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Potential of Forage Kochia and Other Plant Materials in Reclamation of Gardner Saltbush Ecosystems Invaded by Halogeton

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POTENTIAL OF FORAGE KOCHIA AND OTHER PLANT MATERIALS IN RECLAMATION OF GARDNER SALTBUSH ECOSYSTEMS INVADED BY HALOGETON

by

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Approved:

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ABSTRACT

Potential of Forage Kochia and Other Plant Materials in Reclamation of Gardner Saltbush Ecosystems Invaded by Halogeton

by

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Utah State University, 2015

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Gardner saltbush ecosystems are increasingly being invaded by halogeton [*Halogeton glomeratus* (M. Bieb.) C.A. Mey.], a competitive annual weed that increases soil surface salinity and reduces plant biodiversity. This study was established on the Flaming Gorge National Recreation Area, in the Ashley National Forest near Manila, UT to evaluate the ability of forage kochia [*Bassia prostrata* (L.) A.J. Scott], Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski], tall wheatgrass [*Thinopyrum ponticum* (Podp.) Z.-W. Liu & R.-C. Wang], Indian ricegrass [*Achnatherum hymenoides* (Roem. & Schult.) Barkworth], and Gardner saltbush [*Atriplex garneri* (Moq.) D. Dietr.], in monocultures and binary mixtures with Gardner saltbush, to establish and compete in ecosystems dominated by halogeton. A dormant seeding, with and without prior disking, was conducted to determine the ability of plant materials to establish. A spaced-plant evaluation was used to determine the competitive ability of fully established plants by measuring halogeton densities at four 10 cm intervals (10-20, 20-30, 30-40, and 40-50 cm) distal from transplants. Gardner saltbush, tall wheatgrass, and Indian ricegrass did not establish or persist beyond the first year in either study. Conversely, Russian wildrye and forage kochia established and persisted, with Russian wildrye establishment higher ($P \leq 0.05$) in the disked treatment (4.5 and 1.7 plants m^{-2}, respectively) and no-till favoring ($P \leq 0.05$) forage kochia establishment (2.0 and 0.8 plants m^{-2}, respectively). Spaced-plants of these species reduced halogeton by 52% relative to the control. Furthermore, by the second year of evaluation, the competitive ability of Russian wildrye and forage kochia had extended to 50 cm distal from transplant. Transplant survival and halogeton frequency were highly correlated (r = -0.67, P = 0.0001), indicating the important of persistence. These results suggest that Russian wildrye and forage kochia can establish, persist, and compete with halogeton, thereby providing an opportunity for reclamation of halogeton-invaded areas. Conversely, direct restoration to Gardner saltbush and Indian ricegrass does not appear likely.

(49 pages)

PUBLIC ABSTRACT

Potential of Forage Kochia and Other Plant Materials in Reclamation of Gardner Saltbush Ecosystems Invaded by Halogeton

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Gardner saltbush ecosystems are increasingly being invaded by halogeton, a competitive annual weed that increases soil surface salinity and reduces plant biodiversity. This study was established on the Flaming Gorge National Recreation Area, in the Ashley National Forest near Manila, UT to evaluate the ability of forage kochia, Russian wildrye, tall wheatgrass, Indian ricegrass and Gardner saltbush, in monocultures and binary mixtures with Gardner saltbush, to establish and compete in ecosystems dominated by halogeton. A dormant seeding, with and without prior disking, was conducted to determine the ability of plant materials to establish. A spaced-plant evaluation was used to determine the competitive ability of fully established plants by measuring halogeton densities at four 10 cm intervals (10-20, 20-30, 30-40, and 40-50 cm) distal from transplants. Gardner saltbush, tall wheatgrass, and Indian ricegrass did not establish or persist beyond the first year in either study. Conversely, Russian wildrye and forage kochia established and persisted, with Russian wildrye establishment higher ($P \leq 0.05$) in the disked treatment (4.5 and 1.7 plants m^{-2}, respectively) and no-till favoring ($P \leq 0.05$) forage kochia establishment (2.0 and 0.8 plants m^{-2}, respectively). Spaced-plants of these species reduced halogeton by 52% relative to the control. Furthermore, by the second year of evaluation, the competitive ability of Russian wildrye and forage kochia had extended to 50 cm distal from transplant. Transplant survival and halogeton frequency were highly correlated (r = -0.67, P = 0.0001), indicating the

important of persistence. These results suggest that Russian wildrye and forage kochia can establish, persist, and compete with halogeton, thereby providing an opportunity for reclamation of halogeton-invaded areas. Conversely, direct restoration to Gardner saltbush and Indian ricegrass does not appear likely.

DEDICATION

Dedicated to my wife and family for their encouragement and support to continue my graduate education.

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Rob Smith

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INTRODUCTION

In the United States, 42% of total land is rangelands and pastures and three-quarters of all domestic livestock depend on these grazing lands for survival (DiTomaso 2000). The semi-arid and arid rangelands of the western U.S. provide a broad array of ecosystem services, including livestock forage, a diversity of native plants, pollinators, wildlife, and recreational activities. The salt desert shrub ecosystems often found on these rangelands are particularly vulnerable to invasive species. Invasive species are characterized as being extremely competitive and often having allelopathic potential leading to the displacement of native species and resulting in altered hydrology patterns and reduced nitrogen cycling (Levine et al. 2003; Young and Clements 2003). As such, many salt desert shrub rangelands are experiencing a rapid increase in noxious annual weeds such as halogeton [*Halogeton glomeratus* (M. Bieb.) C.A. Mey].

Halogeton is a highly invasive species of Eurasian origin that was first reported near Wells, NV in 1934 (Dayton 1951; Holmgren and Andersen 1970; Young 2002). Halogeton is a warm season (C4 pathway) succulent annual halophyte that increases soil pH, exchangeable sodium, electrical conductivity (EC), and soil salt content by transferring sodium from the soil into the above ground plant tissue, which then is deposited onto the soil surface as the plant material decays after completing its life cycle (Duda et al. 2003; Harper et al. 1996). Halogeton is of concern to livestock producers because it accumulates toxic oxalates in its tissues that are often fatal to livestock when ingested, especially sheep (Cronin and Williams 1966; Tisdale and Zappetini 1953). Halogeton produces two types of seed; black seeds that germinate rapidly and establish whenever conditions permit, and brown seeds that can remain viable in the seed bank for up to 10 years, extending seed bank longevity and allowing the species to reestablish after extended drought conditions (Williams 1960).

For nearly 70 years, land managers have struggled to slow the rate of spread of halogeton. By 1952, halogeton was reported to have spread to 1.5 million acres encompassing deserts of the Great Basin, Colorado Basin (Utah and Colorado), and Wyoming (Tisdale and Zappetini 1953), and is now found in all 11 western states, as well as South Dakota and Nebraska (USDA-NRCS 2015). Within the salt desert shrub ecosystem, there is particular interest in protecting the Major Land Resource Area D34A-Cool Central Desertic Basins and Plateaus in which lies the Lower Green River Basin of Wyoming (NRCS 2011). In these regions, Gardner saltbush [*Atriplex gardneri* (Moq.) D. Dietr.], a valuable shrub that provides a nutritious winter forage for wildlife and livestock, is being displaced and subsequently replaced by the encroachment of halogeton (Goodrich and Zobell 2011). For instance, Goodrich and Zobell (2011) reported that in one area, Gardner saltbush declined from 26% to 0% from 1993 to 2009 where it became predominately a monoculture of halogeton.

A major cause of the Gardner saltbush die off is the soil chemistry change resulting from halogeton's 'salt pumping' which brings salt from the soil into the plant tissue and increases the salt concentrations at the soil surface as the plant senesces (Eckert and Kinsinger 1960; Kinsinger and Eckert 1961). Sodium content is highest in young plants and declines steadily as the plant approaches maturity; ranging from 12% in early summer to 9% in the fall (Morton et al. 1959). This increase of sodium on the soil surface reduces the germination and subsequent establishment and persistence of native grasses and forbs (Eckert and Kinsinger 1960; Kinsinger and Eckert 1961), thus allowing halogeton to spread and densities to increase. Additionally, the chemical and physical structure of the soil is altered causing severe crusting and severely decreasing soil permeability (Eckert and Kinsinger 1960).

Forage kochia [*Bassia prostrata* (L.) A.J. Scott], is an important forage in its native environment of Eurasia, where it is utilized by sheep, goats, camels, and horses (Francois 1976; Waldron et al. 2010). Waldron et al. (2011) recommended forage kochia on western rangelands as it increases nutritional value, carrying capacity, and livestock performance on semiarid rangelands, especially for fall/winter grazing. Forage kochia has been reported to establish, compete, and persist with annual weeds such as halogeton, downy brome (*Bromus tectorum* L.), Russian thistle (*Salsola tragus* L), and medusahead rye (*Taeniatherum caput-medusae* (L.) Nevski) (McArthur et al. 1990; Monsen 1992; Stevens and McArthur 1990; Van Epps and Mckell 1983; Young and Clements 2004), and is widely used to rehabilitate disturbed areas where frequent fire occurs and invasive annuals persist. Forage kochia is well adapted to the semi-arid and arid rangelands of the western U.S. in part due to its high salt and drought tolerance. Forage kochia has been reported to be productive in soils approaching salinity EC values of 20 dS/m (Francois 1976; McFarland et al. 1990; Waldron et al. 2010). It also has an extensive root system, consisting of a taproot extending to 6.5 m in depth (Gintzburger et al. 2003) and fibrous lateral roots of 130-160 cm in length (Baylan 1972) that enables it to compete for limited available water and enhances its drought tolerance (Romo and Haferkamp 1988). These adaptability traits make forage kochia a strong candidate species to compete with and reclaim halogeton-infested semiarid rangelands (Baylan 1972; USDA-NRCS 2015).

The objectives of this study were: 1) to compare the relative abilities of forage kochia, Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski], tall wheatgrass [*Thinopyrum ponticum* (Podp.) Z.-W. Liu & R.-C. Wang], Gardner saltbush, and Indian ricegrass [*Achnatherum hymenoides* (Roem. & Schult.) Barkworth] to compete with halogeton, and; 2) to evaluate the ability of the above species to germinate and establish when seeded into a halogeton monoculture.

MATERIALS AND METHODS

Study Site

This study area was located 11 km northeast of Manila, Utah within the Flaming Gorge National Recreation Area, Ashley National Forest in the lower Green River Basin (41°03.307' North, 109° 36.410' West), within the Cool Central Desertic Basins and Plateaus Major Land Resource Area (MLRA) D-34A. Elevation at the site ranges from 1585 – 2200 m on mostly fine alluvium sediment with excess sodium, and slopes that vary from 1 to 10%. Mean annual air temperature fluctuates between 5-7°C, the frost-free period ranges from 45-160 days, and mean annual precipitation varies between 180-228 mm (NRCS 2011). The mean calendar year annual precipitation (MCYAP; January 1 – December 31) was 228 mm for a 104 year period [1910-2015; based on Manila, UT Western Regional Climate Center (WRCC 2015) station number 425377], 11.6 km southwest of the study area (Figure 1). Calendar year annual precipitation (CYAP) was 96%, 124%, 33%, 110%, and 107% of the MCYAP, in 2011, 2012, 2013, and 2014, respectively. The soils around the study area are dominated by Aridisols and Entisolsare. Both soils are characterized as deep to very deep (≥ 38 cm), and are well drained and calcareous (NRCS 2011). According to the ecological site description (ESDs), which is the smallest unit of a hierarchical nested land classification system used by resource managers in the United States, plants associated with MLRA D-34A are Gardner saltbush, shadscale saltbush [*Atriplex confertifolia* (Torr. & Frém.) S. Watson], winterfat [*Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit], bud sagebrush (*Picrothamnus desertorum Nutt.*), and Wyoming big sagebrush [*Artemisia tridentata* Nutt. ssp.

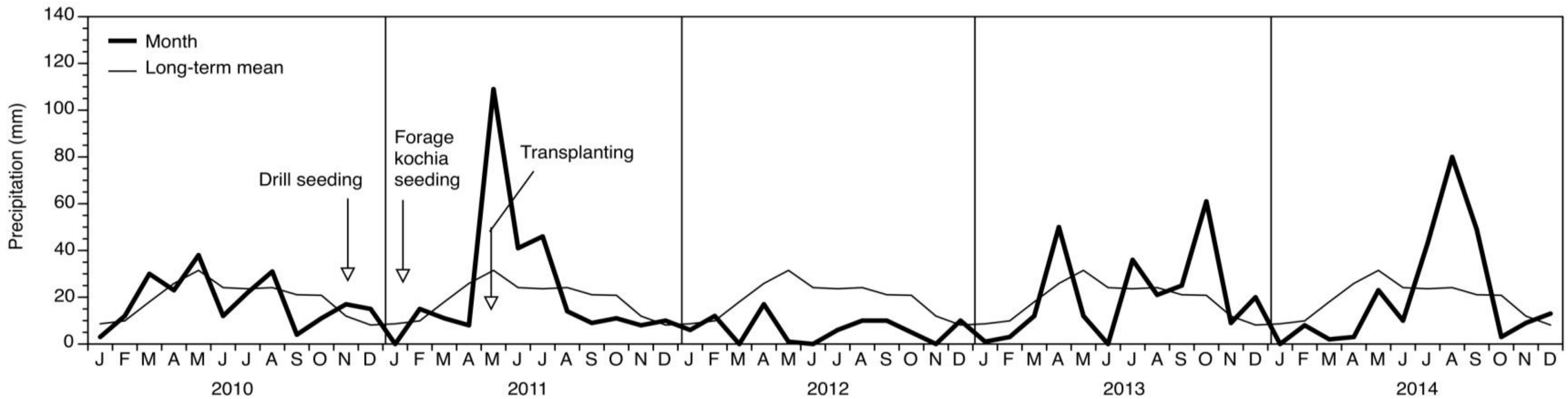

Figure 1. Monthly and long-term mean precipitation for the study area near Manila, UT (WRRC 2015). Monthly data from Manila, UT (1935 M) located approximately 11 km southwest of the study site. The thin solid line represents the 104 year mean and thick solid line represents monthly precipitation in the given year. Data last accessed on 5 February 2015 at http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?utmani

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wyomingensis Beetle & Young]. Common grasses include bottlebrush squirreltail [*Elymus elymoides* (Raf.) Swezey], Indian ricegrass, and needle-and-thread [*Hesperostipa comata* (Trin. & Rupr.) Barkworth] (NRCS 2011).

The selected site had a uniform stand of halogeton and a 1-acre enclosure was fenced to keep out livestock/wildlife. Two experiments were conducted within the enclosure. Experiment #1 was a spaced plant study to elucidate persistence (dead or alive) of the plant materials and their competitive ability with halogeton. Experiment # 2 was a seeded study focusing on establishment of desirable plant materials.

Plant Materials

Plant materials consisted of nine entries, and included Gardner saltbush, forage kochia, and adapted grasses. Forage kochia entries were cultivars Snowstorm (tetraploid, ssp. *grisea*) (Waldron et al. 2013) and Immigrant (diploid, ssp. *virescens*) (Stevens et al. 1985), and breeder populations of KZ6XSEL (hexaploid, ssp. *grisea*), SAHSEL (tetraploid, ssp. *grisea*), and PUSTSEL (diploid, ssp. *virescens*). All entries (except Immigrant) originated from ARS collections made in Kazakhstan (1999) and Uzbekistan (2002) (Waldron et al. 2001; Waldron et al. 2005), and had been previously evaluated for salt tolerance (data unpublished) according to the methods of Peel et al. (2004).

Three cool season grass species including Russian wildrye (cv. Bozoisky II) (Jensen et al. 2006), tall wheatgrass (cv. Alkar) (Schwendiman 1972), and Indian ricegrass (cv. Rimrock) (Jones et al. 1998) were used in this study. Bozoisky II Russian wildrye was developed from Bozoisky-Select (Asay et al. 1985) and is noted for its increased seedling establishment and persistence on alkaline soils. Tall wheatgrass is particularly noted for its capacity to produce forage and persist in areas too saline or alkaline for other forage crops and is adapted to semi-arid rangelands that receive a minimum of 350 mm of annual precipitation. Alkar tall wheatgrass was derived from germplasm (PI-98526) obtained from the N.I. Vavilov Institutes of Plant Industry in 1932, and has been shown to be adapted to alkali soils (Hafenrichter et al. 1968; Schwendiman 1972). Indian ricegrass will tolerate moderately alkaline soils and is considered one the most drought-tolerant native rangeland grasses persisting in areas receiving as low as 177 mm of average annual precipitation. Rimrock Indian ricegrass was originally collected in 1960, north of Billings, MT (PI-478833) and released for revegetating and restoring rangelands, and as a winter forage for livestock and wildlife (Jones et al. 1998). Finally, a commercial source of Gardner saltbush (variety not stated; VNS) was used in this study. Gardner saltbush is a perennial shrub that is widespread throughout the salt desert shrublands in areas receiving 150 to 300 mm of annual precipitation, where it inhabits heavy textured soils and more arid environments than typical for big sagebrush and fourwing saltbush (USU 2015).

Experiment #1 – Competition With Halogeton (Spaced Plants)

Experimental Design. Seed of the aforementioned entries of forage kochia, Russian wildrye, tall wheatgrass, Indian ricegrass, and Gardner saltbush plants were started in the greenhouse at Logan, UT. Seeds were planted on 18 January 2011. The media type used was a 3:1 ratio of perlite based soil and sphagnum peat moss mix. Seeds were planted in Stuewe & Sons SC10 super container, which are 3.8 cm in diameter and 21 cm in depth. Greenhouse temperatures from mid January to the first of May were kept at a mean temperature of 22°C. Plants were watered by an overhead sprinkler system at a rate of approximately 1.9 cm per week. Peter's 20-20-20 water soluble fertilizer was injected into sprinkler system at a rate of 100:1ratio.

The greenhouse grown plants were transplanted to the experimental sight on 3 May 2011 in 16 plant plots. A plot consisted of 16 transplants in a four by four grid with a spacing of 0.5 m within rows and 1 m between rows, and plots were planted as monocultures or mixtures with Gardner saltbush (Figure 2). Mixed plots were planted in an alternating pattern within and across rows with eight plants being either forage kochia or grass and the other eight plants being Gardner saltbush (Figure 2). The dimension of the plot was 2 m x 4 m for a total area of 8 m^2 (Figure 2). Control plots without any transplants were included within the spaced-plant experiment to verify recruitment of halogeton.

The study was arranged in a randomized complete block design (RCBD) with four replications of nine monocultures, eight mixtures, and one control for a total of 72 plots. The plot area was tilled with a Howard tiller on 10 November 2010 to prepare for transplanting. Maintenance of the plots consisted only of mowing transplants in late summer of 2012 and 2013 prior to forage kochia reaching seed maturity. This was done so forage kochia did not recruit new seedlings within the plot area.

Competition Data Collection and Statistical Analyses. Competition data were collected on 29 June 2012, 10 July 2013, and 29 October 2014. Halogeton frequency was determined using the frequency grid protocol described by Vogel and Masters (2001) by laying a grid consisting of 80 10-by-10 cm quadrants between plot rows. Each quadrant containing one or more halogeton plant was scored as present (versus absent). The grid was placed between plants 2 and 3 within the row and between rows 1 and 2, 2 and 3, and

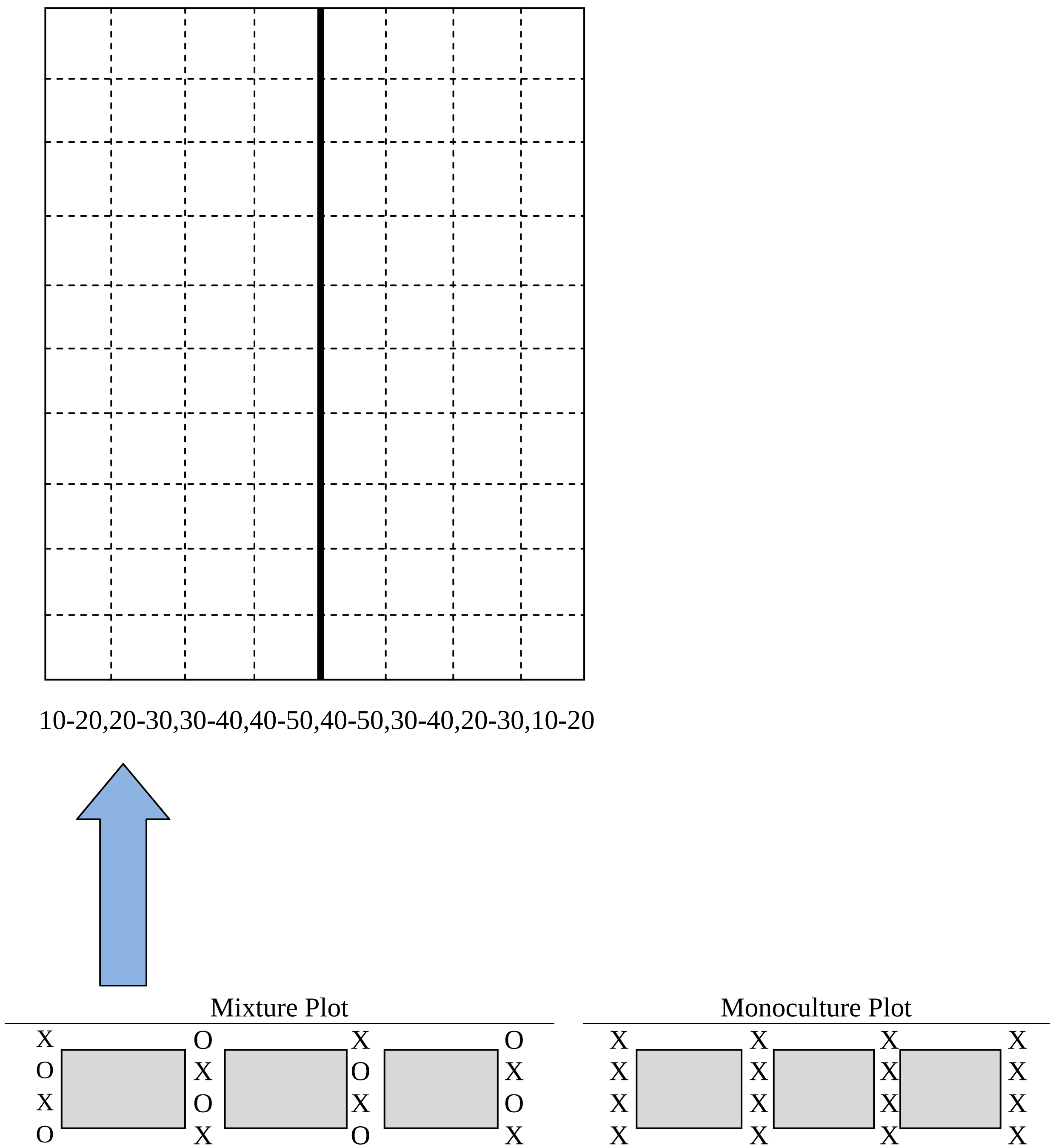

Figure 2. Diagram of transplant layout in monoculture and binary mixture plots in a space plant halogeton competition planted in 2011 planted near Manila, UT. Spacing of plants is 0.5 m within and 1 m across rows. Shaded box indicates the area of data collection within transplants. Grid was 0.8 m x 1.0 m with a total of 80 quadrants. Each quadrant measured 10 x 10 cm. Measurements were taken at 10 cm intervals beginning at 10-20, 20-30, 30-40, and 40-50 cm from desired plant.

3 and 4 (Figure 2). Furthermore, the grid was designed so that frequency was scored in four 10-cm intervals increasingly distal from the transplants (e.g., 10 quadrants each at 10-20, 20-30, 30-40, and 40-50 cm intervals and repeated on both halves of the 1 m inter-row space) (Figure 2). Thus, there were six sub-samples per interval per plot (e.g., two sub-samples between each of three rows, see Figure 2). Transplant survival was determined each time halogeton frequency was measured, and the number of transplants of each species was scored as dead or alive.

Halogeton frequency and transplant survival were first analyzed across years using the MIXED procedure of SAS, (SAS Institute Inc., Version 9.3, Cary, NC) with entry, interval (frequency only), and year as fixed effects, and replication considered random. Year was considered a repeated measure and the best covariance model for each trait were determined and used in the analyses (Littell et al. 2006). Due to a significant Interval × Year interaction, the halogeton frequency data were subjected to analysis of covariance (ANCOVA) within years using the MIXED procedure of SAS and following the strategy outlined in Littell et al. (2006). First, ANCOVA was performed to test if the slope of response between intervals was equal to zero. It was determined to be zero in 2013 and 2014 (e.g. no differences between interval distances), and, thus these data were then analyzed within year using the average halogeton frequency across all interval distances. The data from 2012 were then further analyzed with ANCOVA to determine if slopes for each entry across interval distances were equal. They were found to differ significantly among the entries, so the intercept and slope were determined, and frequency data were further analyzed within an interval distance. Transplant survival was also analyzed within years. The correlations between transplant survival and halogeton frequency (at each interval distance and on average) were determined using the CORR procedure of SAS. Mean comparisons were made between treatments using Fisher's protected least significant difference (LSD) test at the $P \leq 0.05$ level of probability.

Experiment #2 - Establishment into Halogeton Monoculture (Seeded Plots)

Experimental Design. Seed of forage kochia, Russian wildrye, tall wheatgrass, Indian ricegrass, and Gardner saltbush were planted as a fall/winter dormant seeding as monocultures, and as binary mixtures with Gardner saltbush. The grass entries and Gardner saltbush were drilled on 17 November 2010 and the forage kochia entries were broadcast on 12 January 2011. All plots were seeded at a rate of 300 pure live seeds (PLS) m^{-2} (Table 1). Mixture plots received 150 seeds PLS m^{-2} of Gardner saltbush and 150 seeds PLS m^{-2} of the other entry in the binary mix. The rate of 300 PLS m^{-2} resulted in 'Immigrant' forage kochia seeding rate of 3.8 kg ha^{-1} and 'Bozoisky II' Russian wildrye being seeding rate of 12.0 kg ha^{-1}, which is within the recommended rate for planting forage kochia and grasses on harsh rangelands (Table 1).

Table 1. Seeding rates of monoculture and binary mixtures from a seeded plot/halogeton competition study planted in 2010/2011 near Manila, UT. All plots were seeded at a rate of 300 pure live seeds (PLS) m^{-2}, with binary mixtures consisting of 150 seeds PLS m^{-2} of Gardner saltbush and 150 seeds PLS m^{-2} each of the other species individually.

Entry	Species	Monoculture	Mixture	%PLS
		---------kg ha^{-1}---------		
Immigrant	*B. prostrata* (ssp. *virescens*)	3.8	1.9	43
Snowstorm	*B. prostrata* (ssp. *grisea*)	6.0	3.0	73
KZ6XSEL	*B. prostrata* (ssp. *grisea*)	3.6	1.8	75
PUSTSEL	*B. prostrata* (ssp. *virescens*)	4.6	2.3	30
SAHSEL	*B. prostrata* (ssp. *grisea*)	6.6	3.3	54
Gardner	*Atriplex gardneri*	12.4	6.2	40
Alkar	*Thinopyrum ponticum*	23.0	11.5	85
Bozoisky II	*Psathyrostachys juncea*	12.0	6.0	82
Rimrock	*Achnatherum hymenoides*	9.8	4.9	98

Seeded plots were 1.5 m wide by 3.0 m long. Drilled entries were planted with a Hege Model 1000 6-row seeder with 25.4 cm spacing between rows at a depth of 0.6 cm. Broadcast entries were planted with a Hege Model 1000 with the disk opener's raised above the soil. Two soil treatments were applied prior to seeding to determine the affect of tillage on seedling establishment within a halogeton infestation. One-half of the plots were disturbed with an offset disk at a depth of 12 cm to turn the soil over and reduce salt content close to the surface. The other half were no-till planted, which was possible as there were no perennial plants (e.g., Gardner saltbush) remaining in the plot area due to the dense stand of halogeton. The experiment was arranged as a split plot design with tillage as the whole plot and entry as the subplot and included six replications of the 17 monoculture/mixtures plus a control (e.g., not seeded) for a total of 216 plots.

Establishment Data Collection and Statistical Analysis. Establishment data on the seeded study were collected on 2 August 2011, 10 July 2013, and 29 October 2014. Data was not collected in 2012 due to the severity of drought (Figure 2) and resulting lack of seedling growth/establishment. Seedling establishment was measured as plant frequency in 2011 or as plant density (plants m^{-2}) in 2013 and 2014. Frequency was determined using the grid system described by Vogel and Masters (2001) by laying a grid of 42 12.5-by-12.5 cm quadrants over the drilled rows and determining the percentage of quadrants containing at least one seedling. If a plant occurred in every quadrant, establishment frequency was considered to be 100%. Two subsamples were measured in each plot. Establishment data in 2013 and 2014 were measured by taking total plant counts within the plot area. Halogeton establishment within the plots was also determined by taking total seedling counts in 2011 and 2013. Individual plants of halogeton could not be counted in 2014 due to above average precipitation and subsequent high levels of germination/growth of halogeton (Figure 1). Therefore, a visual score of 1-9, (9 = solid monoculture of halogeton and 1 = no halogeton) was utilized to measure the halogeton stand.

Entry and halogeton frequency, density, or visual rating scores were analyzed within years using the MIXED procedure of SAS (SAS Institute Inc.,Version 9.3, Cary, NC) with entry and tillage (disk or no-till) as fixed effects, and replication considered random. Data were analyzed as a split-plot design with tillage being the whole plot and entry the subplot. Mean comparisons were made between treatments using Fisher's protected least significant difference (LSD) test at the $P \leq 0.05$ level of probability. Entry × Tillage treatment means were also compared with an LSD test calculated using the standard error of the Entry × Tillage treatment means.

RESULTS AND DISCUSSION

Experiment 1 – Competition With Halogeton (Spaced Plants)

Transplant Survival. By 2014, transplant survival was highly correlated (r = -0.67, P = 0.0001) with halogeton frequency; therefore it is imperative to first discuss entry survival in this harsh environment prior to the competitive ability of individual entries. The Entry × Year interaction was significant (Table 2) and reflective of subsequent reductions each year in survival of the entries, with the exception of forage kochia and Russian wildrye, which persisted throughout the years of the study (Table 2).

The year following establishment (2012), all entries, except the Rimrock/Gardner binary mix, had 100% survival (Table 3). However, by the next year (2013), persistence of Gardner, Rimrock, Alkar, and their respective binary mixes with Gardner had declined to values approaching complete death; whereas, forage kochia monocultures had survival approaching 100% (Table 1). In contrast, forage kochia/Gardner binary mixtures had approximately 50% survival, reflective of a nearly complete loss of all Gardner plants by the second year after transplanting (Table 3). These 2013 trends were repeated in 2014, with just slightly lower survival values (Table 3).

Comparison among individual entries revealed that in 2013 and 2014, Bozoisky II Russian wildrye was numerically the most persistent entry, but only significantly more so than Immigrant of the forage kochia entries (Table 3). There were no differences among forage kochia entries in 2013, but by 2014 the new cultivar Snowstorm had significantly higher survival than the standard cultivar Immigrant. In a previous study, Snowstorm, KZ6XSEL, and SAHSEL, all within subspecies *grisea* had higher salt tolerance than Immigrant, which is subspecies *virescens* (unpublished data). Increased salt tolerance,

Table 2. Significance of main and interaction effects (P<0.05) of survival of transplants (%) and halogeton frequency from ANOVA using mixed-model analysis and RCB design with four replications. Halogeton frequency was measured between 1-m spaced rows of plants of forage kochia, grasses, and Gardner saltbush in a spaced plant/halogeton competition study established in 2011 near Manila, UT.

	2012		2013		2014		Across Years	
Source[1]	Survival %	Halogeton	Survival %	Halogeton	Survival %	Halogeton	Survival %	Halogeton
Entry	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Interval[2]	--	<0.0001	--	0.0419	--	0.3446	--	<0.0001
Entry × Interval	--	0.0335	--	0.9903	--	1.0000	--	0.9994
Year	--	--	--	--	--	--	<0.0001	<0.0001
Entry × Year	--	--	--	--	--	--	<0.0001	<0.0001
Interval × Year	--	--	--	--	--	--	--	<0.0001
Entry × Interval × Year	--	--	--	--	--	--	--	<0.0001

[1]Source of variation included 18 entries, 4 distances, and 3 years.
[2]Distance was four 10 cm intervals (10-20, 20-30, 30-40, and 40-50 cm) distal from the transplants.

Table 3. Annual and 3-yr mean survival of plant entries transplanted in 2011 into a spaced plant/halogeton competition study conducted near Manila, UT.

Entry[2]	2012[1]	2013	2014	3-Yr Mean
	------------------------------% Survival------------------------------			
Bozoisky II	100 a	98 a	92 a	97 a
Snowstorm	100 a	94 ab	90 a	95 a
PUSTSEL	100 a	90 ab	92 a	94 a
KZ6XSEL	100 a	90 ab	88 ab	92 a
SAHSEL	100 a	85 ab	88 ab	91 a
Immigrant	100 a	79 b	75 b	85 a
Sahro_Gardner	100 a	57 c	46 c	68 b
Bozoisky II_Gardner	100 a	54 c	44 c	66 b
KZ6XSEL_Gardner	100 a	50 c	48 c	66 b
PUSTSEL_Gardner	100 a	50 c	44 c	65 b
Snowstorm_Gardner	100 a	50 c	44 c	65 b
Immigrant_Gardner	100 a	46 c	42 c	63 b
Rimrock	100 a	10 d	6 d	39 c
Gardner	100 a	8 d	6 d	38 c
Alkar_Gardner	100 a	13 d	0 d	38 cd
Alkar	100 a	0 d	0 d	33 cd
Rimrock_Gardner	67 b	6 d	4 d	26 d

[1]Values within each year followed by different letters are significantly different at *P*<0.05 as determined by LSD (0.05) values of 23.2, 17.2, 13.6, and12.3 in 2012, 2013, 2014, and 3-Yr Mean, respectively.

[2]Entries were transplanted in 16-plant (4x4) plots as monocultures or binary mixture with Gardner saltbush.

may explain why all these *grisea* entries had significant, or trends toward higher survival than Immigrant.

However, the difference in survival between Bozoisky II and Alkar tall wheatgrass suggest that drought, in addition to salinity, had a role in persistence. Tall wheatgrass is considered one of the most salt-tolerant perennial cool-season grasses, and is often included as a check in salt experiments (Rauser and Crowle 1962). In this study, Alkar tall wheatgrass was completely dead by the second year, as compared to nearly 100% survival of Bozoisky II. During the establishment year of 2011, precipitation was 124% of the long-term average; however, annual precipitation was only 76.7 mm, or just 33% of normal in 2012 (Figure 1). Undoubtedly, this drought had an effect upon the survival of both Rimrock Indian ricegrass and Alkar tall wheatgrass, both of which are considered moderately drought tolerant (Jensen et al. 2001), as compared to the highly drought tolerant Russian wildrye (Asay et al. 2003) and forage kochia (Waldron et al., 2010). It is not clear, what factors played a role in the death of Gardner saltbush, which is considered both salt and drought tolerant (Nord et al. 1971), but consistent with its recent lack of persistence at this site.

Transplant survival was usually negatively correlated with halogeton frequency within a year, but not on average across years (Table 4). In 2012, there were similar low negative correlations (-0.31 to -0.35) for the three intervals most proximal to the spaced plants, but a non-significant correlation at the 40-50 cm interval (Table 4). Conversely, in 2013 there was a moderate correlation at the closest 10-20 cm interval, and significant but low negative correlations at the other more distal intervals. In contrast, by 2014 survivorship had stabilized (Table 3), and the moderately high negative correlations

Table 4. Pearson correlations and *P*-values (in parenthesis) between transplant survival (percent living) and halogeton frequency in a space plant/halogeton competition study planted in 2011 near Manila, UT. Intervals are four 10 cm intervals distal to the transplant.

Intervals (cm)	2012	2013	2014	Across Years
10-20	-0.35 (0.0100)	-0.50 (0.0002)	-0.67 (0.0001)	-0.13 (0.0945)
20-30	-0.33 (0.0145)	-0.30 (0.0288)	-0.65 (0.0001)	0.02 (0.8384)
30-40	-0.31 (0.0258)	-0.37 (0.0071)	-0.64 (0.0001)	0.11 (0.1562)
40-50	-0.19 (0.1645)	-0.29 (0.0378)	-0.66 (0.0001)	0.17 (0.0359)
Average	-0.33 (0.0148)	-0.41 (0.0023)	-0.67 (0.0001)	0.05 (0.5482)

(-0.64 to -0.67) is reflective of both survivorship and individual entry competitive differences. Similar to our study, Cook (1965) reported that over a six year period, stands within plots of Russian wildrye increased while tall wheatgrass essentially died out. Cook (1965) attributed Russian wildrye's better persistence to being more adapted to low precipitation areas than tall wheatgrass, in addition to having moderate salt tolerance allowing it to persist on saline-alkali soils.

Competitive Effect on Halogeton Frequency. For halogeton frequency, Entry × Year and Interval × Year interactions were found to be significant (Table 2); therefore, analyses were done within year, and, as explained in the Methods section, ANCOVA was used to investigate the relationship between interval distances and years. The ANCOVA revealed that the Interval × Year interaction was largely due to a significant regression slope (differences among interval distances) in 2012, whereas, in 2013 and 2014 interval distance had no affect on halogeton frequency (slope was not significantly greater than zero). In 2012, the positive and significant regression slopes between halogeton frequency and interval distance suggest that the transplant's competitive effect on halogeton was reduced as the interval became more distal from transplant (Table 5). This is further verified by only three entries having significantly less halogeton than the control at the most distal interval of 40-50 cm, as compared to six, nine, and twelve significant entries at the 30-40, 20-30, and 10-20 cm intervals, respectively (Table 5). In contrast, the ANCOVA results for 2013 and 2014 indicate that by the second year, the competitive effect of the entries had already extended to at least 50 cm; therefore, differences among entries (species and cultivars within species) were more biologically

Table 5. Halogeton frequency in 2012 at four intervals (10-20, 20-30, 30-40, and 40-50 cm) distal from transplants in a spaced plant/halogeton competition study established in 2011 near Manila, UT.

Entry[2]	10-20 cm[1]	20-30 cm	30-40 cm	0-50 cm	Slope[3]	Intercept
Control	0.82 a	0.88 a	0.92 a	0.92 a	0.0333	0.8027
Gardner Saltbush	0.83 a	0.73 abcd	0.82 ab	0.80 ab	0.0000	0.7945
Rimrock	0.83 a	0.84 ab	0.92 a	0.96 a	0.0449	0.7751
Rimrock_Gardner	0.77 ab	0.83 ab	0.78 ab	0.89 ab	0.0333	0.7361
Alkar	0.76 ab	0.75 abc	0.85 ab	0.90 ab	0.0516	0.6861
Alkar_Gardner	0.70 abc	0.83 ab	0.86 ab	0.94 a	0.0744	0.6474
KZ6XSEL_Gardner	0.65 bcd	0.76 abc	0.78 ab	0.85 ab	0.0623	0.6025
PUSTSEL_Gardner	0.57 cde	0.67 abcde	0.73 ab	0.79 ab	0.0734	0.5082
SAHSEL_Gardner	0.52 de	0.59 cde	0.74 ab	0.80 ab	0.1001	0.4109
Immigrant_Gardner	0.45 ef	0.69 abcde	0.76 ab	0.87 ab	0.1317	0.3612
KZ6XSEL	0.41 efg	0.64 bcde	0.79 ab	0.88 ab	0.1560	0.2891
Snowstorm_Gardner	0.32 fgh	0.61 cde	0.72 b	0.81 ab	0.1561	0.2252
Immigrant	0.28 fghi	0.56 cde	0.79 ab	0.84 ab	0.1906	0.1417
SAHSEL	0.28 fghi	0.60 bcde	0.68 bc	0.81 ab	0.1659	0.1779
PUSTSEL	0.27 ghi	0.48 ef	0.71 b	0.72 bc	0.1556	0.1554
Snowstorm	0.25 ghi	0.53 de	0.71 b	0.78 ab	0.1762	0.1248
BozoiskyII_Gardner	0.19 hi	0.29 f	0.48 cd	0.57 cd	0.1333	0.0499
BozoiskyII	0.11 i	0.28 f	0.43 d	0.50 d	0.1323	0.0000

[1]Values within each 10 cm interval followed by different letters are significantly different at $P<0.05$as determined by LSD (0.05) values of 0.17, 0.22, 0.20, and 0.19 at 10-20, 20-30, 30-40, and 40-50 cm intervals, respectively.

[2]Entries were transplanted in 16-plant (4x4) plots as monocultures or binary mixture with Gardner saltbush.

[3]Regression lines were estimated by analysis of covariance and slopes were determined to be greater than zero and unequal among entries.

significant in reducing halogeton recruitment than the proximity of plants to the halogeton.

In 2013, average halogeton frequency dropped to 0.14 as compared to 0.68 and 0.46 in 2012 and 2014, respectively. This reduction in halogeton contributed to the Entry × Year interaction; however, was mainly in magnitude as ranking of entries was fairly consistent across years. The low 2013 halogeton frequency was most likely due to the 2012 drought (33% of normal, Figure 1) which would have resulted in less seed produced in 2012 and subsequent lower germination and seedlings in 2013.

Significant differences among entries, with the control always being in the group with the highest halogeton frequency, indicated differences in the competitive effect of entries (Table 6). Rimrock Indian ricegrass did not persist and was never more competitive than the control plot (Table 6). Conversely, Alkar tall wheatgrass and Gardner saltbush also did not persist past the first year, but had less halogeton than the control in the two subsequent years (Table 6). This residual competitive affect of Alkar and Gardner may suggest that future management plans could use seeded annuals to reduce halogeton frequency (in the short term).

Forage kochia and the Bozoisky II Russian wildrye were the most competitive entries, with an average 52% reduction in halogeton, in comparison to the control (Table 6). Bozoisky II started out the most competitive entry with the lowest halogeton in 2012, but by 2014 three forage kochia entries had surpassed the Russian wildrye cultivar with less halogeton frequency (Table 6). The most competitive entry, SAHSEL (ssp. *grisea*) an experimental forage kochia population (Waldron et al. 2005), reduced halogeton densities by 62% compared to the control over the 3-year average. The remainder forage

Table 6. Annual and three-year mean of halogeton frequency measured between 1-m spaced rows of a spaced plant/halogeton competition study established near Manila, UT in 2011. Values are the average frequency over four intervals (10-20, 20-30, 30-40, and 40-50 cm) distal from transplants. Table is sorted by 3-Yr Mean.

Entry[2]	2012[1]	2013	2014	3-Yr Mean
Rimrock	0.89 a	0.23 a	0.83 a	0.65 a
Control	0.89 a	0.22 a	0.84 a	0.65 a
Alkar_Gardner	0.83 ab	0.23 a	0.86 a	0.64 a
Alkar	0.82 ab	0.17 b	0.67 b	0.55 b
Gardner	0.79 ab	0.16 bcd	0.67 b	0.54 b
Rimrock_Gardner	0.82 ab	0.16 bc	0.53 bcd	0.50 bc
KZ6XSEL_Gardner	0.76 bc	0.13 bcde	0.61 bcd	0.50 bc
PUSTSEL_Gardner	0.69 cd	0.11 bcdef	0.49 cd	0.43 cd
Immigrant_Gardner	0.69 cd	0.11 def	0.40 def	0.40 cde
KZ6XSEL	0.68 cd	0.11 cdef	0.40 def	0.39 de
SAHSEL_Gardner	0.66 d	0.11 bcdef	0.39 def	0.39 de
Snowstorm_Gardner	0.62 de	0.08 f	0.38 def	0.36 def
Bozoisky II_Gardner	0.38 f	0.23 a	0.42 de	0.34 ef
Immigrant	0.62 de	0.07 f	0.29 efg	0.33 efg
Bozoisky II	0.33 f	0.16 bc	0.45 de	0.31 fg
Snowstorm	0.57 e	0.11 bcdef	0.21 gh	0.30 fg
PUSTSEL	0.54 e	0.08 f	0.25 fg	0.29 fg
SAHSEL	0.59 de	0.09 ef	0.06 h	0.25 g

[1]Values within each year followed by different letters are significantly different at $P<0.05$ as determined by LSD (0.05) values of 0.10, 0.06, 0.16, and 0.07 in 2012, 2013, 2014, and average over year, respectively.
[2]Entries were transplanted in 16-plant (4x4) plots as monocultures or binary mixtures with Gardner saltbush.

kochia entries, including cultivars Immigrant and Snowstorm, were not significantly different than SAHSEL, except for KZ-6XSEL (ssp. *grisea*) which was less competitive reducing halogeton by 40% as compared to the control (Table 6). In comparison, Stevens and McArthur (1990) reported a similar trend in a seven-year study in which halogeton plant density (plants m^{-2}) was reduced by 69% of the control by establishment of forage kochia. Their research measured the halogeton recruitment within seeded plots with higher forage kochia density (54 plants m^{-2}) than our spaced-plant study. In another study, Russian wildrye significantly reduced halogeton density over six years as compared to an increase within tall wheatgrass plots (Cook 1965), further verifying the competitive ability of Russian wildrye.

Binary mixtures with Gardner saltbush were established to determine if Russian wildrye and forage kochia could help in restoration of saltbush by competing with halogeton and thus promote Gardner saltbush growth and reproduction. As reported earlier, the Gardner saltbush transplants nearly completely died out after one year, resulting in 35% versus 52% reduction in halogeton frequency as compared to the forage kochia monocultures. Inasmuch as monoculture plots of Gardner saltbush also died, we cannot make conclusions from this study about the compatibility between these species and their ability to coexist.

Overall, these results indicate that forage kochia and Russian wildrye can persist in this harsh environment and can compete with halogeton, even at distances up to 50 cm distal from established plants. Snowstorm had slightly better survival than Immigrant forage kochia, but both were equally competitive. These results are in agreement with (Miller 1956; Monaco et al. 2003; Stevens and McArthur 1990) and further support that forage kochia and Russian wildrye may be management options for reclamation of halogeton invaded rangelands.

Experiment #2 - Establishment into Halogeton Monoculture (Seeded Plots)

Analyses revealed that Entry, Soil Treatment, and Entry × Soil Treatment were all significant for establishment of seeded entries (Table 7). The significant Entry × Soil Treatment interaction primarily was the result of rank changes that occurred as grass entries established better within the disked treatment; whereas, forage kochia entries established at a greater density under the no-till treatment (Table 8). For instance, Bozoisky II Russian wildrye final establishment was 4.5 and 1.7 plant m^{-2} compared to the average forage kochia establishment of 0.8 and 2.0 plants m^{-2}, in the disked and no-till treatments, respectively. Establishment into arid/saline sites typical of halogeton is often a difficult and slow process (Monsen 1992; Newhall et al. 2004), and this study was no exception with only 14, 13, and 11 of the possible 34 entry × soil treatment combinations significantly better than the control (no seeding) in 2011, 2012, and 2014, respectively (Table 8). The initial establishment in 2011 appeared to be very poor with only the Alkar tall wheatgrass and Bozoisky II Russian wildrye/disked treatments having greater than 25% frequency of establishment (Table 8). However, by 2013 Alkar had completely died, whereas the Bozoisky II/disked combination remained as one of the most successful treatments throughout the study. By 2014, plants had reached sufficient maturity that they could be more accurately counted, and 11 entry × soil treatment combinations with a plant density of 1.0 to 4.5 plants m^{-2} were determined to be better than the control (Table 8). Bozoisky II Russian wildrye (disked) (4.5 plants m^{-2}) and

Table 7. Significance of main and interaction effects (*P*-Values) and correlation of establishment of seeded plots and resulting halogeton recruitment from ANOVA using mixed-model analysis and split-plot design with six replications. Establishment of seeded entries and halogeton recruitment were measured from a seeded plot/halogeton competition study planted in 2010/2011 near Manila, UT. Unit of measurement varied each year and is shown in the table.

	2011		2013		2014	
Source[1]	Seeded	Halogeton	Seeded	Halogeton	Seeded	Halogeton
	- frequency -	- plants m^{-2} -	------- plants m^{-2} ------		- plants m^{-2} -	- rating -
Entry	0.0001	NS[2]	0.0001	NS	0.0001	0.0001
Soil Treatment	0.0449	0.0001	0.0041	0.0001	0.0049	NS
Entry × Soil Treatment	0.0003	NS	0.0001	NS	0.0001	NS
Correlation						
$R_{(seeded,\ halogeton)}$	0.07 (P=0.2992)		-0.35 (P=0.0001)		-0.56 (P=0.0001)	

[1]Source of variation included 18 entries, and 2 soil treatments (disked and no-till).
[2]NS = Not significant at *P*=0.05

Table 8. Entry × Soil Treatment establishment (disk vs. no-till) in a seeded plot/halogeton competition study planted in 2010/2011 near Manila, UT.

		Seed Plant Establishment[1]		
Entry	Soil Treatment	2011	2013	2014
		-- frequency --	---------- plant m^{-2} ----------	
Bozoisky II	disk	0.28 a	3.6 a	4.5 a
Immigrant	no-till	0.09 def	3.3 a	3.6 a
Immigrant_Gardner	no-till	0.06 efghi	2.1 b	2.2 b
KZ6XSEL_Gardner	no-till	0.03 ghij	1.7 bcd	2.1 bc
Bozoisky II_Gardner	disk	0.11 cde	1.6 bcd	1.8 bcd
KZ6XSEL	no-till	0.02 hij	1.7 bc	1.8 bcd
Bozoisky II	no-till	0.16 bc	1.3 cdef	1.7 bcde
Snowstorm	no-till	0.02 ghij	1.4 bcde	1.5 bcde
Immigrant	disk	0.02 hij	1.1 cdefgh	1.1 cdef
SAHSEL	no-till	0.01 hij	1.0 cdefghi	1.1 cdef
SAHSEL_Gardner	no-till	0.03 ghij	1.1 cdefg	1.0 defg
Bozoisky II_Gardner	no-till	0.08 defg	0.4 fghijk	1.0 defgh
KZ6XSEL	disk	0.01 hij	0.9 defghij	0.8 defgh
Snowstorm_Gardner	no-till	0.01 hij	0.9 cdefghij	0.8 efgh
SAHSEL	disk	0.01 hij	0.7 efghijk	0.7 efgh
Immigrant_Gardner	disk	0.02 hij	0.5fghijk	0.5 fgh
Snowstorm	disk	0.01 hij	0.3 ghijk	0.4 fgh
Snowstorm_Gardner	disk	0.00 hij	0.2 ijk	0.3 fgh
SAHSEL_Gardner	disk	0.00 ij	0.3 hijk	0.3 fgh
KZ6XSEL_Gardner	disk	0.00 ij	0.3 ghijk	0.2 fgh
Rimrock	disk	0.11 cde	0.2 ijk	0.2 fgh
Rimrock_Gardner	no-till	0.04 fghij	0.0 k	0.0 gh
PUSTSEL_Gardner	no-till	0.00 j	0.1 jk	0.0 gh
Gardner	no-till	0.00 j	0.0 k	0.0 h
Rimrock_Gardner	disk	0.09 def	0.3 hijk	0.0 h
Alkar	disk	0.28 a	0.0 k	0.0 h
Rimrock	no-till	0.06 defgh	0.0 k	0.0 h
PUSTSEL	disk	0.00 ij	0.0 k	0.0 h
Control	disk	0.00 j	0.0 k	0.0 h
Alkar_Gardner	disk	0.19 b	0.0 k	0.0 h
Alkar	no-till	0.16 bc	0.0 k	0.0 h
PUSTSEL	no-till	0.00 j	0.1 jk	0.0 h
PUSTSEL_Gardner	disk	0.00 j	0.0 k	0.0 h
Gardner	disk	0.00 j	0.0 k	0.0 h
Alkar_Gardner	no-till	0.12 cd	0.0 k	0.0 h
Control	no-till	0.00 j	0.0 k	0.0 h

[1]Values within each year followed by different letter are significantly different $P<0.05$ as determined by LSD (0.05) values based upon standard error of the entry x soil treatment means and were 0.06, 0.08, and 1.0 in 2011, 2013, and 2014 average within year, respectively.

Immigrant forage kochia (no-till) (3.6 plants m^{-2}) had greater ($P < 0.05$) establishment than all other entry/treatments (Table 8). Conversely, PUSTSEL forage kochia did not establish (Table 8), but was seeded using year-old cold-stored seed with low viability, which has been documented to result in low forage kochia germination and establishment (Creech et al. 2013). Thus, PUSTSEL seeding failure appeared to be more due to forage kochia/seed storage issues and not a reflection of potential variability among forage kochia entries and is not discussed further. Rimrock Indian ricegrass and Gardner saltbush did not establish via seed (Table 8).

The Entry × Soil Treatment affect was not significant for halogeton recruitment, and, for the most part, neither was Entry (except in 2014) (Table 7). It is probable that the low establishment and the immaturity of the few perennial seedlings (mostly less than 4 plants m^{-2}) within the seeding resulted in the non-significant Entry affect on halogeton in 2011 and 2013. However, as seedlings progressed to more mature plants, they began to reduce halogeton frequency, as evidenced by successive correlations between seeded entry establishment and halogeton recruitment of 0.07 (NS), -0.35 (P=0.0001), and -0.56 (P=0.0001) in 2011, 2013, and 2014, respectively. Given this trend combined with the results from our spaced-plant study, it could be expected that those established Russian wildrye and forage kochia plants will become even more competitive with the halogeton over time. In contrast, Soil Treatment had an initial influence on halogeton recruitment, with 2011 halogeton frequency in the disked treatment less than 50% compared to the no-till, but this effect had dissipated by 2014 to no difference between disked and no-till treatments (Table 9). These results suggest that tillage such as disking can reduce initial

Table 9. Establishment of seeded plots and corresponding halogeton in a seeded plot halogeton competition study planted in 2010/2011 near Manila, UT. Gardner saltbush did not establish in this study. Table is sorted by 2014 seeded plant establishment.

	Seeded Plant Establishment[1]			Halogeton Establishment		
Entry[2]	2011	2013	2014	2011	2013	2014
	- frequency -	--- plants m^{-2} ---		---- plant m^{-2} ----		- rating -
Bozoisky II	0.22 a	2.4 a	3.1 a	23.0	4.2	6.8 defgh
Immigrant	0.05 def	2.2 a	2.4 b	21.1	4.0	4.7 i
KZ6XSEL_Gardner	0.01 fg	1.0 bc	1.7 cde	22.7	4.7	6.7 efgh
Bozoisky II_Gardner	0.09 c	1.0 bc	1.4 c	20.0	4.7	7.0 cdefgh
Immigrant_Gardner	0.04 efg	1.3 b	1.3 cd	18.5	3.5	6.4 gh
KZ6XSEL	0.02 fg	1.3 b	1.3 cd	18.0	3.8	6.8 defgh
Snowstorm	0.02 fg	0.8 bc	1.0 cde	16.0	3.4	6.5 fgh
SAHSEL	0.01 g	0.8 bc	0.9 cde	24.2	4.7	6.2 h
SAHSEL_Gardner	0.01 fg	0.7 cd	0.6 ef	18.9	4.5	7.4 bcdefg
Snowstorm_Gardner	0.01 g	0.6 cde	0.6 ef	21.3	4.4	7.6 abcdef
Rimrock	0.09 cd	0.1 de	0.1 f	21.6	4.6	7.9 abcd
Rimrock_Gardner	0.07 cde	0.1 de	0 f	17.7	5.1	7.8 abcde
PUSTSEL_Gardner	0 g	0 e	0 f	21.3	5.2	7.9 abcde
Alkar	0.22 a	0 e	0 f	26.1	5.2	8.1 abc
Alkar_Gardner	0.16 b	0 e	0 f	22.4	4.7	8.1 abc
PUSTSEL	0 g	0 e	0 f	17.9	5.2	8.6 a
Control	0 g	0 e	0 f	25.6	5.7	8.3 ab
Gardner	0 g	0 e	0 f	22.6	5.4	8.1 abc
LSD (0.05)	0.04	0.6	0.7	NS	NS	1.2
Soil Treatment						
disk	0.06 a	0.6 b	0.6 b	13.6 b	5.1 a	7.4
No-till	0.05 b	0.8 a	0.9 a	28.5 a	4.1 b	7.2
LSD (0.05)	0.01	0.2	0.2	2.6	0.5	NS

[1]Values within each year followed by different letter are significantly different at $P<0.05$. LSD (0.05) values are based upon the variation associated with Entry and Soil Treatment mean.
[2]Entries were seeded in 1.5 m x 3.0 m plots as monocultures or binary mixture with Gardner saltbush.

halogeton stands, but as seen in this study, this effect could be short-lived without rapid and successful establishment of perennials.

These results suggest that reclamation of halogeton-infested rangelands will require using the most hardy, easiest establishing plant materials available. Previous authors have reported that Immigrant forage kochia is one of few species that can establish in the presence of some noxious annual weeds currently becoming more dominant on salt-desert shrublands (Monaco et al. 2003; Newhall et al. 2004; Waldron et al. 2010). The results also suggest that an intermediate step of re-establishing perennials like forage kochia and Russian wildrye may be necessary before Gardner saltbush can be restored to its native rangeland.

MANAGEMENT IMPLICATIONS

A large component of rangeland management has always focused on change caused by multiple sources of disturbances such as fire, overgrazing, drought, or recreational activities; and one such negative ramification of disturbance is the onset of noxious and invasive weeds, such as halogeton. It is reported that weeds on rangelands result in an economic loss of at least $2 billion annually, more than all other pests combined (DiTomaso 2000). Areas dominated by such noxious annual weeds normally require intensive site preparation to reduce competition and enhance success of plantings with the hope that these species will persist (Evans and Young 1984). However, many soils in the salt desert shrublands exhibit characteristics such as high sodium, salinity, and alkalinity making it difficult to establish and sustain any perennial vegetation, native or introduced. The need exists to identify species that will establish and persist, allowing successful reclamation and restoration of these environments that are affected by low precipitation, salinity/alkalinity, and the competitive effects of invasive annual weeds. Our study evaluated plant material with documented drought and salt tolerance.

Our results showed that two species, forage kochia and Russian wildrye, were capable of establishing and persisting in this harsh environment; whereas, it also indicated that direct restoration of Gardner saltbush and Indian ricegrass will not be successful. However, even with these hardy species, establishment was a slow process and was originally considered a failure. Our study also uniquely documented the competitive effect of these species by simulating fully established, widely spaced plants. Previous studies had suggested that Russian wildrye and forage kochia may establish and compete with halogeton, but the needed plant density was not known nor, how quickly a competitive effect would be observed. It is of interest to note that the plant density of our spaced-plant study (2 plants m^{-2}) was well within the density range achieved by these species in the seeded study (2 to 4.5 plants m^{-2}), further validating the competition results. Two years following transplanting, the competitive effect of forage kochia and Russian wildrye had extended from 10 to 50 cm distal from the plants. This indicates that even with the low density of plants achieved in the seeded study (2 to 4 plants m^{-2}), halogeton will be reduced/eliminated once the plants reach maturity. Forage kochia was originally introduced to the U.S. to compete with the noxious, invasive and poisonous annual halogeton in salt desert environments (Young and Clements 2004), and both cultivars, Immigrant and Snowstorm, established (seeded study) and persisted and competed (spaced plant study) with halogeton. Bozoisky II Russian wildrye, known for being highly drought tolerant and moderately salt tolerant, also established, persisted, and competed with halogeton. Forage kochia demonstrated a slight advantage over Russian wildrye in the no-till planting, whereas, Russian wildrye establishment was more successful when disking occurred before planting. This knowledge will provide viable options for land managers considering reclaiming and planting salt desert landscapes that have become infested with halogeton. Indian ricegrass, tall wheatgrass, and Gardner saltbush do not appear to be options for initial reclamation efforts. It is noteworthy that volunteer Gardner saltbush seedlings began to appear by the end of this study in the plots that had reduced halogeton, suggesting that restoration may be successful after controlling halogeton.

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