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Original Research

Salinity an Environmental "Filter" Selecting for Plant Invasiveness? Evidence from Indigenous *Lepidium alyssoides* on Chihuahuan Desert Shrublands☆

Triston N. Hooks [a], Geno A. Picchioni [a,*], Brian J. Schutte [b], Manoj K. Shukla [a], David L. Daniel [c], Jamshid Ashigh [d]

[a] *Graduate Student, Professor, and Professor, respectively, Department of Plant and Environmental Sciences, New Mexico State University, Las Cruces, NM 88003, USA*
[b] *Assistant Professor, Department of Entomology, Plant Pathology, and Weed Science, New Mexico State University, Las Cruces, NM 88003, USA*
[c] *Professor, Department of Economics, Applied Statistics, and International Business, New Mexico State University, Las Cruces, NM 88003, USA*
[d] *Field Scientist, Crop Protection R&D, Dow AgroSciences Canada Inc, London, ON, Canada.*

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ABSTRACT

A better understanding of site-specific factors such as soil salinity that regulate plant invasions is needed. We conducted a 3-mo greenhouse study to evaluate the salinity responses of three local maternal sources of *Lepidium alyssoides,* which is an indigenous species shown to aggressively colonize disturbed shrubland sites in the southwestern United States, including those affected by high salinity and sodicity. Results indicated that there were little or no population effects on plant evapotranspiration (ET), growth, and tissue Na and Cl concentrations. Significant reductions in seedling growth and ET were largely independent of various isosmotic saline irrigation solutions that included NaCl, Na_2SO_4, and $CaCl_2$, each at −0.1 MPa and −0.2 MPa, suggesting that ET and growth were controlled by solution osmotic potential. The combined Na and Cl concentrations in leaves were 9–10% of dry weight with no visible sign of injury. However, increasing leaf mortality and abscission as a proportion of total leaf production was observed in the high-salt treatments (−0.2 MPa), with a combined Na and Cl concentration reaching 16% with high NaCl. Under saline conditions, considerable foliage salt loads of this species could deposit high-salt litter to potentially alter a landscape to its own favor and to the detriment of other salt-sensitive species. Results of this study add to a limited quantitative database on site-specific salinity factors governing plant invasions by showing the potential for these populations to behave invasively under saline conditions and, thus, potential for soil salinity assessment to predict incipient populations. However, due to its halophytic traits and indigenous status, *L. alyssoides* may alternatively provide ecosystem services to salinized shrublands of the arid and semiarid southwestern United States.

Introduction

Anthropogenic disturbances promote plant invasions that reduce biodiversity of natural vegetation communities (Hobbs and Huenneke, 1992; Symstad et al., 2003; Sheley et al., 2011). The impacts are especially severe in arid and semiarid regions (D'Antonio and Myerson, 2002), such as southern New Mexico. Many rangelands of the southwestern United States have been degraded by land use intensification to meet the needs of the expanding human populations and industries. Such disturbances include residential development, storm water diversion, road construction, mining operations, excavation, and other landscape changes adjacent to undisturbed lands.

Degradation of the region's rangeland soils and vegetation has important ramifications for the capacity of the land to provide ecosystem services, including those associated with water (Herrick et al., 2010). In recent years, there has been increasing interest in beneficial reuse of nonhazardous water and solid wastes (residuals) on arid and semiarid rangelands of the western United States. Land application of residuals has been recommended as a safe method of disposal to allow the land to process contaminants, increase organic matter and nutrient levels in the soil, and restore disturbed sites (USEPA, 1996; O'Connor et al., 2005). Numerous cases of land application of residuals to arid and semiarid rangeland of the western United States have included treated industrial wastewater, reclaimed municipal wastewater, coproduced water, dairy manure, and municipal biosolids (Levy and Kearney, 1999; Stavast et al., 2005; Sullivan et al., 2006; Bergquist et al., 2007; Brenton et al., 2007; Ganjegunte et al., 2008, 2011; Vance et al., 2008; Cabrera et al., 2009;

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* Correspondence: Geno A. Picchioni, Dept of Plant and Environmental Sciences, New Mexico State University, PO Box 30003, MSC 3Q, Las Cruces, NM 88003, USA. Tel.: +1 575 646 1820.
E-mail address: gpicchio@nmsu.edu (G.A. Picchioni).

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Nemmers et al., 2012; Picchioni et al., 2012a, 2012b). These studies have reported high levels of salinity, sodicity, or both salinity and sodicity in residual materials, and their application to rangeland represents a novel anthropogenic disturbance resulting in secondary salinization to alter quality of the soil water supply and, potentially, the plant species composition. Several of the aforementioned studies have revealed loss in native plant species diversity or encroachment by invasive plant species in response to land application of residuals (Sullivan et al., 2006; Bergquist et al., 2007; Vance et al., 2008; Picchioni et al., 2012b).

Mesa pepperwort (*Lepidium alyssoides* A. Gray var. *alyssoides*) is an herbaceous Brassicaceae perennial that is indigenous to New Mexico and surrounding states (USDA-NRCS, 2015) and has received little study. Two of its herbaceous perennial relatives, perennial pepperweed (*L. latifolium* L.) and whitetop (*L. draba* L.), have attracted considerable attention due to their status as exotic invasive species in the western United States, including rangeland (Francis and Warwick, 2007, 2008). *L. alyssoides* is currently not listed on any state noxious weed list, although it has recently been found to harbor an introduced invasive stink bug (*Bagrada hilaris* Burmeister) along a southern New Mexico highway (Bundy et al., 2012), suggesting that *L. alyssoides* will soon be a plant of concern for land managers in the southwestern United States. In field conditions involving land application of saline-sodic treated industrial effluent to a southern New Mexico shrubland, *L. alyssoides* aggressively colonized the site when shallow-depth soil saturation extract sodium adsorption ratio (SAR) increased from 15 to 35 over a 3-yr period, becoming largely a monotypic stand that replaced six other indigenous herbaceous species in the shrub interspaces (Picchioni et al., 2012a, 2012b). Although indigenous invasive plant species are less common than nonindigenous (introduced) invasive plant species, indigenous plant invasions have been linked to anthropogenic disturbances and loss of biotic integrity (Randall, 1997; Schwartz, 1997). The connection between human land disturbances and indigenous plant species invasiveness represents an understudied yet important component of arid and semiarid shrubland management and biology. A better understanding of these processes may help prevent new indigenous invasions from occurring and thereby aid in the management for indigenous shrubland biodiversity.

Limited data are available for how salinity may regulate plant species invasiveness, although "nonresource" edaphic factors, such as salinity, may play a role in regulating plant species populations on arid and semiarid land (Cox et al., 2006; Miller et al., 2006). Substantial documentation has advocated research for better understanding of site-specific factors, including edaphic factors such as salinity, that lead to proliferation of weedy, invasive plants (Grace, 2001; Byers et al., 2002; D'Antonio and Myerson, 2002; Brooks, 2003; Hobbs et al., 2003; Abella et al., 2009; Andrew and Ustin, 2009; Reynolds and Boyer, 2010; Bertrand et al., 2012). Evidence has supported a role for salinity in driving vegetation distribution patterns, but salinity has received little study in the arid vegetation science literature, particularly in reference to plant invasions (Bui, 2013). Thus, research is needed to identify specific soil salinity characteristics and salinity tolerances of successful invader species in arid and semiarid climates in order to predict incipient populations and their invasive risk.

The aim of our study was to investigate salt tolerance of the indigenous *L. alyssoides*. Improved knowledge of *L.* alyssoides responses to salt stress will clarify the potential role of soil salinity in facilitating *L. alyssoides* invasions previously observed on disturbed Chihuahuan Desert shrubland (Picchioni et al., 2012a, 2012b). Since the growth of some halophytes is known to be stimulated in saline conditions (Flowers and Läuchli, 1983; Subbarao et al., 2003; Flowers and Colmer, 2008), we hypothesized a similar condition for *L. alyssoides*, in that this species possesses halophytic traits that confer salt tolerance. An additional objective was to address potential ecotypic variation in *L. alyssoides* salinity response and further improve the database on the species. For example, a population that is preadapted to high-Na (Picchioni et al., 2012b) may possess higher salt tolerance than nonadapted populations (Epstein and Bloom, 2005). Thus, we studied the growth, water use, and salt partitioning patterns of three local Chihuahuan Desert shrubland populations of this species under various saline irrigation treatments in a greenhouse.

Our study was designed to include isosmotic saline irrigation solutions to address questions on *L. alyssoides*, including: Would Na serve as a beneficial element as for some halophyte species (Subbarao et al., 2003), a plausible hypothesis as suggested by findings from the earlier field study (Picchioni et al., 2012b)? Would either high-Na waters or high-Cl waters impose specific ion toxicity? Would the growth response be indifferent to the ionic composition of irrigation waters and instead, would the osmotic effect predominate? Targeted questions about plant salinity responses address important deficits in the vegetation science literature that have slowed an understanding of factors regulating weed invasions upon arid and semiarid landscapes.

Materials and methods

Seed Collection and Cleaning, as Well as Site Sampling

Seeds of *L. alyssoides* were collected in June 2012, from densely populated stands on disturbed northern Chihuahuan Desert shubland sites near Las Cruces, New Mexico. Three populations of *L. alyssoides*, spanning a land area of approximately 174 km^2, were sampled from the Las Cruces West Mesa (WM, N32°15′9″, W106°54′28″, 1 300-m elevation), the Interstate-10 freeway exit at the town of Mesquite, New Mexico (MQ, N32°10′28″, W106°40′7″, 1 200-m elevation), and the Las Cruces East Mesa (EM, N32°19′46″, W106°43′8″, 1 290-m elevation). The WM seed collection site was adjacent to an industrial park. Since 2002, the WM site has been sprinkler irrigated with saline-sodic, treated industrial effluent from a wastewater treatment plant (WWTP) (Picchioni et al., 2012a, 2012b). The low-lying MQ seed collection site was previously altered by clearing of shrubland vegetation, land grading, road construction, and diverted stormwater incursion. The EM seed collection site was on a raised bank constructed of excavated soil, adjacent to an intermittent discharge stream below a municipal WWTP.

At each site, seeds were collected from three to five well-dispersed positions within an approximate 100-m^2 area and from the upper half of aboveground tissue that included stems, leaves, flowers, and fruit (siliques). Single soil core samples (20 cm in depth and 2.5 cm in width) were taken at each of the seed collection positions and composited for each of the three population sites. The bulked vegetation samples were stored in a laboratory and dried at room temperature for 4 mo. After drying, the vegetation samples were gently abraded with a rubber board to release any seeds remaining in siliques. Seeds were then collected and passed through a 2-mm sieve to screen out large plant debris. A seed blower (757 South Dakota, Seedburo Equipment Co, Des Plaines, IL) was then used to remove any remaining chaff from the seeds. The cleaned seeds of each population were then transferred to sealed watertight glass vials and stored at 4°C to await sowing.

Greenhouse Climate

The study was conducted in a climate-controlled A-frame greenhouse located at the New Mexico State University Fabian Garcia Science Center in Las Cruces, from 18 March to 7 August, 2013. Greenhouse climate data were collected using a Watchdog 2475 Plant Growth Weather Station and analyzed with SpecWare 9 Basic software (Spectrum Technologies, Inc, Aurora, IL). For the duration of saline irrigation (described later), maximum daytime temperature ranged from 25–38°C with a mean of 32°C. Minimum nighttime temperature ranged from 15–23°C with a mean of 20°C. Daily relative humidity ranged from 4% to 93% with a mean of 47%. Maximum photosynthetically active radiation (PAR) was 706 μmol m^{-2} s^{-1}, and the mean daily light integral (DLI) was 11 mol m^{-2} d^{-1}. A nylon shade cloth atop the greenhouse

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