composition on germination and seedling emergence of these species. All three species produce hard seeds, and scarification was necessary to increase germination and seedling emergence. Compared with a 6-mm planting depth, a planting depth of 19 mm retarded the rate of emergence for all species but only reduced the total seedling emergence for basalt milkvetch. With seed scarification in sandy soils, prairie clover seedling emergence exceeded 80% while basalt milkvetch was less than 10%. With seed scarification in soils with higher clay content, prairie clover total seedling emergence reduced to 58–70% while basalt milkvetch increased to approximately 30%. Along with enhancing stand establishment in seed production fields, these data will assist land managers in planning for optimal establishment of these species in rangeland revegetation/restoration projects.

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Introduction

Western rangelands in semiarid climates are exposed to periodic disturbances, such as wildfires, that often require revegetation to reestablish plant communities, avoid soil loss, deter the spread of exotic weeds, prevent impairment of ecosystem structure and function, and mitigate significant threats to human health, safety, life, and property (USDA-FS, 2000). Grasses typically comprise the core of these revegetation/restoration efforts, and seed growers have been successful at producing large volumes of high-quality seed for many grass species. Other plant species, especially native forbs, are disproportionately under-represented in revegetation/restoration projects, both in the number of species and in the volume of seed available for each species (Shaw et al., 2005; USDI-PCA, 2015). Establishing indigenous forbs during revegetation/restoration is central to achieving diverse systems that function sustainably and resist invasion of exotic weeds (Pokorny et al., 2004; Cane, 2011).

Although federal land management agencies are encouraged to use native North American species for restoration and rehabilitation to the extent practical (USDI-PCA, 2015), seed cost and availability have limited their use (Richards et al., 1998). In particular, few seed sources of forbs native to the semiarid western regions of the United States are available for revegetation/restoration of degraded western rangelands that are adapted to annual precipitation zones < 300 mm. These forbs are often available as wildland-collected seeds rather than field-grown seeds, and many forb species are indeterminate, shatter during seed ripening, and are difficult to establish such that seed production is problematic and costly. The amount of time and resources necessary to make wildland collections in quantity results in relatively high seed prices and variable seed quality for for species. As a result, there is a need to identify forbs from western North America that are adapted to low precipitation zones and amenable to field seed production so that these species can be more fully utilized in revegetation/restoration efforts (USDA-FS and USDI-BLM, 2014).

Three such species are western prairie clover (*Dalea ornata* [Douglas ex Hook.] Eaton & J. Wright), Searls' prairie clover (*Dalea searlsiae* [A. Gray] Barneby), and basalt milkvetch (*Astragalus filipes* Torr. ex

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A. Gray). These three forb species are legumes that biologically fix nitrogen in association with rhizobial symbionts, have distributions across the semiarid western United States, and are adapted to sites with 200 to 600 mm annual precipitation (Bhattarai et al., 2008, 2010, 2011). Additionally, they produce numerous inflorescences at a height sufficient for mechanical harvest. Collections of these three species were made previously, and prevariety germplasm sources have been released for western prairie clover and basalt milkvetch (Johnson et al., 2008, 2011). Establishing stands of these species for field seed production, however, has been challenging due to poor germination and seedling emergence.

Additional research of these species is needed to improve establishment in seed production fields, as well as on rangeland sites. Although data specific to these species are lacking, studies from other species in the same genera have highlighted the presence of hard seed coats and the possible benefits of seed scarification (Eisvand et al., 2006; Rawlins et al., 2009; Molano-Flores et al., 2011). We hypothesized that seed scarification and a shallow planting depth would improve germination and emergence of western prairie clover, Searls' prairie clover, and basalt milkvetch. In addition, we hypothesized that planting in soils with a high sand content would increase the rate of germination and emergence in these three leguminous species. Our results evaluated germination and seedling emergence responses of these three species when exposed to seed scarification methods, planting depths, and soil compositions.

Methods

Germplasm Sources

Two glasshouse experiments were conducted using Majestic and Spectrum western prairie clover germplasms (Johnson et al., 2011), Ds-23 and Ds-26 Searls' prairie clover collections (Bhattarai et al., 2011), and NBR-1 basalt milkvetch germplasm (Johnson et al., 2008; Bushman et al., 2010). Seed of Majestic and Spectrum for Experiment 1 were produced at BFI Native Seeds (Moses Lake, Washington), whereas in Experiment 2 seed of Majestic originated from its original wildland collection site near Madras, Oregon (lat 45°17′N, long 121°01′W, elevation 258 m). Seed of Ds-26 was produced at the USDA-NRCS Plant Materials Center at Aberdeen, Idaho. Seeds of Ds-23 and NBR-1 were produced at the Millville Research Farm (lat 41°39′N, long 111°48′W, elevation 1350m) in 2010. Seed from each germplasm source (except Ds-26) was hand-threshed and cleaned at the USDA-ARS Forage and Range Research Laboratory; Ds-26 was threshed and cleaned at the USDA-NRCS Plant Materials Center at Aberdeen, Idaho.

Seeds were tested for viability and germination at the Utah State Seed Laboratory (Salt Lake City, UT). Viability was assayed using tetrazolium staining on 100 seeds from each entry, and total viable seeds were the sum of viable and viable-hard seeds. Seeds that imbibed and stained with tetrazolium were considered viable while seeds that required nick scarification to imbibe and stain were considered viable-hard. This test was conducted for nonscarified and previously scarified seeds. Germination was separately measured on four replications of 78 seeds of each entry, where seeds that germinated within 21 days were summed together. Seedling emergence data in the two glasshouse experiments were adjusted on the basis of total viable seed.

Experiment 1

The purpose of Experiment 1 was to test the effects of seed scarification methods and planting depths. The seeds were planted into sand-filled benches with a soil medium composed of one part peat moss to four parts Kidman fine sandy loam (coarse-loamy, mixed, mesic Calcic Haploxeroll) that was steam treated at 71°C for 2.5 hours. Seeds were placed on the sand surface in 43-cm rows utilizing hardboard templates and covered to either 6- or 19-mm depths with sifted sand. Fifty seeds were planted for each of the five entries (Majestic, Spectrum, Ds-23, Ds-26, and NBR-1), and four replications of each entry were planted in a randomized complete block design in a glasshouse at Logan, Utah. Two separate runs of the experiment were conducted during March and April 2011, respectively, with each run continuing for 28 days after planting.

Three seed treatments were tested: acid scarification, mechanical scarification, and untreated control. For acid scarification, the seeds were soaked in 98% sulfuric acid for 5 minutes, rinsed in tapwater for 3 minutes, and air dried. For mechanical scarification, the seeds were hand rubbed between two pieces of 120-grit sand paper for 30 seconds in small batches. Glasshouse air temperatures were 25:20°C day:night with a 12-h day length maintained with supplemental high-pressure sodium lamps that provided approximately 500 μmol photons $m^{-2}s^{-1}$ daily photosynthetically active radiation. The plots were watered to saturation three times a week using a fine mist. Seedlings were counted as "germinated" as soon as cotyledons, seed coat, or hypocotyls were visible. If the soil surface was pushed up or cracked open by a seedling, but the seedling was not visible, it was not counted as emerged. The number of seedlings that emerged was counted three times a week for the duration of each run. Total emergence (TEM) was determined as the number of seedlings that emerged by the end of the experiment. The rate of emergence (RATE) was calculated as described by Maguire (1962):

$$\mathrm{RATE} = \mathrm{E}_1/\mathrm{D}_1 + (\mathrm{E}_2 - \mathrm{E}_1)/\mathrm{D}_2 + \ldots\ldots + (\mathrm{E}_n - \mathrm{E}_{n-1})/\mathrm{D}_n \quad (1)$$

where E is the number of seedlings emerged on a counting date and D is the number of days since planting.

Experiment 2

The purpose of Experiment 2 was to confirm the effects of scarification and test the effects of soil composition on seedling emergence. Three entries were included in this experiment: Majestic western prairie clover, Ds-23 Searls' prairie clover, and NBR-1 basalt milkvetch. Fifty seeds were planted for each entry in a replicated split-plot design with soil compositions as whole plots and seed treatments as subplots. Experiments were conducted in the same glasshouse as Experiment 1, and two separate runs of the experiment were conducted in March and April 2012. Seeds were planted at a 6-mm soil depth. Two soil types were used: Kidman fine sandy loam (FSL, as described earlier) and Nibley silty clay loam (SCL, fine, mixed, active, mesic Aquic Argixerolls). These two soils were partitioned into 54 × 54 cm whole plots as follows: 100% FSL, 33% SCL/67% FSL, 67% SCL/33% FSL, and 100%SCL, which from here on will be referred to as FSL (sand), 33-SCL, 67-SCL, and SCL (clay), respectively. Each plot was watered every 6 days with 4 L of tap water, saturating the soil for each plot. Seed treatments within each whole plot included acid-scarified seed (as described in Experiment 1) and untreated seed. Seedling TEM and RATE were determined as described in Experiment 1.

Statistical Analyses

Analysis of variance was assessed using the MIXED procedure of SAS (SAS Institute, 2004), where TEM and RATE were dependent variables. Entry, seed treatment, and planting depth or soil composition were considered fixed effects, while replication, run, rep by depth interaction (Experiment 1), and rep by soil type interaction (Experiment 2) were considered random effects. Residuals were checked for normality and homoscedasticity using Shapiro-Wilk and Kolmogorov-Smirnov tests implemented in the Univariate and Transreg procedures of SAS. In Experiment 2 a natural log transformation was necessitated to normalize the data, and means were back-transformed for presentation. The Tukey-Kramer experiment wise test at a $P < 0.05$ level of significance was used to determine significance of mean separations, and alphabetical designations of differences were implemented using the PDmix macro in SAS (Saxton, 1998).

Results

All entries, except Ds-26, showed a high percentage of total viable seeds, ranging from 74% for mechanically scarified Spectrum seeds to 99% for untreated NBR-1 seeds (Table 1). From Ds-26 the total viable seeds ranged from 51–61%. The majority of untreated seeds of the all germplasm sources except Ds-26 were viable-hard, requiring a nick-scarification in order to imbibe and stain with tetrazolium. These showed germination percentages between 4% and 22%. After mechanical or acid scarification, the percentage of seeds classified as viable increased while the percentage of seeds classified as viable-hard (still requiring nick-scarification) decreased substantially. Acid scarification more effectively reduced the percentage of viable-hard seeds than mechanical scarification. Both scarification methods increased the germination percentage of the prairie clover entries, but not the basalt milkvetch entry (see Table 1).

Experiment 1

For TEM, the main effects of seed treatment, entry, and planting depth were significant along with the entry × treatment and entry × planting depth interactions (Table 2). The treatment × planting depth and the three-way interaction were not significant. For RATE, the three main effects and all two-way interactions were significant (see Table 2), but the three-way interaction was not significant.

Both acid and mechanical scarification methods resulted in significantly and substantially higher TEM than untreated seeds, and the two seed scarification methods differed significantly from each other for TEM across all entries (Fig. 1A). Majestic and Spectrum western prairie clovers had similar TEM values, with acid scarification resulting in significantly higher TEM than mechanical scarification (see Fig. 1A). For Searls' prairie clover, the Ds-23 collection also had higher TEM for acid compared with mechanical scarification, but for the Ds-26 collection mechanical scarification had a slightly higher TEM than acid scarification. The TEM of NBR-1 basalt milkvetch was higher with mechanical compared with acid scarification but only improved from 4 emerged seedlings in the untreated seed compared with 16 emerged seedlings in the mechanically scarified seed (see Fig. 1A).

For RATE, acid scarification also led to the most rapid emergence in the four prairie clover entries, followed by mechanical scarification and untreated seed (Fig. 1B). Majestic, Spectrum, and Ds-23 exhibited similar patterns of response for the three seed treatments, with acid scarification resulting in a higher (faster) RATE than mechanical scarification. The Ds-26 collection showed trend of improvement in RATE for acid compared with mechanically scarified seeds. RATE was substantially lower (slower) for NBR-1 compared with the prairie clover entries, and NBR-1 had a trend of higher RATE for mechanically scarified compared with acid-scarified seed (see Fig. 1B).

Deeper planting depth did not have a significant effect on the TEM of Majestic, Spectrum, and Ds-23 prairie clovers, but it reduced the TEM of Ds-26 from 90–74% seedlings and the TEM of NBR-1 from 28–20% seedlings (Fig. 1C). The deeper planting depth did result in significant reductions in RATE for all four prairie clover entries when planted at 19 compared with 6 mm (Fig. 1D). RATE values for NBR-1 were low, and the deeper depth did not result in a significant delay in emergence.

Table 1
Percentages of viable seed, viable hard seed, total viable seed, and germination for 5 germplasm sources of western prairie clover, Searls' prairie clover, and basalt milkvetch. For each entry, seeds were either acid scarified, mechanically scarified, or untreated.

Source	Viable[1]	Viable Hard[2]	Total Viable	Germination (Stdev)[3]
Dalea ornata				
Majestic acid	68	14	82	84 (3%)
Majestic mechanical	43	48	91	60 (4%)
Majestic untreated	11	73	84	11 (1%)
Spectrum acid	72	16	88	85 (1%)
Spectrum mechanical	34	40	74	61 (1%)
Spectrum untreated	16	81	97	22 (4%)
Dalea searlsiae				
Ds-23 acid	87	4	91	83 (1%)
Ds-23 mechanical	69	20	89	74 (1%)
Ds-23 untreated	3	84	87	5 (1%)
Ds-26 acid	51	0	51	68 (4%)
Ds-26 mechanical	37	15	52	65 (4%)
Ds-26 untreated	31	30	61	49 (4%)
Astragalus filipes				
NBR-1 acid	72	23	95	4 (1%)
NBR-1 mechanical	26	61	87	4 (1%)
NBR-1 untreated	4	95	99	4 (1%)

[1] Viable seeds imbibed and stained with tetrazolium.
[2] Viable hard seeds imbibed and stained with tetrazolium after scarification.
[3] Germination was a separate measure of the proportion of seeds that imbibed and germinated.

Table 2
F and *P* values in Experiments 1 and 2 for testing the effects of seed treatments, planting depth, and soil compositionon total emergence (TEM) and rate of emergence (RATE) ofthree legume species.

TEM	*F* statistic	*P* value	RATE	*F* statistic	*P* value
Experiment #1					
Seed treatment (TRT)	1225.25	<0.0001	Seed treatment (TRT)	856.04	<0.0001
Entry	308.14	<0.0001	Entry	285.96	<0.0001
Planting depth (Depth)	28.78	0.001	Planting depth (Depth)	32.49	0.0007
TRT × Entry	85.98	<0.0001	TRT × Entry	83.58	<0.0001
TRT × Depth	0.81	0.4479	TRT × Depth	15.51	<0.0001
Entry × Depth	5.56	0.0002	Entry × Depth	5.81	0.0002
TRT × Entry × Depth	1	0.434	TRT × Entry × Depth	1	0.4382
Experiment #2					
Seed treatment (TRT)	2134.79	<0.0001	Seed treatment (TRT)	4779.01	<0.0001
Entry	436	<0.0001	Entry	1493.87	<0.0001
Soil composition (Soil)	3.62	0.0299	Soil composition (Soil)	1.17	0.3465
TRT × Entry	211.2	<0.0001	TRT × Entry	843.57	<0.0001
TRT × Soil	0.06	<0.0001	TRT × Soil	0.83	0.4801
Entry × Soil	15.53	<0.0001	Entry × Soil	8.69	<0.0001
TRT × Entry × Soil	1.8	0.0983	TRT × Entry × Soil	4.02	0.0007

Experiment 2

Using the Majestic germplasm of *D. ornata,* Ds-23 germplasm of *D. searlsiae,* and NBR-1 germplasm of *A. filipes,* seed treatment and entry were tested along with soil composition. For both TEM and RATE, seed treatment ($F = 2135$ and $F = 4779$, both $P < 0.0001$) and entry ($F = 436$ and $F = 1494$, both $P < 0.0001$). Soil composition was significant for TEM but not for RATE. For both TEM and RATE, treatment × entry and entry × soil composition interaction effects were significant. The significant entry × soil composition interaction and the significant three-way interactions for both TEM and RATE were most likely due to the varying responses of NBR-1 compared with the prairie clover species (Fig. 2).

Similar to Experiment 1, scarified seeds had significantly higher TEM values than untreated seeds for all three entries (see Fig. 2A). TEM of scarified Majestic seeds was 70–82% compared with 8–12% for untreated seeds, scarified Ds-23 was 60–83% compared with 2–4% for untreated seed, and scarified NBR-1 was 15–18% compared with 2–6% for untreated seeds. The four soil compositions used in Experiment 2 ranged from a FSL (sandy) composition to SCL (high clay) composition. Scarified seeds of Majestic and Ds-23 prairie clovers exhibited significant decreases in TEM as the clay content in soils increased while untreated seeds of

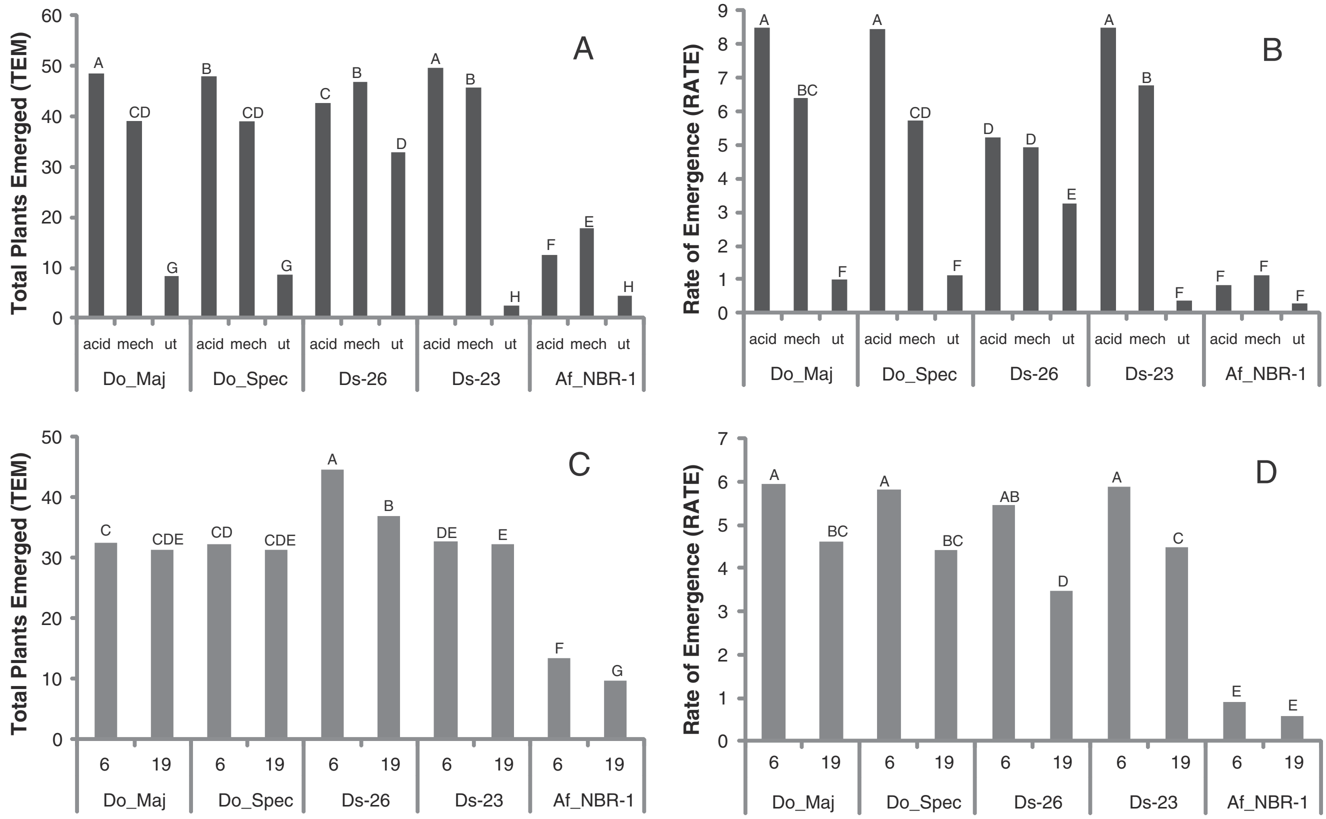

Figure 1. Total emergence (TEM) and rate of emergence (RATE) for western prairie clover (Do_Maj, Majestic; Do-Spec, Spectrum), Searls' prairie clover (Ds-26, Ds-23), and basalt milkvetch (Af_NBR-1) entries in Experiment 1. **A**, TEM and **B**, RATE of entries for seed that was acid-scarified (acid), mechanically scarified (mech), or untreated (ut). **C**, TEM and **D**, RATE of entries planted at 6 or 19 mm planting depths. Bars with different letters on top are significantly different at $P<0.05$ significance level.

Majestic and Ds-23 showed little or no responses to soil composition (see Fig. 2A). NBR-1 again varied from the two prairie clover responses with an overall lower TEM and an increased TEM in soils containing clay compared to FSL (sandy).

The results for RATE exhibited a similar pattern of responses as those for TEM, with scarified seeds of all three entries emerging more rapidly than untreated seeds (Fig. 2B). For scarified Majestic and Ds-23, RATE tended to be faster in FSL (sandy) soils compared with soils with higher clay content. Untreated Majestic and Ds-23 exhibited a low (slow) RATE but no significant differences as clay content increased. For NBR-1 basalt milkvetch, the influence of soil composition on RATE was contrary to that detected in the prairie clovers. Scarified and untreated seeds of NBR-1 showed a significant increase in RATE with higher clay content in the soil (see Fig. 2B).

Discussion

Forb species are in considerable demand for precipitation zones that receive as low as 200 mm in the western United States for revegetation/restoration efforts; however, high-quality seeds in any quantity are difficult and expensive to obtain for these species (Shaw et al., 2005; USDI-PCA, 2015). Rangeland forbs are also often hand-collected in wildlands, and their seed costs can be prohibitively high for large-scale revegetation projects (Richards et al., 1998; McArthur and Young, 1999). Increasing the efficiency of seed production could decrease revegetation/restoration costs for these species, and obtaining reliable stands of forbs is a critical step in that process. The primary aim of our study was to determine how seed scarification treatments, soil depths, and soil composition affected germination and seedling emergence in three legume species. To determine these effects, we examined three species: western prairie clover, Searls' prairie clover, and basalt milkvetch. Additionally, we had two germplasm sources of each prairie clover species, giving five entries in this study. All three species were characterized by a high percentage of hard viable seeds, and mechanical or acid scarification was necessary to reduce that proportion of hard seeds and improve germination. Interestingly, scarification alone increased the western and Searls' prairie clover germination values to over 80% (except Ds-26) while scarification of NBR-1 seed did not increase its germination value. These results suggest that other factors aside from hard-seededness affect NBR-1 germination and are consistent with reports of other recalcitrant *Astragalus* species (Gremer et al., 2012; Long et al., 2012).

The western prairie clover germplasm sources, Majestic and Spectrum, originated in the northern Great Basin and southern Columbia River Plateau in 200-400-mm precipitation zones (Bhattarai et al., 2010; Johnson et al., 2011). These two germplasm sources of western prairie clover species responded in a similar manner. Acid scarification increased the percentage of viable seed to approximately 70% (see Table 1), increased germination to approximately 85% (Table 1), increased TEM to 48 seedlings (96%) (see Figs. 1A and 2A), and increased RATE more than eightfold (see Figs. 1B and 2B) when compared with untreated seed. Meanwhile, mechanical scarification increased viable seed to 34–43% (see Table 1), increased germination to 60–61% (see Table 1), increased TEM to 39 seedlings (78%) (see Figs. 1A and 2A), and increased RATE more than fivefold (see Figs. 1B and 2B). Although acid scarification was more effective than mechanical scarification for both Majestic and Spectrum, both scarification methods would substantially improve seedling germination and emergence.

Neither planting depth (see Fig. 1) nor soil composition (see Fig. 2) exhibited effects as large as seed scarification, but both provided further insights into seedling emergence in western prairie clovers. Planting depth had no significant effect on TEM in Experiment 1, but it did slow RATE (see Fig. 1C and D). This slower RATE may not necessarily reduce TEM in irrigated seed production fields, but under rangeland planting conditions a slower RATE could lead to lower TEM because of

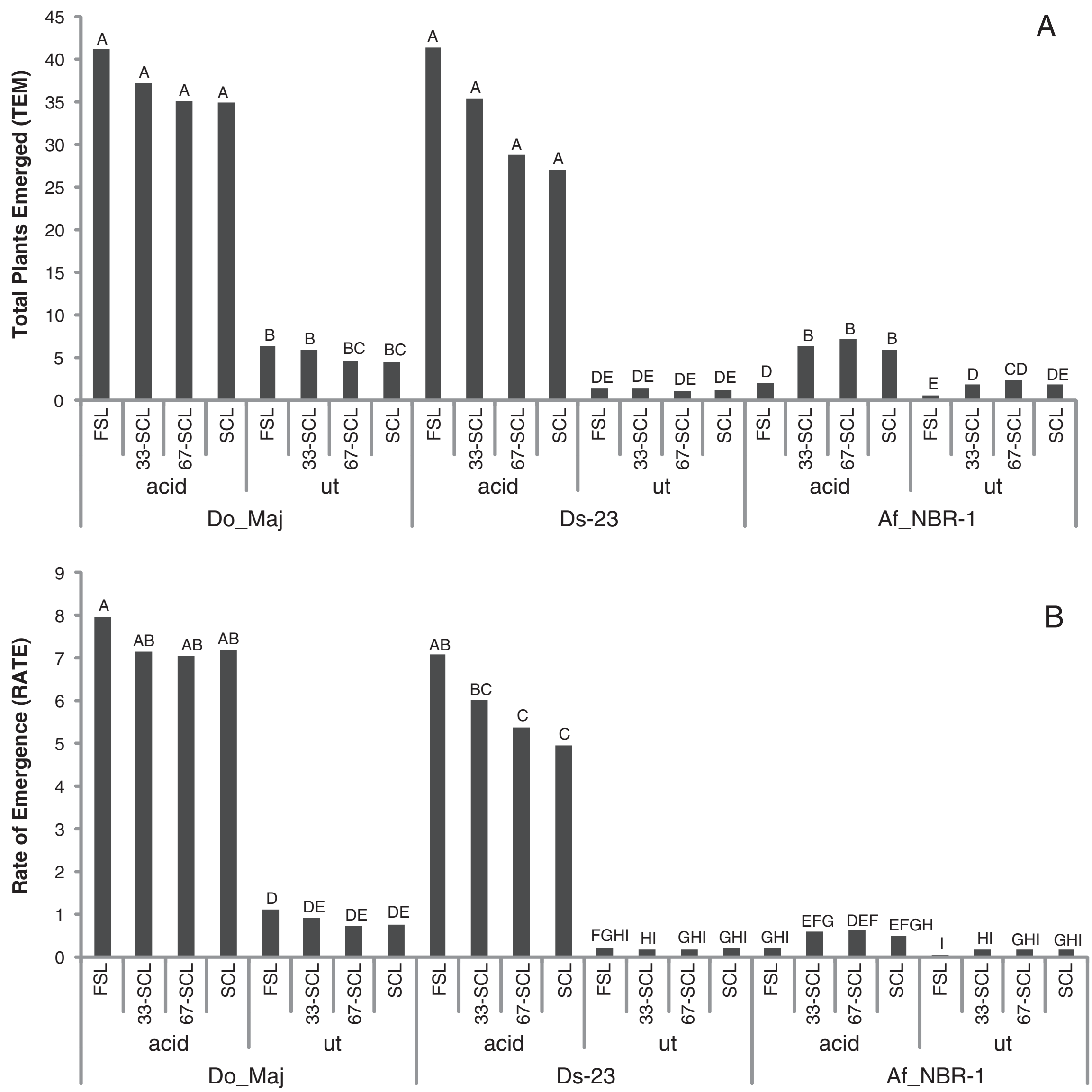

Figure 2. A, Total seedling emergence (TEM) or **B,** rate of emergence (RATE) of western prairie clover (Do_Maj, Majestic), Searls' prairie clover (Ds-23), and basalt milkvetch (Af_NBR-1) entries for seed that was acid-scarified (acid) or untreated (ut) and planted in four soil compositions in Experiment 2. Soil compositions were 100% fine-sandy loam (FSL), 100% sandy-clay loam (SCL), 33% FSL/67% SCL, and 67% FSL/33% SCL. Bars with different letters on top are significantly different at $P<0.05$ significance level.

missed strategic rainfall events or preemption of limited soil water and/or nutrients by invasive weedy species. Soil composition changes resulted in significant effects on TEM and RATE, with slight reductions for both traits in clay-containing soils (see Fig. 2A and B). Clay content in soils can improve the ability of soils to hold water for plant use, but it can also cause crusting that impedes seedling emergence (Wood et al., 1982). For Majestic, the added capacity of clay to hold water was apparently unnecessary, whereas the tendency of clay soils to crust likely prevented some seedlings from emerging. Indeed, at the end of our experiment, we lifted the soil crust and found germinated seedlings that were unable to penetrate the soil crust in the SCL (clay) soil.

The Ds-23 and Ds-26 collections of Searls'prairie clover originated from the central and southern portions of the Great Basin, which receive 150–350 mm precipitation annually (Bhattarai et al., 2011). Untreated Ds-23 had a high proportion of viable hard seed, a low germination percent, and negligible TEM and RATE values (see Figs. 1A and 2A). The Ds-23 Searls' prairie clover responses to scarification and planting depth were highly similar to those of the Majestic and Spectrum western prairie clover and indicate that a similar seed germination protocol could be used for both species. Interestingly, the reduction in TEM and RATE in SCL (clay) soil compositions was more pronounced for Ds-23 compared with Majestic western prairie clover (see Fig. 2A and B), and this deleterious effect of soil crusting was observed to a greater extent for seedlings of Ds-23 that were unable to penetrate the crust by the end of the experiment.

Compared with Majestic, Spectrum, and Ds-23, Ds-26 exhibited a lower viable hard percentage in untreated seeds (see Table 1), attenuated improvement of germination upon scarification (see Table 1), higher TEM and RATE values for untreated seed (see Figs. 1A and 2A), and lower TEM and RATE values for scarified seed (see Figs. 1A and 2A). Seed of Ds-26 was the only seed source not cleaned at the USDA-ARS Forage and Range Research Laboratory at Logan, Utah. It underwent a more aggressive mechanical cleaning process than the other entries (Loren St. John, personal communication) that may have partially scarified the seed and led to different responses detected in this study. However, despite this partial scarification of Ds-26 seed, the additional scarification imposed by our seed treatments still resulted in improved viability, germination, TEM, and RATE. Thus regardless of seed cleaning method or source, a seed scarification process would further improve germination and emergence of prairie clover species.

NBR-1 basalt milkvetch originated from several collections spanning the Northern Basin and Range Level-III Ecoregion, which receives 200–700 mm annual precipitation (Bhattarai et al., 2008). The responses of NBR-1 basalt milkvetch in these experiments were different and often contrary to those of the two prairie clovers. NBR-1 exhibited 95% viable hard seed and 4% germination for untreated seed (see Table 1). Although scarification reduced its percentage viable hard seed, it did not improve the germination percentage (see Table 1) and seedling emergence remained below 20% (see Figs. 1A and 2A). Unlike the prairie clovers, NBR-1 had a higher TEM and RATE upon mechanical compared with acid scarification (see Fig. 1A and B), showed a reduced TEM under a 19 mm planting depth (see Fig. 1C), and resulted in greater TEM and higher RATE in clay containing soils (see Fig. 2A and B). These results are consistent with studies of other *Astragalus* species, wherein acid scarification damaged seed viability while mechanical scarification provided the optimal results (Eisvand et al., 2006). These results highlight a uniqueness of NBR-1 seedling germination and emergence with respect to the prairie clover species and will necessitate a different seedling establishment protocol. Because NBR-1 germinates and emerges at such a slow rate, it may benefit from the increased water-holding capacity that clay soil compositions provide (Wood et al., 1982) and emerge at a higher percentage under rangeland planting conditions in clay-containing soils. The slow NBR-1 emergence, however, may also result in variable and reduced TEM in deep or variable planting depths that sometimes occur in rangeland plantings. Thus despite the information gained about TEM and RATE for NBR-1 in these experiments, the relatively marginal improvements observed for NBR-1 necessitate further studies to more substantially improve its germination and emergence. These results are intriguing because the native distribution of basalt milkvetch is more ubiquitous than either of the prairie clovers, suggesting that it is successful in fitness in rangeland settings.

Implications

Semiarid western United States forb species are in demand by land managers and the public because they enhance biodiversity and provide forage for wildlife, livestock, sage-grouse, and native pollinators. Leguminous forbs native to western North America are of particular interest because they biologically fix nitrogenfor themselves and associated species in semiarid rangeland environments (Johnson and Rumbaugh, 1981). Obtaining reliable commercial stands of these species is critical for the consistent production of high-quality seeds for rangeland revegetation/restoration. In our experiments we examined the effects of seed scarification, planting depth, and soil composition on germination, total seedling emergence (TEM), and the rate of seedling emergence (RATE) for western prairie clover, Searls' prairie clover, and basalt milkvetch. To establish seed production fields and restore rangelands with western (Majestic and Spectrum) or Searls' (Ds-23 and Ds-26) prairie clovers, seed scarification and prevention of soil crusting until seedlings emerge is critical. Planting depth differences, which are inevitable in rangeland seeding but less so in agronomic seed production, indicated that a shallower 6-mm depth results in a faster rate of emergence than the 19-mm depth. For basalt milkvetch, seed scarification and planting in soil with some clay content may improve germination and emergence marginally, but additional research is needed to further improve its germination and seedling emergence. For revegetation/restoration of disturbed rangelands, where an immediate stand is desirable for soil stabilization and competition with invasive weeds while some germination delay would be prudent for future precipitation events, a blend of scarified and untreated seed may be beneficial.

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