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Original Research

Sodium Chloride Effects on Seed Germination, Growth, and Water Use of *Lepidium alyssoides*, *L. draba*, and *L. latifolium*: Traits of Resistance and Implications for Invasiveness on Saline Soils☆

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ABSTRACT

In the semiarid southwestern United States, long-term drought, soil salinity, and land-use intensification have increased the risk of invasive plants that threatens landscape biodiversity. Soil-related factors that regulate plant invasions are not adequately known. We evaluated the salinity responses of three invasive plant species during a 3-mo plant growth period in a greenhouse and during a 2–wk seed germination study in the laboratory. The species included the indigenous *Lepidium alyssoides* A. Gray var. *alyssoides* (mesa pepperwort) and the exotic, invasive *L. draba* L. (whitetop) and *L. latifolium* L. (perennial pepperweed). A NaCl solution at −0.2 MPa reduced germination of *L. alyssoides* by ≈20% and had no effect on germination of *L. draba* and *L. latifolium*, merely delaying their mean germination time by a day or less. Reductions in seedling dry matter production and evapotranspiration (ET) were observed following irrigation with NaCl solutions at −0.1 MPa and −0.2 MPa. However, on the basis of ET and total plant dry matter production under common experimental conditions, the salt resistance of these species greatly exceeded that of salt sensitive bean (*Phaseolus vulgaris* L.) and equaled or exceeded that of salt-resistant cotton (*Gossypium hirsutum* L.). Below-ground propagating structures giving rise to clonal shoots were observed for all *Lepidium* spp., consistent with other reports. The results indicate that vegetative propagule pressure and relatively high resistance to salinity at germination and seedling growth stages could contribute to the invasiveness of these species under saline conditions. A broader impact of the findings is in their application to the larger diversity of invasive species to aid in the understanding of soil salinity and how it may govern plant invasions. This dataset could improve risk assessment measures to favor biodiversity in rangelands and natural ecosystems of semiarid regions.

Introduction

Invasive plants are typically nonindigenous and can displace native vegetation, reduce biodiversity, degrade ecosystems, and infest farmlands (Randall, 1996; DiTomaso, 2000; Sheley et al., 2011). Throughout the western United States, non-native plant species have been reported to occupy about 50% of total land area (Herrick et al., 2010). Anthropogenic disturbances including increased urbanization and land use intensification have increased the risk of invasive plant species in semiarid lands of the southwestern United States (Abella et al., 2012; Belnap et al., 2012; Hobbs and Huenneke, 1992). In semiarid regions, increased demand for irrigation due to population increases and climate change have increased secondary salinization (Yeo, 1999), which in the southwestern United States may alter plant species diversity (Cox et al., 2006).

To successfully and cost-effectively manage the spread of invasive plants, a preventative strategy that incorporates early detection and prediction of new invasions must be adopted by land managers (Davies and Sheley, 2007; Abella et al., 2009; Davies and Johnson, 2011). However, the biology of the invaders, as well as factors that influence invasions, are not adequately known, which has limited the effectiveness of preventative management strategies (DiTomaso, 2000; Byers et al., 2002; Shea and Chesson, 2002; Suazo et al., 2012). Three herbaceous perennial plant species—*Lepidium alyssoides* A. Gray var. *alyssoides*, *L. draba* L., and *L. latifolium* L.—have been noted for their invasiveness and ability to grow on saline, sodic, or alkali soils (Francis and Warwick, 2007, 2008; Picchioni et al., 2012a, 2012b). *L. alyssoides* is indigenous to the

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southwestern United States (USDA-NRCS, 2017a), whereas *L. latifolium* and *L. draba* are Eurasian introductions to the United States and are considered as noxious, invasive species (Francis and Warwick, 2007; Andrew and Ustin, 2009; Cripps et al., 2009; Renz et al., 2012; USDA-NRCS, 2017b; USDA-NISIC, 2017). *Lepidium latifolium* has been a highly invasive weed species throughout the western United States since the 1980s (Francis and Warwick, 2007) and, as early as 2005, began to invade semiarid New Mexico (Renz and Wilson, 2005). Both *L. draba* and *L. latifolium* are known to infest rangelands (Kiemnec and Larson, 1991; Francis and Warwick, 2007) and are designated as noxious weeds in New Mexico (Cattaneo et al., 2011). The latter species have been described as rhizomatous perennials with significant underground propagule pressure and prolific seed production (Francis and Warwick, 2007, 2008; Leininger and Foin, 2009). Such characteristics of *L. alyssoides* have received no prior study, although based on our observations, this species possesses underground vegetative propagules (Hooks et al., 2018). Both *L. alyssoides* and *L. latifolium* have recently been found harboring an introduced invasive stink bug in New Mexico (Bundy et al., 2012).

L. alyssoides has received little study of any kind, although its ability to aggressively occupy a saline, alkaline, and sodic Chihuahuan Desert shrubland in favor of other indigenous herbaceous species has been demonstrated (Picchioni et al., 2012a, 2012b). This species tolerates a combined Na and Cl accumulation in leaves reaching 10% of dry weight with no signs of leaf injury, which is characteristic of halophyte species (Hooks et al., 2018). Salt tolerance of *L. latifolium* and *L. draba* is not a novel subject, but therein lies a problem. *Lepidium draba* (Mulligan and Findlay, 1974; Lyons, 1998; Francis and Warwick, 2008; Santa Margarita–San Luis Rey Weed Management Area, 2015) and *L. latifolium* (Renz and Blank, 2004; Francis and Warwick, 2007; Zhao et al., 2011) are reported to “be adapted,” to be “common” or “abundant,” or to be “common halophytes” on saline and alkaline soils. *Lepidium latifolium* is mentioned to be “suited to” germinate in sodic conditions (Larson and Kiemnec, 2005). Despite the claims, there is virtually no quantitative data to support these statements about *L. draba* and *L. latifolium*. Some of the reports provide only subjective or anecdotal observations, while others make claims by citing references that provide no quantitative data on salt or alkalinity resistance of *L. latifolium* and *L. draba*, such as in Corns and Frankton (1952), Weber (1989), Blank and Young (2002), Zouhar (2004), and Kadrmas and Johnson (2002).

Identification of habitat characteristics that enable invasive plant species to dominate vegetation communities is essential for developing analytical tools to improve land management practices (Hiebert, 1997). Soil salinity is an underappreciated subject in the vegetation science literature, particularly pertaining to its role in regulating plant invasiveness (Bui, 2013). Thus, assessments of soil salinity and sodicity could serve as analytical tools to predict plant invasions, thereby strengthening preventative measures to aid in management of invasive species. Lack of a quantitative salinity database on *Lepidium* spp. makes this taxon a good research model for understanding the association of soil salinity with plant invasions on semiarid lands. We hypothesize that soil salinity and sodicity may increase susceptibility to invasions by *L. latifolium, L. draba,* and *L. alyssoides*. That is, salinity may act as an environmental filter that can favor a species predisposed to rapid spread and aggressive growth (Grace, 2001; Shea and Chesson, 2002; Cox et al., 2006).

Our objective was to evaluate salinity responses of *L. latifolium, L. draba,* and *L. alyssoides* to aid in verifying their ability to infest salt-affected lands. Four independent studies were conducted during 2014–2015. Seed germination and plant growth responses of *L. alyssoides*, *L. draba*, and *L. latifolium* were assessed under saline and controlled environmental conditions. Because of a lack of plant salt resistance information on these *Lepidium* spp., we studied salt-sensitive *Phaseolus vulgaris* L. (common bean) and salt-resistant *Gossypium hirsutum* L. (upland cotton) as known agricultural crop standards (Maas and Hoffman, 1977; Francois and Maas, 1994) under common experimental conditions.

Materials and Methods

Seed Collection and Cleaning

Seeds of *L. alyssoides* were collected from a dense stand in southern New Mexico in June 2012 in the town of Mesquite (southern New Mexico; 106°41′W, 32°10′N; 1 200 m elevation). The low-lying site was previously affected by clearing of shrubland vegetation, land grading, road construction, and storm water diversion. Seeds of *L. draba* and *L. latifolium* were collected in July 2013 from plants growing prolifically in suburban agricultural areas near Los Lunas in central New Mexico. The *L. draba* collection site was south of Los Lunas along a weedy fence row (34°43'11"N, 106°43'48"W, 1 472 m elevation) while the *L. latifolium* collection site was north of Los Lunas along a weedy irrigation canal (34°49'47"N, 106°40'33"W, 1 481 m elevation). At the latter two sites, landscape alterations included storm water diversion and close proximity to managed farmland *(L. draba)* and access to surface water along with soil excavation *(L. latifolium)*. At each site, seeds were collected from three to five evenly dispersed positions within an approximate 100 m^2 area densely populated by the parents. We removed the upper one-half of aboveground vegetation that included leaves, stems, flowers, and fruit (siliques) that bore the seeds. The vegetation was dried for 3 mo at room temperature, and the seeds were cleaned and stored following standard methods (Hooks et al., 2018). Seeds of ‘Contender’ common bean and Acala 1517-99 upland cotton required no pretreatment before use.

At each of the *Lepidium* sites, a single soil core (2.5 cm wide × 20 cm deep) was sampled per seed collection position (Hooks et al., 2018). The three to five cores were composited at each site, and the physical and chemical properties were analyzed using the online methods of the New Mexico State University Soil, Water, and Air Testing Laboratory (NMSU-SWAT, 2017). The purpose of the composite soil sampling was to only broadly characterize the edaphic conditions under which the *Lepidium* spp. proliferations were occurring.

Saline Treatments

For all studies, three salt treatments were used, consisting of NaCl at 0 mM (nonsaline control), 24 mM (–0.1 MPa; low salinity), and 48 mM (–0.2 MPa; high salinity). The electrical conductivities (ECs) of the low and high saline solutions met or exceeded soil saturation extract salinities in the previous reports that demonstrated invasiveness of *L. alyssoides* on the salt-affected Chihuahuan Desert shrubland (Picchioni et al., 2012a, 2012b). For the *Lepidium* spp. seed germination study, the salt treatments were prepared with deionized water (< 10 μS m^{-1}; pH 6.0) to provide ECs of 2.7 and 5.2 dS m^{-1} for the –0.1 MPa and –0.2 MPa treatments, respectively. For the plant growth studies, salt treatments were prepared in tap water (0.6 dS m^{-1}; pH 7.8) and included complete Hoagland’s nutrient solution 1 (Hoagland and Arnon, 1950) at half-strength (1.0 dS m^{-1}; pH 5.8). The tap water included (in meq L^{-1}) Na (2.8), Ca (2.4), Mg (1.0), Cl (0.5), SO_4 (4.0), and HCO_3 (1.8). The saline solution characteristics of the plant growth studies are shown in Table 1.

Seed Germination Study

The *Lepidium* spp. seed germination study was designed as a two-way, completely randomized design with four replications. The three salt treatments and three plant species served as the two factors, for a total of 36 experimental units (EUs), each consisting of a single 10-cm-wide × 1-cm-deep petri dish.

On 21 October, 2014, seeds of *L. alyssoides*, *L. draba*, and *L. latifolium* were placed in the petri dishes, each lined with a blotting paper (9-cm diameter, Anchor Steel Blue Seed Germination Blotter, Anchor Paper Co., Saint Paul, MN). The salt treatments were applied to the blotting paper in 5-mL volumes to reach complete saturation, and 50 seeds