RESEARCH NOTE

Do Container Volume, Site Preparation, and Field Fertilization Affect Restoration Potential of Wyoming Big Sagebrush?

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ABSTRACT: Land management practices, invasive species expansion, and changes in the fire regime greatly impact the distribution of native plants in natural areas. Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*), a keystone species in the Great Basin, has seen a 50% reduction in its distribution. For many dryland species, reestablishment efforts have focused on direct seeding but achieved only minor success due to irregular seed germination and poor survival. We investigated the effects of container volume and fertilization on the performance of nursery-grown Wyoming big sagebrush seedlings following outplanting. Additionally, to evaluate the impact of site preparation, one-year-old seedlings were outplanted into tilled and untilled field conditions. Initial seedling size increased with container volume; larger seedlings exhibited significantly higher root collar diameter (RCD) growth than smaller seedlings. As container volume increased from 108 to 251 and 336 cm^3, seedling survival on the tilled plot increased from 28 to 44 and 43%, respectively, whereas no influence was observed on the untilled plot (57 to 61, and 60%, respectively). Fertilization reduced seedling survival on tilled (by 25%) and untilled (by 14%) plots. Fertilizer increased RCD growth on the untilled plot but final nutrient status was unaffected. Thus, container volume may influence seedling morphology and optimize establishment, while field fertilization, especially during spring outplanting when planting sites have low moisture availability, may hinder first-year survival.

Index terms: arid ecosystems, *Artemisia tridentata* ssp. *wyomingensis*, container stock, Great Basin, seedling size

INTRODUCTION

The sagebrush steppe ecosystem, which spans 30 to 50 million hectares, is one of the most imperiled biomes in North America (Noss et al. 1995; Sankey et al. 2012). A key component of this system, Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* Beetle & Young), strongly influences myriad ecosystem processes through control of nutrient distribution, microclimate, and edaphic conditions (Jackson and Caldwell 1993; Davies et al. 2011; Boyd and Davies 2012). Furthermore, it provides critical habitat to more than 350 plant and animal species (Suring et al. 2005; Wisdom et al. 2005), including Greater Sage-Grouse, which, until 2015, was being evaluated for listing under the Endangered Species Act.

In recent decades, land degradation and the expansion of annual exotics, such as cheatgrass (*Bromus tectorum* L.), and the accompanying changes in the fire regime have led to a significant decrease in sagebrush distribution (Chambers 2000; Brooks et al. 2004). Natural recruitment of *A. tridentata* from seeds is inconsistent due to low seed viability, variable germination, and harsh site conditions (Perryman et al. 2001; Cione et al. 2002). In addition to poor germination, regeneration through supplemental seeding is largely unsuccessful due to insufficient availability of quality, source-identified seeds within an appropriate time frame, and low seedling survival (Shaw et al. 2005). Consequently, the interest in exploring the potential for increased restoration success by planting seedlings of *A. tridentata* is great (e.g., McAdoo et al. 2013). Generally, seedling mortality is highest in the first year in sagebrush stock (Dettweiler-Robinson et al. 2013), which is considered the greatest barrier to establishment, and diminishes in subsequent years. Thus, a better understanding of the factors that contribute to seedling survival and development immediately after planting is crucial to restoration planning for the Great Basin.

Our study objectives were to (1) understand the effects of container volume and fertilizer application on the establishment and survival of *A. tridentata* following outplanting, and (2) to evaluate the influence of site preparation on seedling performance. We predicted that seedling survival and growth would increase with container volume. Similarly, supplemental fertilization with controlled release fertilizer (CRF) was expected to improve establishment success. Tillage was anticipated to reduce competition and influence the distribution of available water in the soil profile. This work aims to guide recommendations for seedling production and outplanting treatments that optimize *A. tridentata* establishment on degraded sites throughout the western United States.

METHODS

Site Description

The field site was near Mountain Home, Idaho, USA (42°58'N, 115°38'W). The soil was classified as a Scism series (coarse-silty, mixed, superactive mesic Xereptic Haplodurid) (Soil Survey Staff 1996). Historical mean maximum and minimum air temperatures calculated over 29 years (1981–2010) were 18 °C and 3 °C, respectively. Mean annual precipitation at the site is 253 mm, primarily occurring as winter precipitation (http://www.wrcc.dri.edu). The site was formerly occupied by *Artemisia tridentata* ssp. *wyomingensis*, with smaller components of basin big sagebrush (*Artemisia tridentata* Nutt. ssp. *tridentata*), antelope bitterbrush (*Purshia tridentata* (Pursh) DC.), and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Á. Löve) (Kinter et al. 2007).

Experimental Design

In a randomized complete block design composed of three container volumes × two fertilization treatments, each treatment combination was composed of four replicates for a total of 24 experimental units (EUs). Mechanical site preparation was performed on half of the field site using a standard rangeland drill (P & F Services, Kemmerer, WY, USA); discs were 30.5 cm apart and chains dragged behind the drops resulting in a relatively level surface. Thus, to investigate the influence of tillage on seedling performance, we installed 24 EUs on the tilled plot and another 24 EUs on the untilled plot. The container volumes (108, 251, and 336 cm^3) (Table 1) and fertilizer rates (0 or 7.5 g/plant) were randomly assigned to rows within four, 5 × 19-m replicates. Fertilizer (10-12-12 Controlled-Release Plant Food; Schultz™ Spectrum Brands, Atlanta, GA, USA; Table 2) was applied to the bottom of the planting holes. In all 48 EUs, seedlings were planted at 1-m spacing with 20 seedlings per container volume × fertilization treatment combination, resulting in 480 seedlings per tillage treatment.

Plant Materials

Seeds of *A. tridentata* were collected in Humboldt and Elko Counties, Nevada, USA, in 2006, stored at 21–23 °C, and sown in May 2007 into three types (volumes) of Styroblock™ containers (Beaver Plastics, Acheson, Alberta, Canada) (Table 1). Fertilizers were mixed to achieve the

Table 1. Specifications for Beaver Plastics (Beaver Plastics, Acheson, Alberta, Canada) Styroblock™ trays used. Trays had uniform length (60 cm), width (35 cm), and depth (15 cm), but individual cells varied in volume, top diameter, and density.

Container Designation		Volume	Top Diameter	Density
Metric	Block Model	cm^3	mm	cavities m^{-2}
615 A	20	336	59	213
515 A	15	251	51	284
415 B	6	108	36	530

Table 2. Height and root collar diameter (mean ± standard error) of outplanted seedlings on the tilled plot as influenced by container volume and field fertilization.

Container Volume (cm^3)	Height (cm) Initial[a]	Height (cm) Final[b]	Height (cm) Growth	Root Collar Diameter (mm) Initial[a]	Root Collar Diameter (mm) Final[b]	Root Collar Diameter (mm) Growth
336	19.8 ± 0.4a	18.2 ± 0.7a	-1.6 ± 0.6b	2.9 ± 0.1a	4.7 ± 0.1a	1.8 ± 0.1a
251	15.9 ± 0.3b	15.0 ± 0.7b	-0.9 ± 0.6ab	2.5 ± 0.1b	3.9 ± 0.1b	1.4 ± 0.1ab
108	10.0 ± 0.2c	10.4 ± 0.6c	0.4 ± 0.6a	1.9 ± 0.1c	2.9 ± 0.1c	1.0 ± 0.1b
Field Fertilization						
No	15.2 ± 0.4a	14.7 ± 0.6a	-0.5 ± 0.4a	2.4 ± 0.1a	3.7 ± 0.1a	1.3 ± 0.1a
Yes	15.2 ± 0.4a	15.0 ± 0.7a	-0.2 ± 0.6a	2.5 ± 0.1a	4.1 ± 0.1a	1.6 ± 0.1a
Volume (V)	$P < 0.0001$	$P < 0.0001$	$P = 0.00110$	$P < 0.0001$	$P < 0.0001$	$P = 0.0005$
Fertilization (F)	$P = 0.2547$	$P = 0.8267$	$P = 0.4534$	$P = 0.5475$	$P = 0.2516$	$P = 0.6531$
V × F	$P = 0.1532$	$P = 0.0956$	$P = 0.1873$	$P = 0.2765$	$P = 0.1765$	$P = 0.0981$

Different letters indicate significance differences based on Tukey's HSD at $\alpha = 0.05$.

[a]Initial measurements were collected directly prior to outplanting; $n = 480$.

[b]Final measurements were collected 216 days after outplanting; $n = 123–370$.

Growth = Final – Initial.

following nutrient ratios: 100N ($50NO_3^-$: $50NH_4^+$): 55P: 41K: 27Ca: 16Mg: 34S, plus micronutrients (Peters Professional S.T.E.M., The Scotts Company, Marysville, OH, USA) tailored to each container size. Fertigation frequency was determined gravimetrically and was applied when the mass of the sown container at field capacity reached 65% (Dumroese et al. 2015). The application of nutrients was tailored to container size and irrigation frequency in order to supply the same proportion of N (mg) per unit volume on a weekly basis. Seedlings were moved to an open-walled greenhouse on 26 October 2007 for hardening and overwintering, a standard practice for seedling production in this region. Containers were arranged in a completely randomized design and rerandomized every 14 days. Individual seedlings served as the measurement unit.

Measurement of Plant Morphology and Nutrient Status

Seedlings were outplanted on 14–15 March 2008, at which point initial height and root collar diameter (RCD) were measured. All surviving seedlings were remeasured at the end of the growing season, 216 days after planting (DAP; 13 October 2008), and three seedlings from each treatment combination were harvested, washed, and shoot and root volumes were determined using a water displacement method (Burdett 1979). Additionally, seedling dry mass (DM) was determined after drying at 70 °C for 72 hr (Grieve Industrial Oven NB-350, Grieve Corporation, Round Lake, IL, USA). Root-to-shoot ratios by volume (R_v:S_v) and mass (R_m:S_m) were then calculated.

Samples for foliar nutrient analyses were collected 30 and 216 DAP. Samples were dried, ground, sifted with a 1-mm screen, and analyzed for nutrient contents using standard methods by A&L Great Lakes Laboratory (Fort Wayne, IN, USA). Total N was measured in a LECO FP-428 combustion analyzer (LECO CORP., St. Joseph, MI, USA). All other minerals were analyzed using a Thermo Jarrell Ash model 61E ICP (Thermo Electron Corporation, Waltham, MA, USA).

Data Analysis

We used a two-way ANOVA to determine the influence of container volume, fertilizer rate, and their combination on seedling survival, morphology (height, RCD, DM, volume, R_v:S_v, and R_s:S_s), and foliar nutrient status following outplanting. Post-hoc treatment comparisons were done using Tukey's HSD (α = 0.05). The influence of tillage and container type on seedling establishment was analyzed separately due to the layout of the study, but followed the same analysis structure.

RESULTS

Site Treatment: Tillage

No significant two-way interactions were observed between container volume and field fertilization among any of the response variables (Tables 2 and 3). Container volume significantly influenced survival (P = 0.0026), with seedlings grown in the larger containers (336 and 251 cm^3) exhibiting higher survival (44 and 43%, respectively) than their cohort in the smallest containers (28%). Initial seedling size (height and RCD) at outplanting was directly proportional to container volume (Table 2). At the end of the experiment, this initial height difference was still evident in terms of final height; seedlings from the smallest containers, however, had greater height growth than those from the largest containers (Table 2). In terms of RCD, seedlings from the largest containers exhibited significantly more growth compared to those from the smallest containers (Table 2). Seedlings from the largest containers exhibited greater shoot volume as well as root and shoot DM compared to seedlings from the other two container volumes (Table 3). Shoot DM did not differ, however, between seedlings from the intermediate (251 cm^3) and smallest (108 cm^3) containers. Seedlings from the two largest containers had significantly greater root volume than their cohort from the smallest container. Container volume did not significantly influence R_v:S_v and R_m:S_m.

Field fertilization significantly reduced survival, with unfertilized seedlings exhibiting higher survival compared to fertilized seedlings (77 and 66%, respectively). No other significant effects of fertilization were observed (Tables 2 and 3). Field fertilization did not influence foliar nutrient concentrations 30 days after outplanting (data not shown). Some nutritional differences were observed, however, at the end of the experimental period, 216 DAP. Specifically, comparing fertilized to unfertilized seedlings, Mg concentration (mg kg^{-1}) was higher (0.24 ± 0.01 vs. 0.19 ± 0.01; P = 0.0400), Zn was lower (33 ± 1 vs. 37 ± 1; P = 0.0419), and Al was lower (581 ± 42 vs. 678 ± 40; P = 0.0483).

Site Treatment: No Tillage

No significant two-way interactions between container volume and field fertilization were observed (Tables 4 and 5). Seedling survival was unaffected by container volume (P = 0.7604), with seedlings from the 336, 251, and 108 cm^3 containers exhibiting 60, 61, and 57% survival, respectively. Initial, final, and growth increment of height and RCD followed the same patterns observed in the tilled plots (Table 4). Shoot volume of the seedlings at the untilled site was not significantly different across container volumes. Root volume and shoot DM were significantly greater in the largest compared to the smallest containers, with 251-cm^3 container volume eliciting an intermediate response (Table 5). R_v:S_v was significantly higher for seedlings from the largest container compared to those from the two smaller container volumes and root DM was higher from the two largest container volumes compared to the smallest (Table 5). Shoot volume and R_m:S_m were unaffected by container size.

Survival was significantly lower (P = 0.0391) for field fertilized (55%) than for unfertilized seedlings (64%). Additionally, fertilized seedlings exhibited greater height and RCD growth as well as higher final RCD values (Table 4). Shoot volume and shoot DM were significantly greater among seedlings that received field fertilization (Table 5). Conversely, the absence of field fertilization resulted in seedlings with larger root volumes and higher R_v:S_v and

Table 3. Morphological characteristics (mean ± standard error) of outplanted seedlings on the tilled plot 216 days after outplanting.

Container Volume (cm^3)	Shoot Volume (cm^3)	Root Volume (cm^3)	R_v:S_v [a]	Shoot Dry Mass (g)	Root Dry Mass (g)	R_m:S_m [b]
336	7.8 ± 0.7a	8.3 ± 0.0a	0.6 ± 0.1a	2.9 ± 0.3a	1.6 ± 0.1a	0.6 ± 0.1a
251	5.4 ± 0.5b	6.8 ± 0.6a	0.8 ± 0.1a	1.6 ± 0.2b	1.2 ± 0.1b	0.8 ± 0.1a
108	3.1 ± 0.5c	3.1 ± 0.3b	0.8 ± 0.1a	1.0 ± 0.2b	0.6 ± 0.1c	0.8 ± 0.1a
Field Fertilization						
No	5.2 ± 0.5a	5.7 ± 0.5a	1.3 ± 0.1a	1.8 ± 0.2a	1.1 ± 0.1a	0.7 ± 0.1a
Yes	5.8 ± 0.6a	6.6 ± 0.7a	1.4 ± 0.2a	2.0 ± 0.3a	1.2 ± 0.1a	0.7 ± 0.1a
Volume (V)	$P < 0.0001$	$P < 0.0001$	$P = 0.4300$	$P < 0.0001$	$P < 0.0001$	$P = 0.0779$
Fertilization (F)	$P = 0.3747$	$P = 0.1859$	$P = 0.4432$	$P = 0.3583$	$P = 0.2735$	$P = 0.6133$
V × F	$P = 0.1087$	$P = 0.0765$	$P = 0.2041$	$P = 0.1761$	$P = 0.1432$	$P = 0.1764$

Different letters indicate significance differences based on Tukey's HSD at α = 0.05.

[a]Root:Shoot (R_v:S_v) values were calculated using volume.

[b]Root:Shoot (R_m:S_m) values were calculated using dry mass.

R_m:S_m values. Field fertilization increased foliar N concentrations ($P = 0.0021$) from 14.0 ± 0.1 g kg^{-1} to 16.5 ± 1.4 g kg^{-1} 30 days after outplanting (DAP), a response that disappeared when final foliar measurements were made 216 DAP. No other significant differences among seedling nutrient concentrations were observed.

DISCUSSION

Our findings suggest that tillage prior to outplanting may play an important role in determining the influence of container volume on seedling survival. In the tilled plots, increasing container volume improved seedling survival, with the larger container volumes (336 and 251 cm^3) yielding 55% higher survival compared to the smallest treatment volume (108 cm^3) at the end of the experiment. In the absence of tillage, however, container size did not influence survival. This may be because tillage substantially reduced the initial soil water content within the top 24 cm (Figure

Table 4. Height and root collar diameter (mean ± standard error) of outplanted seedlings on the untilled plot as influenced by container volume and field fertilization.

	Height (cm)			Root Collar Diameter (mm)		
Container Volume (cm^3)	Initial[a]	Final[b]	Growth	Initial[a]	Final[b]	Growth
336	18.2 ± 0.3a	18.1 ± 0.5a	-0.1 ± 0.3b	3.0 ± 0.1a	4.6 ± 0.1a	1.6 ± 0.1a
251	16.4 ± 0.3b	15.6 ± 0.4b	-0.8 ± 0.4b	2.7 ± 0.1b	3.9 ± 0.1b	1.2 ± 0.1b
108	10.6 ± 0.2c	12.2 ± 0.4c	1.6 ± 0.4a	2.1 ± 0.1c	3.3 ± 0.1c	1.2 ± 0.1b
Field Fertilization						
No	15.2 ± 0.3a	15.0 ± 0.4a	-0.2 ± 0.3b	2.6 ± 0.1a	3.7 ± 0.1b	1.1 ± 0.1b
Yes	14.9 ± 0.3a	15.8 ± 0.4a	0.9 ± 0.4a	2.6 ± 0.04a	4.3 ± 0.1a	1.7 ± 0.10a
Volume (V)	$P < 0.0001$	$P < 0.0001$	$P < 0.0002$	$P < 0.0001$	$P < 0.0001$	$P < 0.0078$
Fertilization (F)	$P = 0.3231$	$P = 0.2434$	$P = 0.0109$	$P = 0.1651$	$P < 0.0001$	$P < 0.0020$
V × F	$P = 0.4561$	$P = 0.3521$	$P = 0.4532$	$P = 0.3421$	$P = 0.2453$	$P = 0.0643$

Different letters indicate significance differences based on Tukey's HSD at α = 0.05.

[a]Initial measurements were collected directly prior to outplanting; $n = 480$.

[b]Final measurements were collected 216 days outplanting; $n = 274–307$.

Growth = Final – Initial.

Table 5. Morphological characteristics (mean ± standard error) of outplanted seedlings on the untilled plot 216 days after outplanting.

Container Volume (cm^3)	Shoot Volume (cm^3)	Root Volume (cm^3)	R_v:S_v[a]	Shoot Dry Mass (g)	Root Dry Mass (g)	R_m:S_m[b]
336	7.9 ± 1.1a	13.6 ± 0.5a	2.3 ± 0.5a	2.6 ± 0.4a	1.8 ± 0.2a	1.0 ± 0.2a
251	7.9 ± 0.5a	8.6 ± 0.7ab	1.3 ± 0.1b	2.0 ± 0.2ab	1.5 ± 0.1a	0.8 ± 0.1a
108	5.3 ± 0.8a	3.9 ± 0.3b	1.2 ± 0.2b	1.4 ± 0.2b	0.8 ± 0.1b	0.8 ± 0.1a
Field Fertilization						
No	5.6 ± 0.5b	10.1 ± 2.4a	1.9 ± 0.3a	1.6 ± 0.2b	1.4 ± 0.1a	1.00 ± 0.1a
Yes	7.9 ± 0.8a	7.4 ± 0.8b	1.3 ± 0.2b	2.4 ± 0.3a	1.4 ± 0.1a	0.7 ± 0.1b
Volume (V)	P = 0.0778	P = 0.0670	P = 0.0386	P = 0.0243	P < 0.0001	P = 0.3440
Fertilization (F)	P = 0.0194	P = 0.2562	P = 0.0692	P = 0.0177	P = 0.8482	P = 0.0255
V × F	P = 0.0665	P = 0.3562	P = 0.1568	P = 0.0615	P = 0.0712	P = 0.0891

Different letters indicate significance differences based on Tukey's HSD at $\alpha = 0.05$.

[a]Root:Shoot (R_v:S_v) values were calculated using volume.

[b]Root:Shoot (R_m:S_m) values were calculated using dry mass.

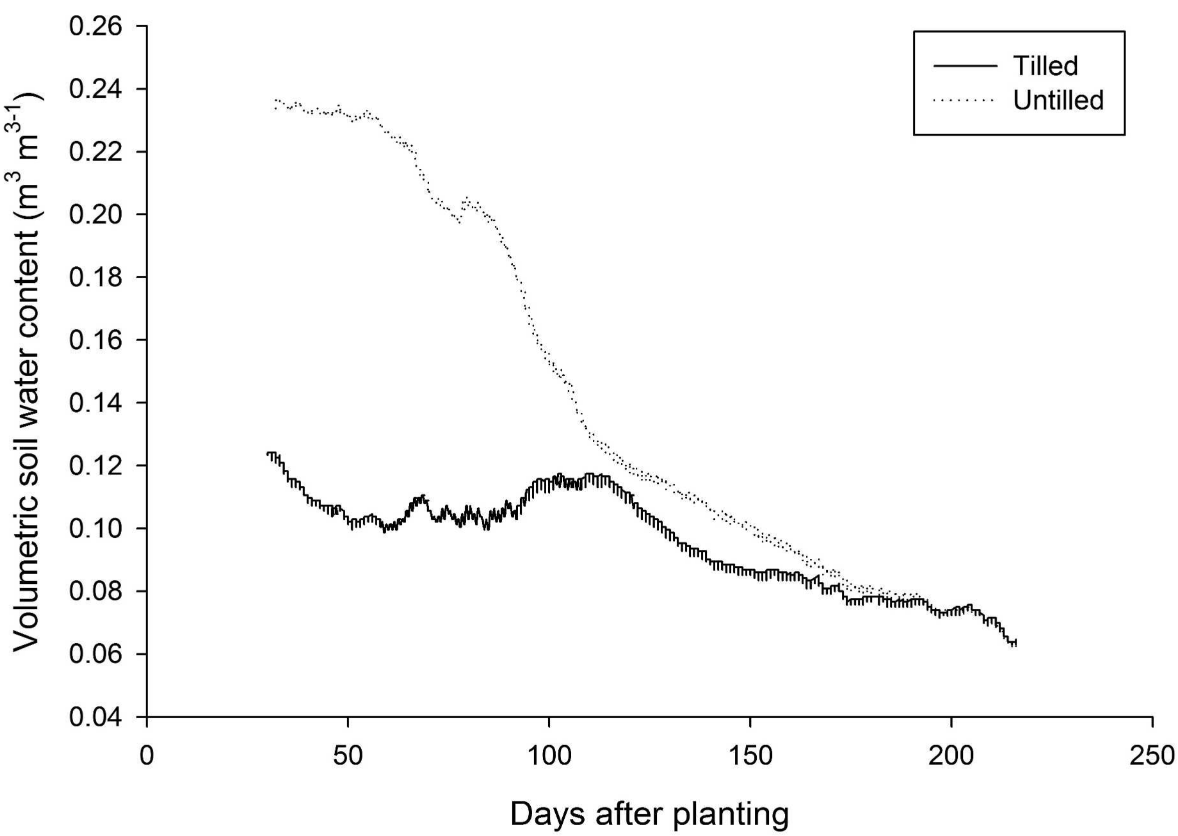

Figure 1. Soil moisture at the 24-cm depth measured as volumetric soil water content, for the tilled (black) and untilled (gray) plots.

1) during the most critical period for plant growth in the Great Basin (Comstock and Ehleringer 1992). Similar to our results, greater initial seedling size has been linked to higher seedling growth and survival among several shrub species native to the southwestern USA (Donovan et al. 1993; Matthes-Sears and Larson 1999; Bean et al. 2004; Johnson and Okula 2006).

At outplanting and after the first growing season, RCD was highest for the largest container treatment—likely a residual effect of higher resource availability achieved through lower seedling growing densities during nursery culture (Pinto et al. 2011). Seedling RCD is commonly used as a general measure of root system size, resilience capacity to drought and heat damage, and field survival (Mexal and Landis 1990; Pinto et al. 2011; Grossnickle 2012). Optimal seedling size is significantly site-dependent because successful establishment of planted seedlings requires equilibrium between shoot evaporative demand and root water uptake (Grossnickle 2012). Thus, despite having greater RCDs that are correlated with improved survival (Rose et al. 1997), larger seedlings are not always best suited for harsh sites because significant resources are required to maintain photosynthetic rates in warm, arid environments (Leiva and Fernandez-Ales 1998; Jacobs et al. 2005). Furthermore, the combination of several distinct stress periods characteristic of the Great Basin (e.g., low winter-spring temperatures combined with high summer temperature and drought) may restrict plant growth to an even greater extent than is seen in warm deserts (Comstock and Ehleringer 1992). Within the context of our study, however, a larger seedling size did not inhibit development, indicating that an aridity threshold at which the maintenance demand of the aboveground biomass would be too high to meet seedling moisture supply was not reached.

Field fertilization reduced seedling survival regardless of tillage and had negligible effects on foliar nutrient concentrations 216 DAP. Survival may have been reduced because N fertilization can promote growth of exotic annuals (Goodman 1973) that compete with outplanted seedlings. Moreover, elevated levels of fertilizers (salts) could affect water movement through the soil profile, effectively causing physiological drought. It appears that achieving a positive response at outplanting with CRF is largely dependent on soil moisture availability. Jacobs et al. (2004) observed poor performance of fertilized Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings under low soil water availability. This type of physiological drought associated with high solute concentrations can occur when soil moisture is lacking, as shown by the Palmer Drought Severity Index (PDSI) data (Figure 2, Palmer 1965). Thus, despite potential for improvements in seedling establishment fertilization with CRF, field fertilization may create conditions that adversely affect seedling survival and function.

The lack of any field fertilization effect on foliar nutrient concentrations could suggest a lack of nutrient release from the CRF or a lack of transport from the CRF to the seedling. Soil moisture within the first 75 DAP remained higher in the untilled versus tilled plots and corresponded to a higher foliar N content measured 30 DAP. This effect disappeared, however, by the end of the growing season (≥100 days following a substantial decrease in Volumetric Water Content (VWC)). On sites where soil moisture is limiting, it may be advisable to avoid field fertilization.

CONCLUSIONS

This study demonstrates that outplanting survival of nursery-grown Wyoming big sagebrush seedlings is nearly double the documented survival rates of direct seeding restoration efforts. Survival was unaffected by site preparation and was reduced by field fertilization. Survival on the tilled plot increased with increasing container volume (which yielded larger seedlings),

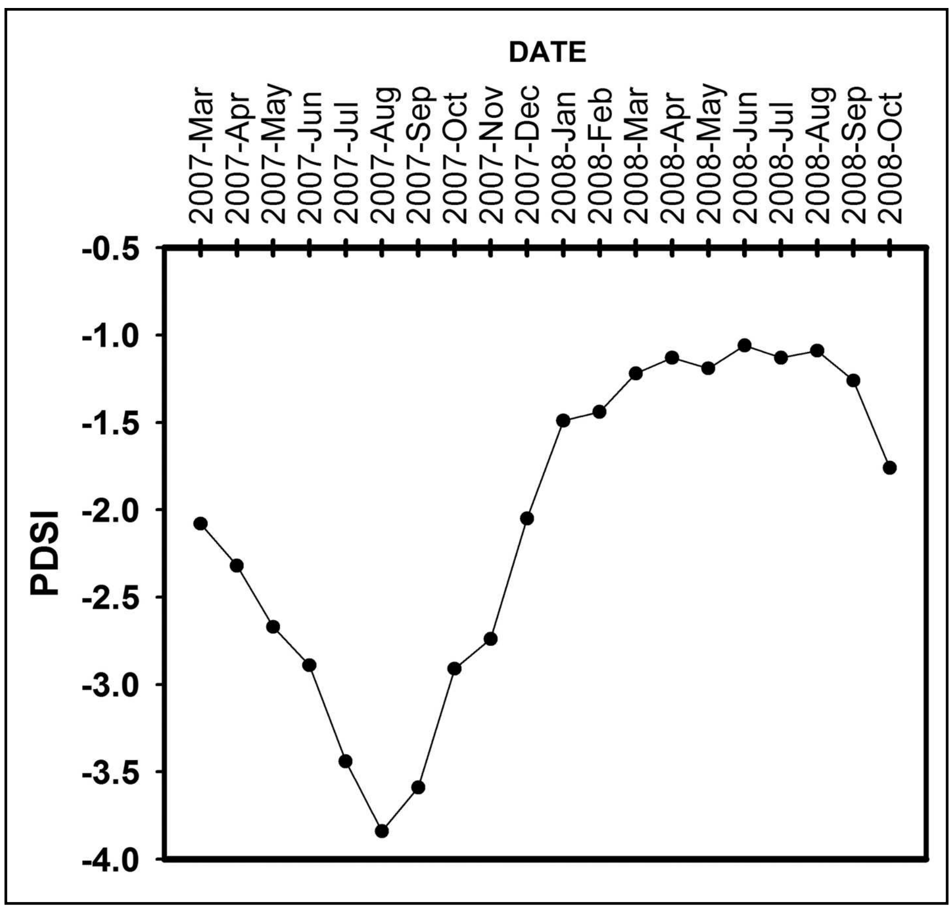

Figure 2. The Palmer Drought Severity Index (PDSI; Palmer 1965) beginning the year prior to the March 2008 outplanting and 216 DAP. PDSI categories: *Wet*: 0.5–2, slightly; 2–3, moderately; 3–4, very. *Drought*: -0.5 to -1, incipient; -1 to -2, mild; -2 to -3, moderate; -3 to -4, severe.

but no effect of container volume was observed on the untilled plots, despite the increased seedling size when grown in larger containers. Given the need to improve *A. tridentata* restoration practices, it is necessary to better understand the role of field fertilization and container size on seedling establishment. The need for testing multiple sites across multiple years to examine the survival and performance of various plant stocktypes is warranted. Such work will further the understanding of the role of interannual weather variation and site variables (e.g. water availability, soil fertility) in seedling establishment. Furthermore, refinement of specific seedling guidelines for particular site conditions will assist restoration programs and reduce the costs associated with the use of container seedlings.

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LITERATURE CITED

Bean, T.M., S.E. Smith, and M.M. Karpiscak. 2004. Intensive revegetation in Arizona's hot desert: The advantages of container stock. Native Plants Journal 5:173-180.

Boyd, C.S., and K.W. Davies. 2012. Differential seedling performance and environmental correlates in shrub vs. interspace environments. Journal of Arid Environments 87:50-57. doi:10.1016/j.jaridenv.2012.06.010.

Brooks, M.L., C.M. D'Antonio, D.M. Richardson, J.B. Keeley, J.M. Ditomaso, R.J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. BioScience 54:677-688.

Burdett, A.N. 1979. A non destructive method for measuring the volume of intact plants. Canadian Journal of Forest Research 9:120-122.

Chambers, J.C. 2000. Seed movements and seedling fates in disturbed sagebrush steppe ecosystems: Implications for restoration. Ecological Applications 10:1400-1413. doi:10.2307/2641294.

Cione, N.K., P.E. Padgett, and E.B. Allen. 2002. Restoration of a native shrubland impacted by exotic grasses, frequent fire, and nitrogen deposition in southern California. Restoration Ecology 10:376-384. doi:10.1046/j.1526-100X.2002.02038.x.

Comstock, J.P., and J.R. Ehleringer. 1992. Plant adaptation in the Great Basin and Colorado Plateau. The Great Basin Naturalist 52:195-215.

Davies, K.W., C.S. Boyd, J.L. Beck, J.D. Bates, T.J. Svejcar, and M.A. Gregg. 2011. Saving the sagebrush sea: An ecosystem conservation plan for big sagebrush plant communities. Biological Conservation 144:2573-2584. doi:10.1016/j.biocon.2011.07.016.

Dettweiler-Robinson, E., J.D. Bakker, J.R. Evans, H. Newsome, G.M. Davies, T.A. Wirth, D.A. Pyke, R.T. Easterly, D. Salstrom, and P.W. Dunwiddie. 2013. Outplanting Wyoming big sagebrush following wildfire: Stock performance and economics. Rangeland Ecology and Management: 66:657-666. doi:http://dx.doi.org/10.2111/REM-D-12-00114.1.

Donovan, L.A., J. Mausberg, and J.R. Ehleringer. 1993. Seedling size and survival for *Chrysothamnus nauseosus*. Great Basin Naturalist 53:237-245.

Dumroese, R.K., M.E. Montville, and J.R. Pinto. 2015. Using container weights to determine irrigation needs: A simple method. Native Plants Journal 16:67-71.

Goodman, P.J. 1973. Physiological and ecotypic adaptation of plants to salt desert conditions in Utah. Journal of Ecology 61:473-494. doi:10.2307/2259040.

Grossnickle, S.C. 2012. Why seedlings survive: Influence of plant attributes. New Forests 43:711-738.

Jackson, R.B., and M.M. Caldwell. 1993. The scale of nutrient heterogeneity around individual plants and its quantification with geostatistics. Journal of Ecology 74:612-614.

Jacobs, D.F., R. Rose, D.L. Haase, and P.O. Alzugaray. 2004. Fertilization at planting inhibits root system development and drought avoidance of Douglas-fir (*Pseudotsuga menziesii*) seedlings. Annals of Forest Science 61:643-651.

Jacobs, D.F., K.F. Salifu, and J.R. Seifert. 2005. Relative contribution of initial root and shoot morphology in predicting field performance of hardwood seedlings. New Forests 30:235-251. doi:10.1007/s11056-005-5419-y.

Johnson, R., and J. Okula. 2006. Antelope bitterbrush reestablishment: A case study of plant size and browse protection events. Native Plants Journal 7:125-133. doi:10.2979/NPJ.2006.7.2.125.

Kinter, C.L., B.A. Mealor, N.L. Shaw, and A.L. Hild. 2007. Postfire invasion potential of rush skeletonweed (*Chondrilla juncea*). Rangeland Ecology and Management 60:386-394.

Leiva, M.J., and R. Fernandez-Ales. 1998. Variability in seedling water status during drought within a *Quercus ilex* ssp. *ballota* population, and its relation to seedling morphology. Forest Ecology and Management 111:147-156. doi:10.1016/S0378-1127(98)00320-X.

Matthes-Sears, V., and D.W. Larson. 1999. Limitation to seedling growth and survival by the quantity and quality of rooting space: Implications for the establishment of *Thuja occidentalis* on cliff faces. International Journal of Plant Sciences 160:122-128.

McAdoo, J.K., C.S. Boyd, and R.L. Sheley. 2013. Site, competition, and plant stock influence transplant success of Wyoming big sagebrush. Rangeland Ecology and Management 66:305-312. doi:10.2111/REM-D-12-00136.1.

Mexal, J.G., and T.D. Landis. 1990. Target seedling concepts: Height and diameter. Pp. 17–36 *in* R. Rose, S.J. Campbell, T.D. Landis, eds., Target Seedling Symposium: Proceedings of the Western Forest Nursery Associations. General Technical Report RM-200, US Department of Agriculture, Forest Service, Forest and Range Research Station, Fort Collins, CO.

Noss, R.F., E.T. LaRoe III, and J.M. Scott. 1995. Endangered Ecosystems of the United States: A Preliminary Assessment of Loss and Degradation. Biological Report 28, National Biological Service, Washington, DC.

Palmer, W.C. 1965. Meteorological Drought. Research Paper 45, US Weather Bureau, Office of Climatology, Washington, DC.

Perryman, B.L., A.M. Maier, A.L. Hild, and R.A. Olson. 2001. Demographic characteristics of big sagebrush in Wyoming. Journal of Range Management 54:166-170.

Pinto, J.R., J.D. Marshall, R.K. Dumroese, A.S. Davis, and D.R. Cobos. 2011. Establishment and growth of container seedlings for reforestation: A function of stocktype and edaphic conditions. Forest Ecology and Management 261:1876-1884. doi:10.1016/j.foreco.2011.02.010.

Rose, R., D.L. Haase, F. Kroiher, and T. Sabin. 1997. Root volume and growth of ponderosa pine and Douglas-fir seedlings: A summary of eight growing seasons. Western Journal of Applied Forestry 12:69-73.

Sankey J.B., M.J. Germino, T.T. Sankey, and A.N. Hoover. 2012. Fire effects on the spatial patterning of soil properties in sagebrush steppe, USA: A meta-analysis. International Journal of Wildland Fire 21:545-556. doi:10.1071/WF11092.

Shaw, N.L., A.M. Debolt, and R. Rosentreter. 2005. Reseeding big sagebrush: Techniques and issues. Pp. 99–108 *in* N. Shaw, M. Pellant, and S.B. Monsen, compilers. Sage-grouse Habitat Restoration Symposium Proceedings. RMRS-P-38, US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Soil Survey Staff. 1996. Keys to Soil Taxonomy. 8th edition. US Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

Suring, L.H., M.M. Rowland, and M.J. Wisdom. 2005. Identifying species of conservation concern. Pp. 150–162 *in* M.J. Wisdom, M.M. Rowland, and L.H. Suring, eds., Habitat Threats in the Sagebrush Ecosystem – Methods of Regional Assessment and Applications in the Great Basin. Alliance Communications Group, Lawrence, KS.

Wisdom, M.J., M.M. Rowland, L.H. Suring, L. Schueck, C.W. Meinke, and S.T. Knick. 2005. Evaluating species of conservation concern at regional scales. Pp. 5–24 *in* M.J. Wisdom, M.M., Rowland, and L.H. Suring, eds., Habitat Threats in the Sagebrush Ecosystem – Methods of Regional Assessment and Applications in the Great Basin. Alliance Communications Group, Lawrence, KS.