Scarification and high, diurnal temperatures produce optimal germination of sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray)

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ABSTRACT
Sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray [Poaceae]) is a native, warm-season perennial bunchgrass that has value in conservation seedings in the Intermountain West. Aberdeen Plant Materials Center conducted 3 experiments to determine whether seed treatments could improve percent germination and coefficient of germination (CG, germination speed) of various accessions of sand dropseed. The effects of temperature, scarification, cold/moist stratification, and germination in Petri dishes or aerated water baths (bubblers) were investigated in a growth chamber. Initial Petri dish experiments with one accession at optimal

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germination temperatures indicated that scarification did not increase final percent germination (FPG) at 14 d after initiation (DAI) but did increase CG from 7.9 to 10.4. Scarification did not increase FPG or CG at 28 DAI at suboptimal temperatures. A larger study with 3 accessions and 8 treatment combinations of scarification, stratification, bubblers, and Petri dishes at optimal temperatures found the highest FPG and CG for each accession occurred with scarified seed germinated in Petri dishes. In some cases, stratification alone improved germination, but in other cases, it resulted in lower germination due to fungal growth. For all 3 accessions, germination in Petri dishes was superior to that in bubblers. These results suggest that scarification, and possibly stratification (both of which can be used for field-scale plantings), may improve the success of sand dropseed establishment in conservation seedings.

INTRODUCTION

Sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray [Poaceae]) is a perennial, warm-season bunchgrass native to much of the United States and parts of Canada and Mexico (USDA NRCS 2023). The species is highly polymorphic and adaptable to varying environmental conditions with numerous growth forms (Quinn and Ward 1968). In the Intermountain West, it is most abundant in deserts and lowlands, especially on sandy soil (Monsen and others 2004). Sand dropseed is extremely drought tolerant and is adapted to sites receiving 175 to 410 mm (7 to 16 in) annual precipitation (Ogle and others 2023). Uses include erosion control (Tilley and others 2009) and forage for livestock and wildlife (Monsen and others 2004). In the Intermountain West, it is an early seral species that can be used to slow the spread of the invasive annual, cheatgrass (USDA FS 1937; Monsen and others 2004).

Sand dropseed produces an abundance of tiny seeds. In one study, a single panicle yielded approximately 10,000 seeds (Brown 1943). Unpublished data from the Aberdeen Plant Materials Center (IDPMC) show sand dropseed has approximately 9,830,000 seeds/kg (4,460,000 seeds/lb). The seed (caryopsis) of sand dropseed has been described as having a hard, impermeable seed coat (USDA FS 1937; Tilley and others 2009), a claim that has not been adequately tested. In the caryopsi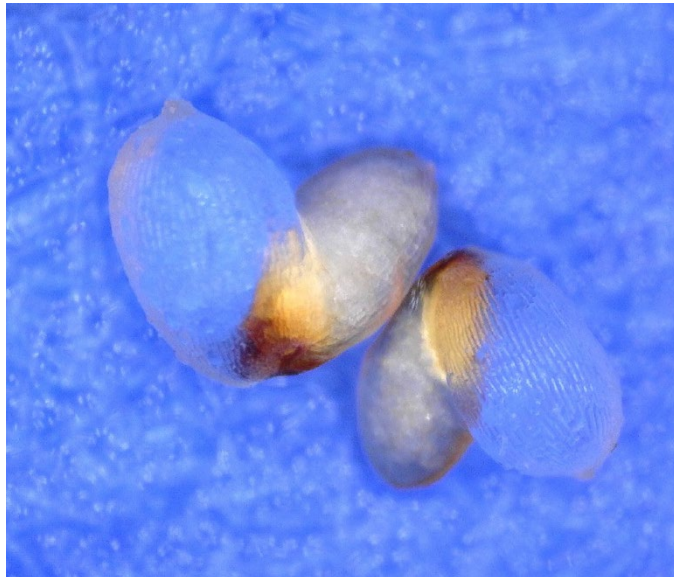s of most grass species, the seed is adnate (fused) to the pericarp (Zomlefer 1994); however, in most *Sporobolus* species, the pericarp is free from the seed and becomes mucilaginous when moist (Barkworth and others 2007) (Figure 1). Sand dropseed seed is known to exhibit physiological dormancy rather than physical dormancy (Baskin and Baskin 2001).

Figure 1 Pericarp of sand dropseed falling away from seed after 2 hrs on moistened blotter paper. Magnification is 125x. Photo by Derek Tilley.

Germination percentage of sand dropseed can vary greatly depending on the seed source. Staff at IDPMC have observed that germination of sand dropseed can be low, uneven, or delayed depending on source population as well as on germination conditions. Germination of recently collected seed from multiple populations ranged from 0.5% to 89% in a 14 d preliminary evaluation (unpublished data). Various methods to increase germination have been described in the literature. Diurnal light and temperature cycles of 35 °C/21 °C (95 °F/70 °F) were found to be better than lower or constant temperatures (Toole 1941). Cold-stratification (prechilling) at 3 °C (37 °F) increased germination (Toole 1941), as did short periods of moist, warm treatment at alternating temperatures of 45 °C/15 °C (113 °F/59 °F) (Sartor and Marone 2010). Jackson (1928) reported that scarification by shaking the seed with sand for 4 to 9 h did not increase germination; however, Ferrari and Parera (2015) increased germination with scarification by rubbing the seed

with sandpaper prior to germinating it at temperatures up to 35 °C (95 °F). Chemical scarification with concentrated sulfuric acid (71%) increased germination in laboratory experiments (Toole 1941). Germination of sand dropseed has also been improved by nicking the seed with a razor blade (Larson 2022).

The promptness of seed to germinate when exposed to conducive conditions, referred from this point forward as coefficient of germination (CG), can be a critical trait for successful establishment in arid and semiarid environments (Agneray and others 2022). In the Intermountain West, most precipitation falls as snow in winter and early spring, outside of the growing season (Smith and others 2012); soil moisture levels peak in the early growing season and rapidly diminish as temperatures increase. Plant growth under these conditions depends largely on soil moisture accumulated during the previous winter, and growth is curtailed by drying soils in early or mid-summer (Comstock and Ehleringer 1992). Germination conditions for warm-season species in the Intermountain West are even more constrained. The seasonal window is limited to the concomitant occurrence of warm soil temperatures and sufficient soil moisture necessary for germinating warm-season grasses such as sand dropseed. Warm-season grass seeds that germinate rapidly are better able to take advantage of this short window, while slower germination requires more prolonged periods of soil moisture (Roundy and Biedenbender 1996). A pre-plant treatment that can increase an accession's CG could provide an advantage to establishment.

Many of the documented seed treatments for sand dropseed are time- and labor-intensive or otherwise burdensome for end users. Concentrated sulfuric acid, for example, is highly corrosive and hazardous (NOAA 2023), making it unsuitable for field-scale use. Likewise, nicking individual seeds is not scalable for conservation plantings. Our goal was to find seed treatments that resulted in more rapid, uniform, and complete germination of sand dropseed using methods that can be scaled to larger quantities of seed prior to conservation plantings. To this end, we conducted 3 growth chamber germination experiments, each successive experiment building on the previous, to test combinations of potentially beneficial seed treatments.
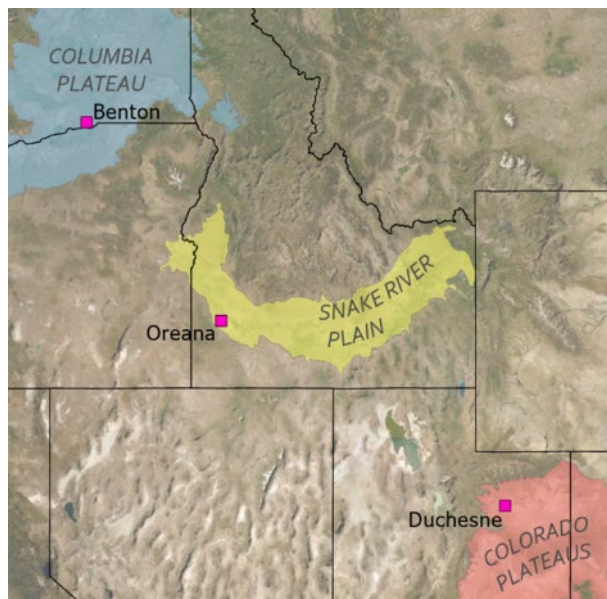
MATERIALS AND METHODS

Figure 2. Sand dropseed collection locations within Level III Ecoregions (Omernik, 1987). Map source: Esri, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo and the GIS User Community.

Germination experiments were conducted with 3 populations of sand dropseed representing a range of ecoregions and environmental conditions in the Intermountain West (Figure 2): Oreana, Duchesne, and Benton. Accession locations and environmental characteristics are presented in Table 1. All seed was collected from native populations (G0) in 2022, stored at room temperature, and was less than 1 y old at the time of testing.

Approximately 30 cm^3 (1/8 cup) of each accession was run for 20 s in a Forsberg electric sample seed scarifier (Thief River Falls, MN) lined with 40-grit sandpaper. Because the grit was large (essentially the same size as the seed), the machine failed to scarify the seed as expected (the pericarp was intact as observed under magnification), but the process did detach the lemma and palea (hulls) (Figure 3). Winnowing with an air screen cleaner separated the detached hulls. To accomplish scarification of the pericarp, clean winnowed seed was rubbed between 2 pieces of 180-grit fine sandpaper for 30 "rubs" about 10 cm (4 in) in length, similar to Ferrari and Parera (2015). Fine

sandpaper scarification did not remove pericarps, as visible in Figure 4. In the following experiments, all seed was run in the Forsberg and winnowed to remove hulls. This seed was considered non-scarified. For scarified treatments, we followed the Forsberg treatment with the Ferrari and Parera (2015) fine sandpaper method to scarify the pericarp of hulled seed.

Table 1. Location and environmental characteristics of 3 accessions of sand dropseed collected by the IDPMC in 2022.

IDPMC Accession	Location	Provisional Seed Zone[1]	Level III Ecoregion[2]	Elevation (m)	Annual Precipitation (mm)[3]
9106745	Oreana, Owyhee Co., Idaho	20-25/arid	Snake River Plain	835	202
9106723	Duchesne, Duchesne Co., Utah	5-10/semiarid	Colorado Plateaus	1850	272
9106698	Benton Co., Washington	25-30/semiarid	Columbia Plateau	334	232

[1]Bower and others (2014)
[2]Omernik (1987)
[3]PRISM (2023)

Figure 3. Hulled sand dropseed with lemma and palea separated and removed (left) and non-hulled seed (right). Magnification is 50x. Scale bar is 1 mm and applies to both photos. Photo by Derek Tilley

Experiment 1. Scarified vs non-scarified at optimal temperature
Because we observed Oreana germinating remarkably well by 7 d in an earlier germination test, we chose it for this experiment. For each treatment (scarified and non-scarified), we placed 25 seeds in each of 4 replicate 90 mm Petri dishes lined with blotter paper moistened with distilled water and sealed with paraffin film and placed the 8 Petri dishes randomly in a Hoffman growth chamber (Hoffman Manufacturing, Inc., Corvallis, Oregon). Chamber settings were a 17 h light/7 h dark cycle with 35 °C (95 °F) day and 22 °C (72 °F) night temperatures, optimal conditions determined by Toole (1941). New germinants were counted at 2, 5, 7, and 14 d after initiation (DAI). At 14 DAI, we observed nearly 100% germination in the scarified treatments and used that date as the cutoff for calculating final percent germination (FPG) and coefficient of germination (CG). CG was calculated using the method described by Maguire (1962), where the number of new germinants at each counting (in this case, 2, 5, 7, and 14 DAI) is divided by the DAI, and the values are summed at the end of the test:

$$CG = \left(\frac{no.\,of\,seedlings}{DAI\,first\,count}\right) + \left(\frac{no.\,of\,seedlings}{DAI\,second\,count}\right) + \cdots + \left(\frac{no.\,of\,seedlings}{DAI\,final\,count}\right)$$

A comparatively higher CG indicates a faster rate of germination.

CG was analyzed with a Two Sample T-test (α = 0.05). FPG data was not normally distributed, so it was analyzed with a Wilcoxon Rank Sum test (α = 0.05). Statistical tests for this and subsequent experiments were performed using Statistix 10 (Analytical Software, Tallahassee, Florida).

Experiment 2. Scarified vs non-scarified at suboptimal

Because germination of scarified and non-scarified seed of the Oreana accession at optimal temperatures exceeded expectations, we repeated Experiment 1 as described above, but at a sub-optimal, constant germination temperature, namely room temperature (21 °C, 70 °F). A 17 h light/7 h dark cycle was provided with the LED grow lights from an AeroGarden Bounty Basic home hydroponics unit (AeroGrow International, Inc., Boulder, CO).

Figure 4. Scarified sand dropseed after being rubbed with 180 grit sandpaper. Note the scratches on the outer coat. Magnification is 125x. Photo by Derek Tilley.

Germination occurred more slowly at room temperature than in Experiment 1, so new germinants were counted at 7, 14, 21, and 28 DAI. FPG and CG at 28 DAI were calculated and analyzed with Two-Sample T-tests (α = 0.05). Because a different evaluation schedule was used, CG could not be directly compared between experiments 1 and 2.

We used data from Experiments 2 and 3 (both evaluated at 7, 14, 21, and 28 DAI) to compare the effect of temperature on FPG and CG of untreated Oreana seed. FPG and CG at optimal (diurnal 35 °C/22 °C) and suboptimal (21 °C constant) temperatures were analyzed with a Two-Sample T-Test (α = 0.05).

Based on the results from Experiments 1 and 2, we conducted a larger experiment to test several germination factors and possible interactions. We included 2 additional accessions, Benton and Duchesne. The study was designed with 8 treatments consisting of 3 factors, each with 2 ranks: cold/moist stratification (yes and no), scarification (yes and no), and germination environment (aerated water bath [bubbler] or Petri dish). The combinations of treatments are as follows: (B) no stratification, no scarification, in bubbler; (P) no stratification, no scarification, in Petri dish (control); (ScB) no stratification, scarification, bubbler; (ScP) no stratification, scarification, Petri dish; (StB) stratification, no scarification, bubbler; (StP) stratification, no scarification, Petri dish. (ScStB) scarification, stratification, bubbler; (ScStP) scarification, stratification, Petri dish. We did not include seed source location as a factor because of differences in site history and potential maternal effects (Luzuriaga and others 2005; Nguyen and others 2021), but evaluated the three populations separately.

Seed was scarified as described above. Seed was stratified by placing it in fine mesh bags and burying it in damp coarse sand for 28 d at 2 °C (36 °F), conditions Toole (1941) described as sufficient. Exposed to moisture, the seed pericarps swelled and became mucilaginous, resulting in a solid mass of pericarps and seed when the bags were opened after 28 d. During stratification, fungal mycelia formed the mass of pericarps in all accessions, whether previously scarified or not.

Stratified seed was separated from the mass of pericarps by adding distilled water to a small amount of the mass and stirring in a Petri dish. We blotted the wetted mass with paper towels then scraped the seed onto a piece of paper for counting. To prevent further fungal growth in the growth media, all stratified seed was
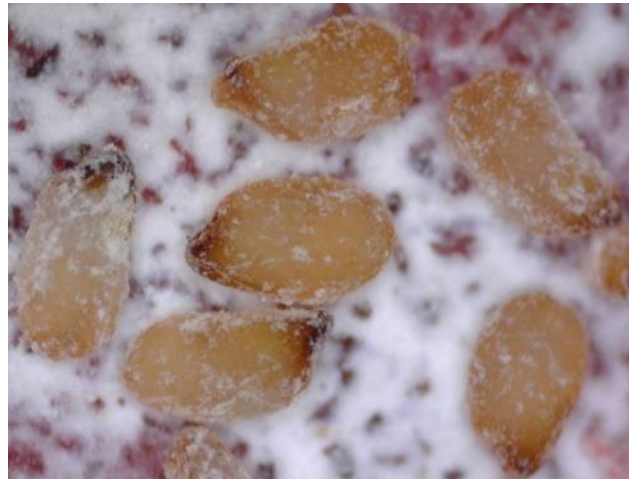
subject to a 10 min bath in a 1:8 bleach solution (6% sodium hypochlorite : water) followed by thorough rinsing. Non-stratified seed was treated with the same bleach bath conditions before placement in bubblers but not before placement in Petri dishes.

Seed was germinated in aerated water or Petri dishes. For the aerated water treatment (bubbler), we placed seed in fine mesh bags and submerged the bags in 0.95 L (1 qt) Mason jars filled with 500 mL (0.5 qt) distilled water. Seed bags were weighted with a glass stone to prevent floating. Whisper AP 150 aquarium air pumps (Spectrum Brands Pet LLC, Blacksburg, VA) fitted with 2.5 cm bubbling air stones were used to provide each jar with aeration following the procedure described by Tilley and Pickett (2021). Petri dishes were prepared as described above. Each experimental unit (bag or Petri dish) contained 25 seeds and was replicated 6 times.

The 8 treatments were completely randomized within the growth chamber described above with a diurnal cycle of 17 h light, 35 °C/7 h dark, 22 °C. New germinants were counted at 7, 14, 21, and 28 DAI. FPG and CG were calculated from these counts.

Generalized linear mixed models with three fixed factors (scarification, stratification, and environment) were performed on untransformed data to determine the effect on final percent germination. Individual effects and interactions among seed mix treatments and rates were evaluated using the GLIMMIX procedure of SAS software (SAS Institute Inc.). Replications were treated as random effects in all models. The best model fit for FPG based on AIC score was achieved using a beta distribution with a logit link function. For CG data, the best fit was achieved with a Gaussian distribution and log link function. Means were separated with a post hoc Tukey-Kramer test when $\alpha \leq 0.05$. In addition to individual treatment effects, we analyzed full treatment combinations and similarly separated means.

RESULTS

Experiment 1. Scarified vs non-scarified at optimal temperature
Rapid germination at 17 h light, 35 °C/7 h dark, 22 °C led us to evaluate at short intervals (2, 5, 7, and 14 DAI). At 2 DAI, scarification was significant ($P = 0.0042$). Germination of scarified seed (74%) exceeded non-scarified seed (51%). At 14 DAI, scarification was no longer significant ($P = 0.1429$); FPG was 99% and 89% for scarified and non-scarified seed, respectively (Figure 5). During this same 14-d period, scarification was significant for CG ($P = 0.0021$), with scarified seed (10.4) exceeding non-scarified seed (7.9).
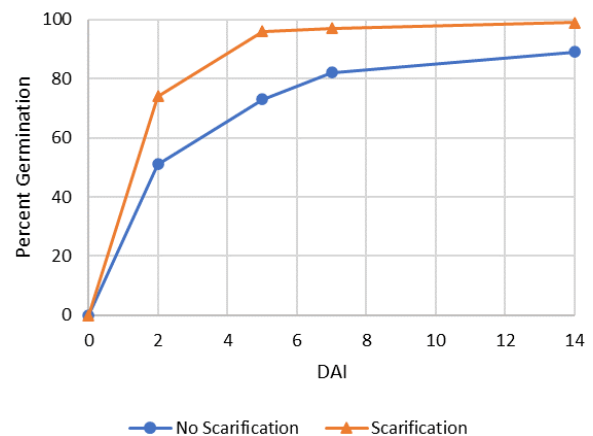

Figure 5. Percent germination of non-scarified vs. scarified seed of Oreana accession sand dropseed at optimal (diurnal 17 hr 35 °C/7 hr 22 °C) temperatures at 2, 5, 7, and 14 DAI.

Experiment 2. Scarified vs non-scarified at suboptimal temperature
At room temperature (constant 21 °C), scarification was not significant for either FPG ($P = 0.9990$) or CG ($P = 0.9294$) at 28 DAI. Both treatments had the same FPG (51%) and similar CG (1.86 scarified and 1.83 non-scarified).

When germination of untreated Oreana seed was compared at optimal (diurnal 17 h 35 °C/7 h 22 °C) vs. suboptimal (21 °C constant) temperatures, FPG was significantly higher ($P = 0.0408$) at the optimal temperature regime, 75.3% vs 51% at suboptimal temperature. CG was also significantly greater ($P = 0.0497$) at the optimal temperature, 2.66 vs 1.83 at the suboptimal temperature.

Experiment 3. Multi-factor germination treatments
Significant differences were observed for all single factors, with the exception of scarification and stratification treatments of the Oreana accession (Table 2). We also saw a significant interaction effect of scarification and stratification within all 3 accessions. CG results closely reflected those for FPG; no further data are presented.

All *P* values for Experiment 3 are provided in Table 2. FPG varied significantly by scarification treatment from Benton and Duchesne but not from Oreana (Figure 6). Scarified seed from Benton showed a 400% increase in germination compared to non-scarified seed (64% and 16%, respectively). However, scarification of seed caused a small but significant decrease in FPG within seed collected at Duchesne. No significant difference in FPG was observed from the Oreana seed.

Cold/moist stratification of seed significantly increased FPG of Benton seed (45% and 29%) but significantly decreased FPG of Duchesne seed (39% and 70%). FPG of seed from Oreana was unaffected by stratification (77% non-stratified and 71% stratified).

Table 2. *P* values of treatments and interactions on final percent germination (FPG) and coefficient of germination (CG) at 28 DAI. * indicates a *P* value of ≤ 0.05; ** ≤ 0.01.

Benton.	FPG (28 DAI).	CG
Treatment	*P* value	*P* value
Scarification	<0.001**	<0.001**
Stratification	<0.001**	0.020*
Environment	0.001**	0.019*
Scarification*Stratification	0.040*	0.069
Scarification*Environment	0.658	0.146
Stratification*Environment	0.089	0.280
Scarification*Stratification*Environment	0.117	0.908
Full Treatment	<0.001**	<0.001**

Duchesne	FPG (28 DAI)..	CG
Treatment	*P* value	*P* value
Scarification	0.044*	<0.001**
Stratification	<0.001**	<0.001**
Environment	0.004**	0.001*
Scarification*Stratification	<0.001**	<0.001**
Scarification*Environment	0.115	0.250
Stratification*Environment	0.818	0.788
Scarification*Stratification*Environment	0.471	0.216
Full Treatment	<0.001**	<0.001**

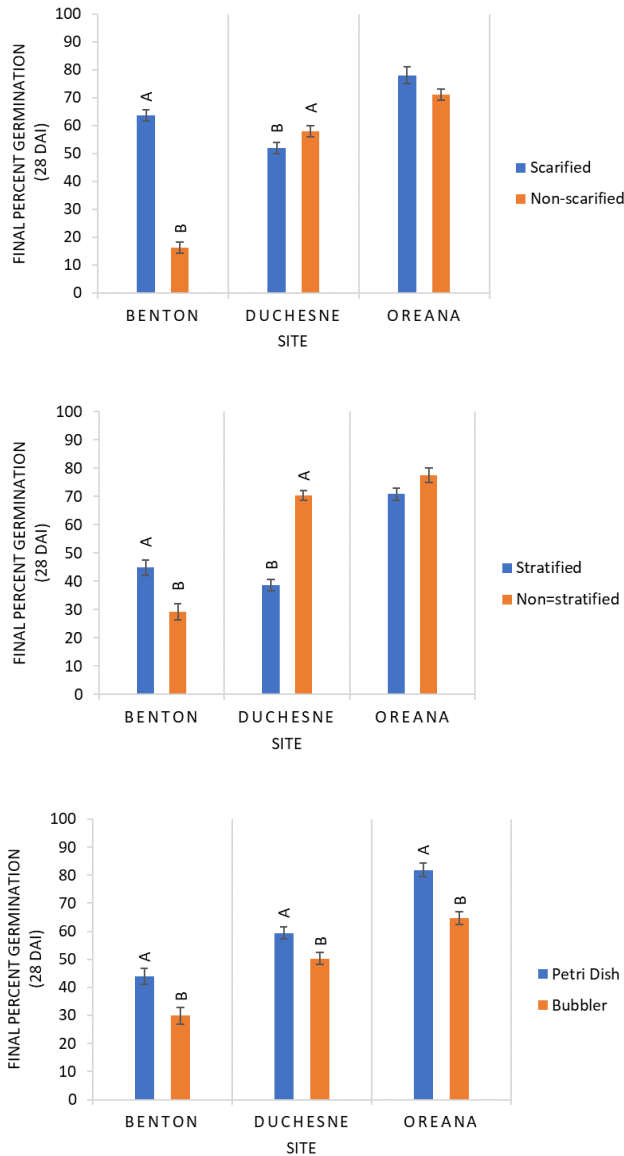| Oreana	FPG (28 DAI).	CG
Treatment	*P* value	*P* value
Scarification	0.074	0.168
Stratification	0.060	0.114
Environment	<0.001**	<0.001**
Scarification*Stratification	<0.001**	<0.001**
Scarification*Environment	0.479	0.054
Stratification*Environment	0.261	0.126
Scarification*Stratification*Environment	0.074	0.698
Full Treatment	<0.001**	<0.001**

Figure 6. Final percent germination (FPG) in response to seed scarification, cold/moist stratification and germination environment. Different letters above bars signify differences within a site when α≤0.05. Specific P values are identified in Table 2. Error bars indicate ± 1 standard error.

Germination in an aerated bath significantly decreased germination with seed from all 3 locations. Benton seed achieved 44% FPG in a standard Petri dish environment, while seed in the aerated bath germinated at 30%. The bubbler environment reduced germination from 59% to 50% with Duchesne seed and from 82 to 65% with Oreana seed.

Full treatment FPG differences were highly significant within all 3 seed source locations (all *P* < 0.001). Trends varied by site; however, the ScP treatment produced the greatest FGP from all 3 seed sources.

For Benton, ScP did not differ significantly from the StScB and StScP treatments (Figure 7). All treatments had a higher FPG than the control (P) except for stratification in the bubbler (StB) and bubbler alone (B). All treatments involving scarification increased FPG (47% to 77% vs 25% compared with non-stratified, non-scarified seed germinated in Petri dishes. However, stratification may be less important than scarification, as the 4 highest FPGs for this accession were all from scarified treatments.

The Duchesne accession had the highest control (P) FPG (83%) of the 3 accessions for non-stratified, non-scarified seed germinated in Petri dishes, although scarification alone was similar. All treatments that included stratification had poorer germination when compared to the control (P) treatment. Similarly, regardless of germination environment, stratification plus scarification (ScStP and ScStB) appears to have increased susceptibility to fungal growth, producing the lowest FPGs (29% and 23%, respectively).

The Oreana accession's control (P) FPG (75%) is lower than the (P) FPG of Duchesne (83%). However, scarification in the ScP treatment led the Oreana accession to a FPG of 99%, making it the highest-performing treatment and accession in this study. While stratification alone (StP and StB) increased FPG, stratification combined with scarification did not perform as well as the control (P).
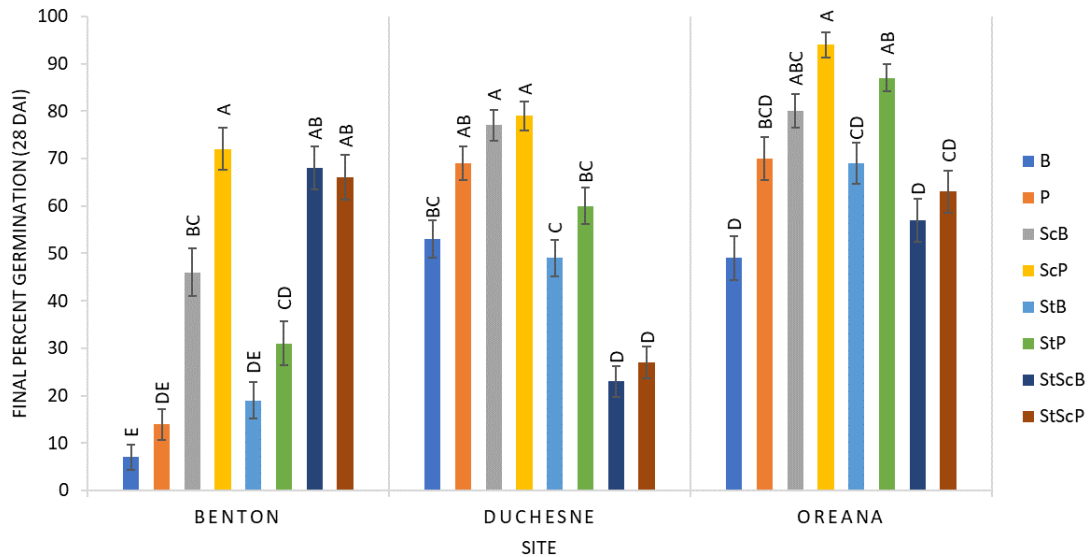
Figure 7. Final percent germination (FPG) at 28 DAI of three accessions of sand dropseed, Benton (Benton Co., WA), Duchesne (Duchesne Co., UT) and Oreana (Owyhee Co., ID). B= no stratification, no scarification, and in bubbler; P= no stratification, no scarification, in a petri dish; ScB= no stratification, scarification, in bubblers; ScP= no stratification, scarification, and petri dish; StB= stratification, no scarification, and bubbler; StP= stratification, no scarification, and petri dish. ScStB= scarification, stratification, in bubbler; ScStP= scarification, stratification, and petri dish. Error bars are ±1 SE. Means within a collection location followed by the same letters are not significantly different at P<0.05.

DISCUSSION

We observed pericarps swelling, splitting, and falling away from the seed within hours of contact with water for all accessions. This observation contradicts reports by USFS (1937) and Tilley and others (2009) of an impermeable pericarp. It is possible that the testa (seed coat), rather than the pericarp, is impermeable, although this is unlikely due to a high degree of germination observed in the untreated seed of some accessions in our study. Pericarp impermeability has not been reported in other *Sporobolus* species, which have mostly been classified as having physiological dormancy (Baskin and Baskin 2014).

We saw significantly greater FPG and CG of a single accession at higher temperatures. Germination at higher temperatures can be expected with warm-season grasses such as sand dropseed; however, it poses challenges for Intermountain West restoration practices. The most problematic weeds in Intermountain rangelands are cool-season, annual grasses [Poaceae], namely cheatgrass (*Bromus tectorum* L.), ventenata (*Ventenata dubia* (Leers) Coss.), and Medusahead wildrye (*Taeniatherum caput-medusae* (L.) Nevski) that germinate during periods of late fall or early spring moisture, which gives them a distinct advantage over warm-season species. Optimal germination conditions for sand dropseed, high temperatures and adequate moisture, are rare in the Intermountain region, and seed used in restoration plantings may lie dormant for years. Torok and others (2023) reported that sand dropseed can form persistent soil seed banks.

Toole (1941) reported that sand dropseed can germinate quickly once needed environmental conditions are met. Our results substantiate Toole's report as we saw germination occurring within 2 DAI at optimal temperatures (Figure 8), and maximum germination was reached in most cases by 14 DAI (not shown). This is encouraging as wet conditions during the hot summer months in the Intermountain region can be fleeting. Fast, uniform germination would presumably result in better establishment than a slower germination rate. Nevertheless, it is important to field-test this assumption because observations from other grass species native to the region indicate that a slower or more dispersed germination process may benefit long-term establishment success. This is especially relevant considering the substantial year-to-year fluctuations in

weather conditions, characteristic of the Intermountain West, which can lead to widely varying emergence rates and early life-stage survival (Baughman and others 2023; Copeland and others 2023).

Figure 8. Germinants of scarified Oreana sand dropseed 2 DAI on blotter paper at 17 hr light, 35 °C/7 hr dark, 22 °C. Photo by Derek Tilley.

The effect of scarification on sand dropseed was variable. Scarification increased FPG compared to non-treated seed (P) for all accessions. Scarification improved FPG and CG of stratified seed for the Benton accession and the Oreana accession in the Petri dish but not for the Duchesne accession or the Oreana accession in the bubbler.

Stratification improved germination compared to the non-treated Petri dish control and the non-treated bubbler seed for the Benton and Oreana accessions but not for the Duchesne accession. The anomalous response from the Duchesne seed may have been due to seed losses from fungal infection. Adding stratification to scarified seed reduced FPG for all accessions, with the exception of the Benton accession in the aerated bath.

Seed germination in an aqueous environment has been shown to increase overall germination and increase germination speed for several species (Tilley 2014; Tilley and Pickett 2021). This has potential application in greenhouse seedling production and for hydroseeding. However, final germination percentages of sand dropseed were lower in bubblers than in Petri dishes. It is possible that the slightly lower water potential in the Petri dish environment was more favorable to sand dropseed germination.

CONCLUSION

Although each of the 3 accessions responded differently to the treatments, the highest mean FPG and CG for each accession occurred in Petri dishes with scarification (ScP) under optimal germination temperatures. Cold/moist stratification led to the growth of fungal mycelia in all accessions; however, stratification improved germination in some cases. The effectiveness of scarification plus stratification appeared to be related to each accession's susceptibility to fungal damage. Germination in aerated water baths was less effective than germination in Petri dishes. Germination at higher, diurnal temperatures was significantly greater than at room temperature. At suboptimal temperatures, scarification did not increase either FPG or CG. Scarification with fine-grit sandpaper may be a way to increase the number of germinants and the speed at which they germinate in conservation plantings.

Processing the seed for 20 s in a Forsberg scarifier with coarse (40-grit) sandpaper removed vegetative structures (lemma and palea), but the grit was too large to scratch the seed. Additional rubbing with fine (180-grit) sandpaper was required to achieve scarification. Further study is needed to determine means to scarify larger quantities of sand dropseed for restoration scale projects; however, lining a Forsberg scarifier with 180-grit sandpaper seems reasonable.

Differences in germination observed between populations may reflect local environmental conditions of the year (maternal effect), or they may indicate genetic variation. For restoration purposes, using local seed sources or a deliberate mixture of phenotypes is recommended (Massatti 2019).

LITERATURE CITED

Agneray AC, Parchman TL, Leger EA. 2022. Phenotypes and environment predict seedling survival for seven co-occurring Great Basin plant taxa growing with invasive grass. Ecology and Evolution 2022;12:e8870. doi: 10.1002/ece3.8870.

Barkworth ME, Anderton LK, Capels KM, Long S, Piep MB, editors. 2007. Manual of Grasses for North America. Logan (UT): Intermountain Herbarium and Utah State University Press. 627 p.

Baskin JM, Baskin CC. 2001. Propagation protocol for production of Container (plug) *Sporobolus cryptandrus* (Torr.) Gray plants. Lexington (KY): University of Kentucky. In: Native Plant Network. URL: http://NativePlantNetwork.org (accessed on 23 December 2022). US Department of Agriculture, Forest Service, National Center for Reforestation, Nurseries, and Genetic Resources,

Baskin CC, Baskin JM. 2014. Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination (2nd ed., Vol. 86, Issue 6) Elsevier, Academic Press.

Baughman OW, Kerby JD, Boyd CS, Madsen MD, Svejcar TJ. 2023. Can delaying germination reduce barriers to successful emergence for early-germinating, fall-sown native bunchgrass seeds in cold deserts? Restoration Ecology 31: e13761. https://doi.org/10.111/rec13761

Bower AD, St. Clair JB, Erickson V. 2014. Generalized provisional seed zones for native plants. Ecological Applications 24(5):913-919. doi: 10.1890/13-0285.1.

Brown, HR. 1943. Growth and seed yields of native prairie plants in various habitats of the mixed-prairie. Transactions, Kansas Academy of Science 46: 87-99.

Comstock JP, Ehleringer, JR. 1992. Plant adaptation in the Great Basin and Colorado Plateau. Great Basin Naturalist 52(3):195-215.

Copeland SM, Bradford JB, Hardegree SP, Schlaepfer DR, Badik KJ. 2023. Management and environmental factors associated with simulated restoration seeding barriers in sagebrush steppe. Restoration Ecology 31: e13722. https://doi.org/10.111/rec.13722

Ferrari FN, Parera CA. 2015. Germination of six native perennial grasses that can be used as potential soil cover crops in drip-irrigated vineyards in semiarid environs of Argentina. Journal of Arid Environments 113:1-5.

Jackson CV. 1928. Seed germination in certain New Mexico range grasses. Botanical Gazette 86: 270-294.

Larson J. 2022. Personal communication. Burns (OR): USDA-ARS Eastern Oregon Agricultural Research Center-Burns. Postdoctoral Researcher.

Luzuriaga AL, Escudero A, Pérez-García P. 2005. Environmental maternal effects on seed morphology and germination in *Sinapis arvensis* (Cruciferae). Weed Research 46: 163-174.

Maguire JD. 1962. Speed of germination--Aid in selection and evaluation for seedling emergence and vigor. Crop Science 2:176-177.

Massatti R. 2019. Genetically-informed seed transfer zones for *Pleuraphis jamesii*, *Sphaeralcea parvifolia*, and *Sporobolus cryptandrus* across the Colorado Plateau and adjacent regions: US Geological Survey. 11p.

Monsen SB, Stevens R, Shaw N. 2004. Grasses. In: Monsen SB, Stevens R, Shaw NL, compilers. Restoring western ranges and wildlands. Fort Collins(CO): USDA Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-136-vol-2. p. 295-424.

Nguyen CD, Jianjun C, Perez D, Huo H, Porceddu, M. 2021. Effects of maternal environment on seed germination and seedling vigor of *Petunia* x hybrida under different abiotic stresses. Plants 10(3): 581.

[NOAA] USDC National Oceanic and Atmospheric Administration. 2023. Sulfuric acid Chemical Datasheet. Cameo Chemicals Database of Hazardous Materials, National Oceanographic and Atmospheric Administration. URL: https://cameochemicals.noaa.gov/chemical/5193 (accessed 6 March 2023).

Ogle D, Tilley D, St. John L, Stannard M, Holzworth L, Wolf M. 2023. Conservation plant species for the Intermountain West. Boise (ID): USDA Natural Resources Conservation Service. Idaho Plant Materials Technical Note No. 24. 75 p.

Omernik JM. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77:118–125.

[PRISM] PRISM Climate Group. 2023. URL: https://prism.oregonstate.edu (data created 15 December 2022, accessed 15 March 2023). Corvallis (OR): Oregon State University.

Quinn JA, Ward RT. 1968. Ecological differences in sand dropseed (*Sporobolus cryptandrus*). Ecological Monographs 39(1): 61-78.

Roundy BA, Biedenbender SH. 1996. Germination of warm-season grasses under constant and dynamic temperatures. Journal of Range Management 49 (5) 425-431.

Sartor CE, Marone L. 2010. A plurality of causal mechanisms explains the persistence or transience of soil seed banks. Journal of Arid Environments 74:303-306.

Smith SD, Monson RK, Anderson JE. 2012. *Physiological Ecology of North American Desert Plants*. Berlin, Heidelberg. Springer Science and Business Media. 288 p.

Tilley D. 2014. Soaking Nebraska sedge seeds in warm, aerated water improves germination. Native Plants Journal 14(1): 55-58.

Tilley D, Pickett T. 2021. Germination response of curlycup gumweed seed to oxygenated water treatment. Native Plants Journal 22(1): 4-12.

Tilley D, St. John L, Ogle D. 2009. Plant guide for sand dropseed (*Sporobolus cryptandrus*). Aberdeen (ID): USDA Natural Resources Conservation Service, Aberdeen Plant Materials Center. 4 p.

Toole VK. 1941. Factors affecting the germination of various dropseed grasses (*Sporobolus* spp.). Journal of Agricultural Research 62 (12) 691-715.

Torok P, Espinoza-Ami FD, Szel-Toth K, Diaz Cando P, Guallichico Suntaxi LR, McIntosh-Buday A, Habenczyus AA, Toro-Szijgyarto V, Kovacsics-Vari G, Tolgyesi C, Tothmeresz B, Sonkoly J. 2023. Accumulated soil seed bank of the invasive sand dropseed (*Sporobolus cryptandrus*) poses a challenge for its suppression. Authorea. July 22, 2023.

[USDA FS] USDA Forest Service. 1937. *Range Plant Handbook*. Washington, DC. United States Government Printing Office.

[USDA NRCS] USDA Natural Resources Conservation Service. 2023. The PLANTS Database. URL: https://plants.sc.egov.usda.gov/home/plantProfile?symbol=SPCR (accessed 1 March 2023). Greensboro (NC): National Plant Data Team.

Zomlefer WB. 1994. *Guide to Flowering Plant Families*. Chapel Hill (NC): The University of North Carolina Press. 408 p.

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