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The good, the bad, the salty: Investigation of native plants for revegetation of salt-impacted soil in the northern Great Plains, United States

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Abstract: Salt-impacted soils are formed through anthropogenic or natural causes. In the northern Great Plains region of North America, salts that occur in the soil parent materials move upward through the soil profile due to changing land-use and precipitation regimes. If these salts accumulate in the surface soil layer, they impact the ecological integrity of a site, creating the need for ecological restoration. Common methods for addressing salt-impacted soil were developed in the irrigated soils of the southwestern United States and are often ineffective in noncrop areas and the northern Great Plains due to differences in soil properties, elevated gypsum concentrations, and poor soil drainage. Therefore, the objective of this study was to identify native plant species suited for revegetation in salt-impacted soils in the northern Great Plains region of North America. This field study evaluated the survival and performance of eight native plant species in soils with high, medium, or low salt concentrations. Survival was evaluated at summer and end-of-season sampling (five months total) and performance variables (plant height, basal diameter, number of flowering heads, number of tillers/stems, and aboveground biomass) were evaluated at end-of-season sampling. Seven of the eight species evaluated exhibited some salt tolerance and could be suitable for the revegetation of moderately salt-impacted soil. Overall, *Asclepias speciosa*, *Gaillardia aristata*, and *Helianthus maximiliani* grew in minimally salt-impacted soils, whereas *Elymus canadensis*, *Elymus trachycaulus*, and *Pascopyrum smithii* grew in moderately salt-impacted soils, and only *Sporobolus airoides* grew in highly salt-impacted soils. As these native plants establish and grow, they will spur autogenic recovery by stabilizing soil structure and improving water movement in the soil. These results indicate that salt tolerance must be considered when selecting species that could revegetate these areas.

Key words: ecological restoration—native plants—plant survival—revegetation—saline/sodic soil—transplants

Soils are formed by the chemical and physical weathering of geological material and accumulation of organic material and contain inorganic and organic compounds, including salt (Jenny 1941). Salts are a natural component of all soils; however, high levels of salt can lead to salt impaction (Rengasamy 2006). Salt-impacted soils occur due to anthropogenic or natural causes. Anthropogenic activities that contribute to salt impaction include the application of fertilizers and other soil amendments (Rengasamy 2010), irrigation with saline water (Maas and Grattan 1999), the application of roadway deicers (Dudley et al. 2014), and oil and gas production, where saltwater is unearthed during drilling (Merrill et al. 1990). Naturally occurring salt-impacted soils develop when salts accumulate in the soil through wind deposition, rain, seawater intrusion, or parent material (Maas and Grattan 1999). In the northern Great Plains region of North America (NGP), marine sediments in parent materials have high salt concentrations. Increased precipitation in the region is creating conditions where the water table is rising and bringing salts from the parent material further up in the soil profile (Rhoades and Halverson 1976; Seelig 2000; Lobell et al. 2010; Carlson et al. 2016). After evaporation, salts accumulate near the soil surface where they can affect plant growth.

Common methods to reduce surface salts include tile drainage, gypsum application, and salt leaching with low salt-concentrated water (Seelig 2000; Carlson et al. 2013). Tile drainage may improve soil drainage and help leach salt from the soil (Seelig 2000; Carlson et al. 2013). The application of calcium (Ca) sources (i.e., gypsum and lime) is supposed to counteract the dispersive properties of sodium (Na) in salt-impacted soil. Similar to tile drainage, the application of water with low salts helps move salts down from the soil surface (Seelig 2000; Carlson et al. 2013). Although these methods are beneficial in the arid, irrigated soils of the southwestern United States, they are ineffective in the semiarid, nonirrigated soils of the NGP, possibly aggravating the problem due to differences in soil properties, elevated gypsum concentrations, and poor soil drainage (Birru et al. 2019). Further, irrigation is outside the scope of most ecological restoration activities. Because these traditional methods are ineffective in the NGP, other methods are under investigation, including revegetation (Fiedler et al. 2022).

Revegetation can initiate the autogenic recovery of a salt-impacted site. Autogenic recovery is the process by which plants, through their growth and senescence, create positive feedback that gradually improves conditions (Whisenant 1999). An example of autogenic recovery of soil conditions by native plants is the degradation of polycyclic aromatic hydrocarbons in soil through root

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growth and exudation (Reddy et al. 2019). In salt-impacted soils, autogenic recovery is expected as plants stabilize soil structure and improve water movement in the soil. Soil structure is an important part of ecosystem function, influencing water movement, soil processes, nutrient cycling, and productivity (Bronick and Lal 2005). Salt-impacted soil has disrupted soil structure and poor aggregation since Na ions disperse aggregates. Plants can improve soil structure and water movement through root production. Plant roots enmesh soil particles and release compounds that help aggregate soil particles (Bronick and Lal 2005). Root growth, development (Lal 1991), distribution, and water uptake (Rampazzo et al. 1998; Pardo et al. 2000) increase as soil structure improves. Plant roots also create macropores that increase gas exchange and water movement in the soil. As roots decay, macropores are formed and new plants use the pores for root growth (Elkins et al. 1977). Ultimately, the effects of plants restore soil structure, allowing salts to leach back down below the rooting zone, which decreases salts in surface soil (Bronick and Lal 2005). The revegetation of plants on salt-impacted soil can improve soil health, and consequently, be an effective method of restoring salt-impacted soils. These benefits would subsequently cascade into a healthier ecosystem that provides multiple and sustainable benefits on the landscape (Paschke et al. 2019; Perkins et al. 2019).

To establish plants in salt-impacted soil and begin autogenic recovery, plant species with salt tolerance need to be identified. Salt stresses plants in two ways: roots experience restricted water uptake, and leaves accumulate salt, causing salt toxicity (Ryan et al. 1975). Plants have varying tolerances to salt, with some using salt-specific physiological mechanisms to manage salt stress, including osmotic stress tolerance, Na exclusion, and tissue tolerance (Munns and Tester 2008). Growth responses to salinity range from halophytes (that exhibit increased growth in soils with higher salt concentrations) or salt-tolerant nonhalophytes (that maintain growth in salt-impacted soils) compared to salt-sensitive nonhalophytes that do not grow in salt-impacted soils (Barrett-Lennard 2002). Unfortunately, in some salt-impacted soils, salt-sensitive native species are replaced by nonnative plants that are halophytes or salt-tolerant nonhalophytes (Fischer 2001). For example, nonnative species *Bassia scoparia* (burning bush) was abundant at the study site (personal observation) due to high salt tolerance (Ungar 1966). *Hordeum jubatum* (foxtail barley) was also found at the site (personal observation); although it is a native grass in the region, it is disliked and considered "weedy" by many landowners and managers (DiTomaso et al. 2013). Therefore, investigating which native plant species exhibit salt tolerance will help inform revegetation practices necessary to restore salt-impacted soil in the NGP without the negative ecological effects of nonnative species or "weed" type natives (Santos et al. 2011).

The identification of native plant species suitable for the revegetation of salt-impacted soil in the NGP is critical to help maintain ecosystem services and health. In this study, we evaluated the response of eight native plant species to naturally occurring high, medium, and low salt concentrations at a field site with salt-impacted soil. Summer and end-of-season survival and end-of-season performance variables including plant height, basal diameter, and number of flowering heads were measured, with aboveground biomass sampling occurring after senescence. Our objective was to determine which native plant species could be used to tolerate the salts and revegetate these areas.

Materials and Methods

Study Area. The study site was located in Clark County, South Dakota, on private cropland in corn (*Zea mays* L.)–soybean (*Glycine max* [L.] Merr.) rotation. The study was conducted on an area of crop fields that had decreased yield due to salt problems and were not planted in the previous year. The surrounding cropland was primarily corn and soybeans, with some grass pasture for cattle grazing. Clark County is in northeastern South Dakota in the James River Valley and is characterized by a temperate, continental climate with semihumid summers and cold, dry winters. Average annual temperatures range from 11.9°C to 0.0°C. The average annual precipitation is 571.0 mm, 60% of which falls during the growing season (June to October) (US Climate Data 2020). However, during our field season 584.0 mm of precipitation fell. This is 13 mm higher than the average precipitation for the entire year for Clark County (NOAA 2020), making it an unusually wet season. The soil was primarily Cavour-Ferney loams with a water table depth of 1.0 to 1.5 m below the soil surface. The maximum salinity in the soil profile is slight to moderate salinity for Cavour (4.0 to 10.0 dS m^{-1}) and moderate to strong salinity for Ferney (8.0 to 16.0 dS m^{-1}) (Soil Survey Staff 2020).

Transplants. Based on previous research conducted in these salt-impacted soils (Blanchard 2021), eight perennial plant species (forbs: *Asclepias speciosa*, *Desmodium canadense*, *Gaillardia aristata*, *Helianthus maximiliani*; and grasses: *Elymus canadensis*, *E. trachycaulus*, *Pascopyrum smithii*, and *Sporobolus airoides*) were chosen. Briefly, the previous study examined the ability of plants native to the region to imbibe and germinate in salt-impacted conditions. These species were less negatively affected than others. We chose these with the idea that if they could survive from transplants and reproduce, the seeds may have the ability to imbibe and germinate. Seeds were sourced from Great Basin Seed (Uphraim, Utah), Millborn Seeds, Inc. (Brookings, South Dakota), Prairie Moon Nursery, Inc. (Winona, Minnesota), and Prairie Restorations, Inc. (Princeton, Minnesota) (table 1). Seeds were planted in 2.5 × 16.1 cm (66 mL) Ray Leach Pine Cell Cone-tainers (Stuewe and Sons, Inc., Tangent, Oregon) filled with potting media (Miracle-Gro potting mix) in March of 2019. Multiple seeds were planted in each tube and were misted twice daily until germination, which concluded after one week. Seeds were then watered twice daily, to ensure adequate moisture throughout the tube until mid-May of 2019. As the plants grew, each tube was thinned to one individual plant per tube. Greenhouse temperature fluctuated between 10.0°C to 25.0°C with ambient lighting throughout the two and a half months the plants were in the greenhouse. In mid-May of 2019 (two weeks before planting in the field), transplants were moved outside for hardening and were watered as needed.

Field. Before planting, existing vegetation (*Bassia scorparia* and *Hordeum jubatum*) was mowed. Woven ground cover (DeWitt Co., Sikeston, Missouri) was placed onto the 10.0 × 120.0 m plot to control *Bassia scorparia* and *Hordeum jubatum* regrowth and competition with the transplants. The study plot spanned three landscape positions that had high, medium, and low salt concentrations (which corresponded to footslope, midslope, and summit, respectively). The landscape positions were contiguous, and the salt concentrations occurred along a

Table 1

Scientific name, common name, growth form, salt-tolerance (based on our results), and seed sources where seeds were purchased.

Scientific name	Common name	Growth form	Salt-tolerance	Seed distributor (location)
Asclepias speciosa	Showy milkweed	Forb	Salt-tolerant nonhalophytes	Prairie Moon Nursery, Inc. (Winona, Minnesota)
Desmodium canadense	Showy ticktrefoil	Forb	Salt-sensitive nonhalophyte	Prairie Moon Nursery, Inc. (Winona, Minnesota)
Elymus canadensis	Canada wildrye	Grass	Salt-tolerant nonhalophytes	Prairie Restorations, Inc. (Princeton, Minnesota)
Elymus trachycaulus	Slender wheatgrass	Grass	Salt-tolerant nonhalophytes	Millborn Seeds, Inc. (Brookings, South Dakota)
Gaillardia aristata	Blanketflower	Forb	Salt-tolerant nonhalophytes	Millborn Seeds, Inc. (Brookings, South Dakota)
Helianthus maximiliani	Maximilian sunflower	Forb	Salt-tolerant nonhalophytes	Prairie Moon Nursery, Inc. (Winona, Minnesota)
Pascopyrum smithii	Western wheatgrass	Grass	Salt-tolerant nonhalophytes	Millborn Seeds, Inc. (Brookings, South Dakota)
Sporobolus airoides	Alkali sacaton	Grass	Halophyte	Great Basin Seed (Ephraim, Utah)

natural gradient. Electrical conductivity was 7.9 dS m^{-1} (high salt), 3.2 dS m^{-1} (medium salt), and 0.3 dS m^{-1} (low salt). Six strips per landscape position were designated from the woven ground cover for planting with surrounding unplanted buffers for walking and data recording. Strips were 120.0 m long (covering the entire study plot) and placed adjacent to each other. Slits were cut into the ground cover at 0.3 × 0.3 m spacing. A total of 2,016 transplants, with 84 transplants per species per landscape position, were planted with one plant per slit in June of 2019. The placement of transplants was predetermined using a random number generator. Plants were lightly watered during planting. No supplemental watering occurred during the growing season; however, the study site received above-average precipitation during the growing season.

Summer (July of 2019) and end-of-season survival (October of 2019) was recorded, and end-of-season performance was assessed with plant height (cm), basal diameter (cm), number of flowering heads, and number of tillers or stems. Additionally, aboveground biomass (g) sampling occurred after plant senescence (November of 2019). Biomass samples were dried until a constant weight was achieved and weighed.

Due to the COVID-19 pandemic and restricted travel, transplant survival and performance could not be recorded the following year (2020), nor could the experiment be replicated in time.

Statistical Analysis. Statistical analysis for summer and end-of-season survival was conducted using logistic binomial regression, with summer and end-of-season survival as response variables and species and salt concentration as explanatory variables. Statistical analyses for transplant performance were conducted with end- of-season performance variables (plant height, basal diameter, number of flowering heads, number of tillers or stems, and aboveground biomass) as response variables, and species and salt concentration as explanatory variables. Of the 2,016 transplants, 13 were mis-planted and therefore dropped from analysis. Subsequently, statistical analysis was conducted on 2,003 transplants. Plant height ($p = 0.050$) and aboveground biomass ($p = 0.880$) met the assumptions of normality and were analyzed using analysis of variance (ANOVA), but basal diameter ($p = 0.008$) did not. However, basal diameter could not be transformed to meet the assumptions of normality or equal variance; therefore, a nonparametric test, Kruskal-Wallis, was run. The post-hoc test, Student's *t*-test, was performed to determine differences in explanatory variable effects. RStudio (RStudio Team 2020, PBC, Boston, Massachusetts) and JMP (JMP Pro, Version 14, SAS Institute Inc., Cary, North Carolina) software were used for statistical analysis.

Results and Discussion

Transplant Survival. Initial analysis for summer and end-of-season survival indicated that species ($p < 0.001$) and salt concentration ($p < 0.001$) were significant. One thousand and fourteen (51%) transplants survived one month after outplanting from June of 2019 to July of 2019 (summer survival). By end-of-season sampling (October of 2019) four months after outplanting, transplant survival was 35% (701 transplants) among all salt concentrations. Summer survival was affected ($p < 0.05$) by salt concentration for all species whereas end-of-season survival was significantly affected by salt concentration for all species except *H. maximiliani* (table 2, figure 1). Grasses (*E. canadensis*, *E. trachycaulus*, *P. smithii*, and *S. airoides*) survived in all salt concentrations at both sampling dates (figure 1). Two forb species (*A. speciosa* and *D. canadense*) survived in all salt concentrations at summer sampling and *G. aristata* and *H. maximiliani* survived in the medium and low salt concentrations. For end-of-season sampling, no forbs survived in the high salt concentration, but *A. speciosa*, *G. aristata*, and *H. maximiliani* had surviving transplants in the medium and low salt concentrations, and *D. canadense* survived in the low salt concentration (figure 1).

Transplant Performance. Initial analysis indicated that species was significant for plant height ($F = 15.52$, df = 2, $p < 0.001$), basal diameter ($F = 55.88$, df = 7, $p < 0.001$), and aboveground biomass ($F = 22.14$, df = 7, $p < 0.001$); therefore, subsequent analysis was conducted separately for each species, except for number of flowering heads and number of tillers or stems. Salt concentration did not influence number of flowering heads ($p = 0.282$) and number of tillers or stems ($p = 0.128$). *D. canadense* did not have surviving transplants for analysis. Of the surviving transplants, plant height was significantly affected by salt concentration for *A. speciosa*, *P. smithii*, and *S. airoides* (table 3). Mean plant height was lower (cm) in the medium salt concentration ($\mu = 12.31$, SE = 3.20) than the low salt concentration ($\mu = 28.97$, SE = 3.38) for *A. speciosa*. Plant height increased as salt concentration decreased for *P. smithii*:

Table 2

Summary of the effects of salt concentration on plant survival for each species transplanted from logistic binomial regression. Survival was recorded in the summer after transplanting and at the end of the growing season. Chi-square values and *p*-values of plant survival among salt concentrations at summer and end-of-season survival. Bold *p*-values are significant to $p < 0.05$.

	Survival			
	Summer		End-of-season	
Plant species	χ^2(df)	*p*	χ^2(df)	*p*
A. speciosa	67.82(2)	**<0.001**	28.12(2)	**<0.001**
D. canadense	72.81(2)	**<0.001**	15.27(2)	**<0.001**
E. canadensis	38.84(2)	**<0.001**	53.66(2)	**<0.001**
E. trachycaulus	54.50(2)	**<0.001**	85.97(2)	**<0.001**
G. aristata	70.42(2)	**<0.001**	27.20(2)	**<0.001**
H. maximiliani	18.23(2)	**<0.001**	4.26(2)	0.119
P. smithii	12.07(2)	**0.002**	20.33(2)	**<0.001**
S. airoides	14.93(2)	**<0.001**	31.39(2)	**<0.001**

high salt (μ = 19.48, SE = 1.78), medium salt (μ = 27.27, SE = 1.39), and low salt (μ = 30.15, SE = 1.45). *S. airoides* plant height (cm) was lowest in the high salt concentration (μ = 47.03, SE = 2.48) and highest in the medium salt concentration (μ =59.60, SE = 2.66), with plant height in the low salt concentration (μ = 55.79, SE = 3.23) in-between. Basal diameter was significantly decreased by increasing salt concentration for all species except *E. trachycaulus* and *H. maximiliani* (table 3, figure 2). Only one species (*G. aristata*) demonstrated a significant response to salt concentration in aboveground biomass (table 3). Mean aboveground biomass (g) produced by *G. aristata* increased from the medium salt concentration (μ = 2.38, SE = 4.29) to the low salt concentration (μ = 12.37, SE = 1.85).

Discussion. Four of our study species, *E. canadensis*, *E. trachycaulus*, *P. smithii*, and *S. airoides*, showed promise as candidates for the revegetation of salt-impacted soils based on their survival and performance in the field. Along with their ability to survive transplanting into salt impacted soils, *E. canadensis*, *E. trachycaulus*, and *S. airoides* provide wildlife forage, and *P. smithii* is beneficial for erosion control (USDA NRCS 2021). Three forb species, *A. speciosa*, *G. aristata*, and *H. maximiliani*, also showed promise as candidates for revegetation, but only for areas with medium to low salt impaction. *D. canadense* had low survival and therefore cannot be recommended. These forb species would provide additional ecosystem services: *A. speciosa* provides pollinator forage and habitat, *H. maximiliani* provides wildlife forage and cover, and *G. aristata* provides both (USDA NRCS 2021).

Our objective was to determine which native plant species are suited for revegetation. Our survival results suggest that all species except *D. canadense* exhibited some salt tolerance and could be suitable for revegetation. *E. canadensis*, *E. trachycaulus*, *P. smithii*, and *S. airoides* survived in all salt concentrations, with *E. canadensis*, *E. trachycaulus*, and *P. smithii* survival higher in the medium and low salt concentrations compared to the high salt concentration. *E. canadensis* has been reported to exhibit high survival and germination in other studies where native vegetation was subjected to roadway deicers (Harrington and Meikle 1992). *E. trachycaulus* and *P. smithii* exhibited salt tolerance and aided in controlling the undesirable, salt-tolerant weeds *H. jubatum* and *Bromus tectorum* (Steppuhn et al. 2017). *E. trachycaulus* also responded positively to salt impaction in germination studies, with consistent germination in high, medium, and low concentrations of roadway deicer salt solutions (Dudley et al. 2014). *S. airoides* survival increased as the salt concentration increased, which was the only species to exhibit higher survival in higher salt concentrations. Therefore, the salt tolerance of *S. airoides* makes it a suitable species for areas with high salt impaction. Interestingly, one study found that *S. airoides* transplanted into nonsalt-impacted soil had low survival one-year postplanting (Abella et al. 2012). High survival in our study for *S. airoides* could be due to a reliance on salt impaction, similar to halophytes.

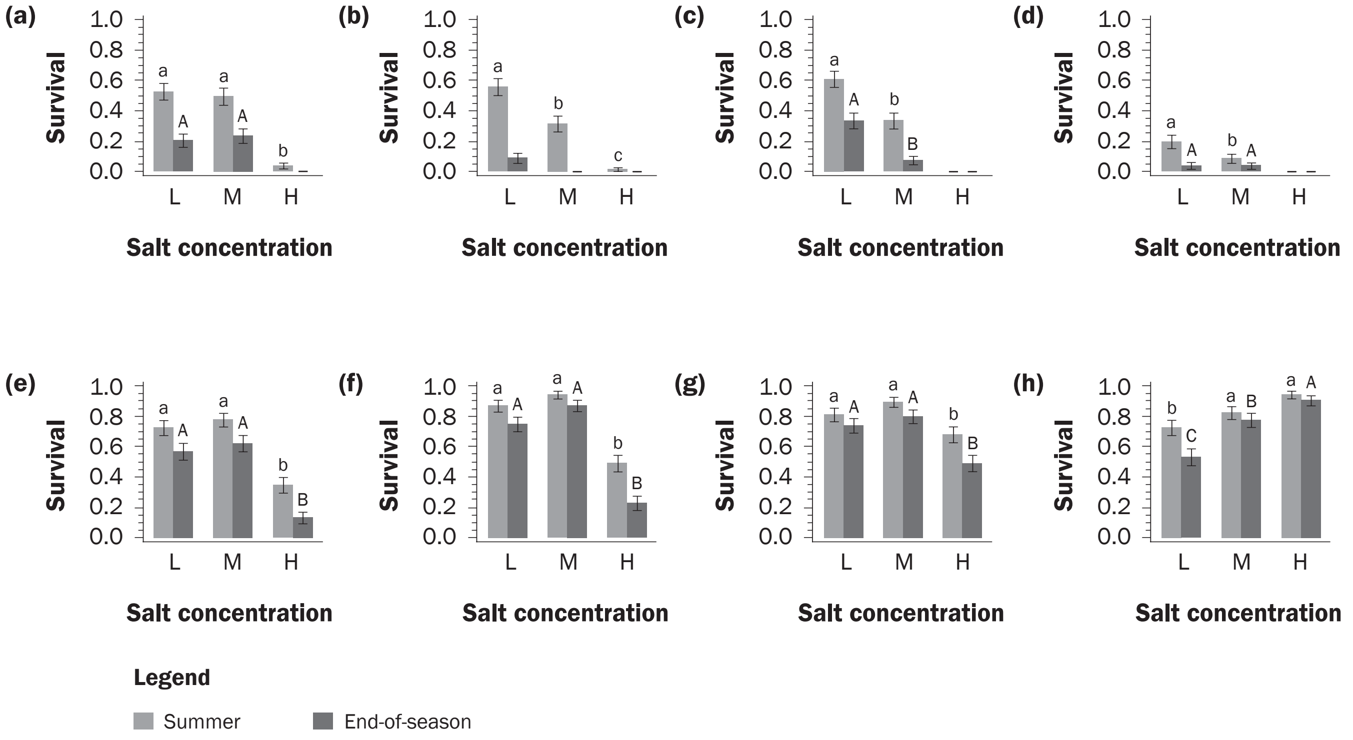
The survival of *A. speciosa*, *D. canadense*, *G. aristata*, and *H. maximiliani* was more affected by salt concentration. Most survived only in the medium and low salt concentrations. No forb species survived in the high salt concentration at end-of-season sampling, and of the *A. speciosa* and *D. canadense* transplants that survived in the high salt concentration at summer sampling, both only had a few surviving individuals. The salt tolerance of *A. speciosa*, *G. aristata*, and *H. maximiliani* made them suitable candidates for areas with medium to low salt impaction. *G. aristata* exhibited similar salt tolerance to our field study under greenhouse conditions (Niu and Rodriguez 2006). Studies involving the salt tolerance of *A. speciosa* and *H. maximiliani* could not be found in the literature.

Salt-tolerant nonhalophytes are expected to maintain growth in salt-impacted soil, and halophytes are expected to perform better in salt-impacted soil compared to normal (nonsalt-impacted) soil (Barrett-Lennard 2002). Transplant performance (plant height, basal diameter, and aboveground biomass) results indicate that most of our species had growth responses similar to salt-tolerant nonhalophytes, except *D. canadense*, which had growth responses similar to salt-sensitive nonhalophytes, and *S. airoides*, which had growth responses similar to halophytes. For the remaining species, the response of plant height, basal diameter, and aboveground biomass to salt impaction could classify those species as salt-tolerant nonhalophytes. These results are similar to previous research that examined the relative growth rate of *Distichlis spicata*, a salt-tolerant species, compared to the growth rate of *P. smithii* (Aschenbach 2006). These results suggested that the relative growth rate of *P. smithii* was greater than *D. spicata* in all experimental salt concentrations, making it a comparable restoration candidate to *D. spicata* for salt-impacted areas (Aschenbach 2006). Our study yielded similar results, with *P. smithii* survival and performance making it a suitable candidate for revegetation of salt-impacted soil.

S. airoides survival increased as the salt concentration increased, and performance (plant height, basal diameter, and aboveground biomass) was among the greatest among salt concentrations compared to the other species—a response expected of halophytes. This result agrees with previous research that examined the growth responses of a *S. airoides* cultivar to salt impaction in drylands (Pessarakli et al. 2017). Results indicated high salt tolerance and suitability as a revegetation candidate in a dryland system (Pessarakli et al. 2017), similar to the results of our study

Figure 1

Proportion of native plant transplants that survived to summer and end-of-season in soils with naturally occurring salt concentrations. H refers to high salt concentration (EC = 7.9 dS m^{-1}), M refers to medium salt concentration (EC = 3.2 dS m^{-1}), and L refers to low salt concentration (0.3 dS m^{-1}). Bars = 1 S.E. Significance is based on Student's *t*-test by salt concentration and within species (significance in mean survival recorded in the summer is indicated by lowercase letters and significance in mean survival recorded at the end-of-season is indicated by uppercase letters). A value of 0 indicates no survival and a value of 1 indicates 100% survival. Species are as follows: (a) *A. speciosa*, (b) *D. canadense*, (c) *G. aristata*, (d) *H. maximiliani*, (e) *E. canadensis*, (f) *E. trachycaulus*, (g) *P. smithii*, and (h) *S. airoides*.



in a temperate to semiarid system. Further, *S. airoides* promise as a suitable restoration candidate increases with demonstrated invasion resistance. Populations of *S. airoides* were assessed for lineages with and without historic invasions and found that the lineage with historic invasions demonstrated invasion resistance, with greater germination and plant growth (Sebade et al. 2012). For the NGP, the salt tolerance and potential invasion resistance of *S. airoides* make its restoration suitability even more promising.

Compared to the forb species, our grass species had greater survival and growth responses to salt concentration, which indicates that these grass species could be more suitable for the revegetation of salt-impacted soils, even in high salt concentrations. In another study looking at the effects of roadway deicers on forb and grass germination, results indicated that for their selected forb species (*Linum lewisii* and *Penstemon strictus*), germination was least affected by the high

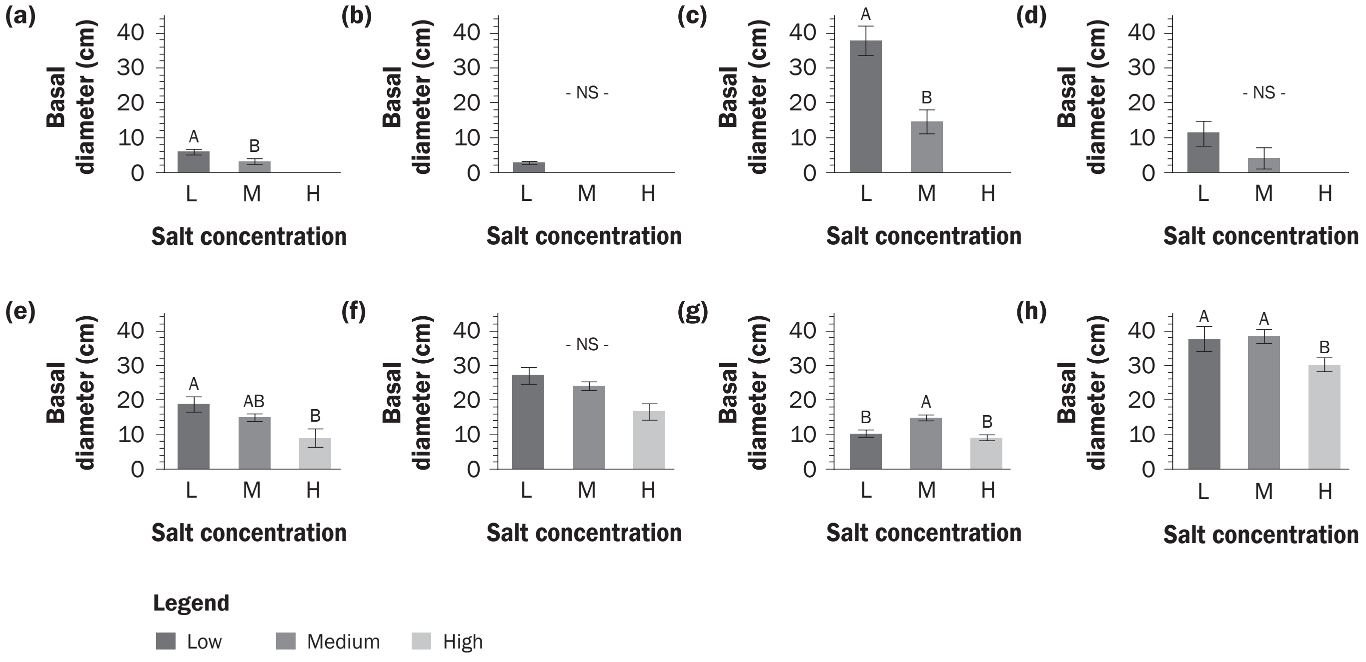
Table 3

Test statistics and *p*-values of plant performance among salt concentrations on end-of-season performance variables plant height, basal diameter, and aboveground biomass. Plant height and aboveground biomass were analyzed using ANOVA, and basal diameter was analyzed using Kruskal-Wallis. Bold *p*-values are significant at $p < 0.05$.

	End-of-season performance					
	Plant height		Basal diameter		Aboveground biomass	
Plant species	F(df)	*p*	χ^2(df)	*p*	F(df)	*p*
A. speciosa	12.78(1)	**0.001**	10.10(1)	**<0.001**	2.46(1)	0.129
D. canadense	0.00	0.00	0.00	0.00	0.00	0.00
E. canadensis	0.57(2)	0.570	6.51(2)	**0.039**	1.41(2)	0.249
E. trachycaulus	0.77(2)	0.463	5.81(2)	0.055	2.65(2)	0.074
G. aristata	1.10(1)	0.302	6.18(1)	**0.013**	4.57(1)	**0.041**
H. maximiliani	0.28(1)	0.623	1.23(1)	0.268	0.11(1)	0.759
P. smithii	11.08(2)	**<0.001**	23.94(2)	**<0.001**	2.23(2)	0.111
S. airoides	6.29(2)	**0.002**	7.18(2)	**0.028**	0.31(2)	0.734

Figure 2

Mean basal diameter of native plant transplants the species in soils with naturally occurring salt concentrations. H refers to high salt concentration (EC = 7.9 dS m^{-1}), M refers to medium salt concentration (EC = 3.2 dS m^{-1}), and L refers to low salt concentration (0.3 dS m^{-1}). Bars indicated with different letters have significantly different mean basal biomass in different salt concentrations. NS indicates no significant differences in mean basal biomass. Bars = 1 S.E. Significance is based on Student's *t*-test by salt concentration and within species. Species are as follows: (a) *A. speciosa*, (b) *D. canadense*, (c) *G. aristata*, (d) *H. maximiliani*, (e) *E. canadensis*, (f) *E. trachycaulus*, (g) *P. smithii*, and (h) *S. airoides*.



salt concentrations (Dudley et al. 2014). However, these forb species were selected due to their mixed elevation tolerance, giving them a broad ecological niche and perhaps an increased salt tolerance. Interestingly, *E. trachycaulus* was also selected for this study due to its mixed elevation tolerance and was one of the species least affected by high salt concentrations as well. Perennial plant cover is recommended as a management strategy to lower the water tables of saline soils within the NGP (Black et al. 1981). All species selected for this study were perennial.

Some limitations for this study exist, including uneven salinity throughout the plot and the use of ground cover. In a field study, not all other covariates can be controlled. For example, in the footslope landscape position (high salt concentration), water would pool, waterlogging the soil and potentially affecting the salt concentration and subsequently transplant survival and performance. Future studies could extend the study over multiple seasons to examine transplant survival and performance across time and season, whereas this study only examined one season. Future studies could compare the performance of these species for seed-based restoration of salt-impacted soils. Although this study found transplants successfully established in salt-impacted soil, seeds are more commonly used and potentially a less expensive restoration method.

Summary and Conclusions

Overall, we can conclude that almost all species selected for this study are suitable for the revegetation of at least moderately salt-impacted areas via transplants. Responses to salt impaction were species-specific, with some species having greater salt tolerances than others. In general, the grass species in this study (*E. canadensis*, *E. trachycaulus*, *P. smithii*, and *S. airoides*) had greater survival and performance across salt concentrations than the forb species (*A. speciosa*, *G. aristata*, and *H. maximiliani*). *D. canadense* showed little suitability for the revegetation of salt-impacted soils because of low survival and growth responses similar to salt-sensitive nonhalophytes. All remaining species, besides halophytic *S. airoides*, had similar growth responses to salt-tolerant nonhalophytes. Therefore, *A. speciosa*, *G. aristata*, and *H. maximiliani* can be recommended for minimally salt-impacted soils; *E. canadensis*, *E. trachycaulus*, and *P. smithii* can be recommended for moderately salt-impacted soils; and *S. airoides* can be recommended for highly salt-impacted soils. We suggest using these species as transplants to revegetate salt-impacted areas and continuing research to find other native species to revegetate and begin autogenic recovery of salt-impacted soils in the NGP.

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