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Effect of Forage Kochia on Seedling Growth of Cheatgrass (*Bromus tectorum*) and Perennial Grasses

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Note

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Abstract

Forage kochia [*Bassia prostrata* (L.) A. J. Scott] is competitive with annual weeds and has potential for use in reclamation of disturbed land. However, land managers are reluctant to use forage kochia in revegetation programs due to lack of understanding of its compatibility with or invasiveness in the native plant community. We conducted two greenhouse experiments, one to compare the competitive effect of forage kochia versus perennial grasses on growth of cheatgrass (*Bromus tectorum* L.) and one to study the effect of forage kochia on growth of native perennial grasses. In the first experiment, a single seedling of *B. tectorum* was grown with increasing neighbor densities (0 to 5 seedlings pot^{-1}) of either forage kochia, crested wheatgrass [*Agropyron cristatum* (L.) Gaertner × *A. desertorum* (Fisch. ex Link) Schultes; nonnative perennial grass], or thickspike wheatgrass [*Elymus lanceolatus* (Scribn. & J. G. Sm.) Gould; native perennial grass]. *Bromus tectorum* growth was reduced moderately by all three perennial neighbors, but *A. cristatum* and *E. lanceolatus* had more effect on *B. tectorum* when compared with forage kochia. This experiment was repeated and similar results were observed. In the second experiment, forage kochia was grown with each of four native cool-season grass species: basin wildrye [*Leymus cinereus* (Scribn. & Merr.) Á. Löve], bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) Á. Löve], *E. lanceolatus*, and western wheatgrass [*Pascopyrum smithii* (Rydb.) Á. Löve]. Forage kochia had no effect on height, tiller number, and aboveground biomass of native grasses. Similarly, native grasses did not show a significant effect on forage kochia seedlings. This experiment was also repeated, and forage kochia somewhat reduced the aboveground biomass of *L. cinereus* and *P. spicata*. However, all native grasses significantly reduced change in height, branching, and aboveground biomass of forage kochia. These results suggest that forage kochia interfered with *B. tectorum* seedling growth, but it showed little competitive effect on native grass seedlings.

Introduction

A major threat to the western rangelands is invasion by exotic weeds. Overgrazing, drought (Brooks and Pyke 2001; O'Connor 1991; Pyke 1999), wildfire (Young and Evans 1978), and disturbance for energy development opened the landscape for further spread of invasive exotic species (Copeland et al. 2011). Cheatgrass (*Bromus tectorum* L.) is one of the highly invasive species in the United States (Knapp 1996; Mack 2011; Menalled et al. 2008). It is the dominant species on about 20 million hectares in the western United States (Bradley and Mustard 2005). Abundant soil seed reserve (Young et al. 1969), early germination pattern (Menalled et al. 2008; Young et al. 1969), better uptake of soil moisture (Knapp 1996) and nitrogen (Blank and Morgan 2011; Lowe et al. 2003), promotion of grass-fire cycle, and tolerance to fire regimes (Belnap and Phillips 2001; Bolton et al. 1993; Brandt and Rickard 1994; Brooks et al. 2004; Hulbert 1955; Stewart and Hull 1949; Young et al. 1987) contribute to competitive advantage and dominance of *B. tectorum* over native vegetation. *Bromus tectorum*–dominated areas can be restored by establishing and maintaining stands of robust perennial forage species (Asay et al. 2001; Cronin and Williams 1966; Thompson et al. 2006; Whitson and Koch 1998). Forage kochia [*Bassia prostrata* (L.) A. J. Scott] is a promising forage species for restoring annual weed–infested areas.

Forage kochia is a desirable perennial species for greenstripping (Clements et al. 1997; Harrison et al. 2002; Monsen 1994; Pellant 1990), reclamation of drastically disturbed areas, and forage production during fall and winter seasons in the semiarid rangelands (Harrison et al. 2000, 2002; Keller and Bleak 1974; McArthur et al. 1974; Sullivan et al. 2013). It is a drought- and salt-tolerant species (Keller and Bleak 1974; Stevens et al. 1985) that can compete with annual exotic weeds such as halogeton [*Halogeton glomeratus* (M. Bieb.)

Management Implications

Previous reports suggest that forage kochia (*Bassia prostrata*) can compete with annual weeds. However, there are no reports comparing competitive ability of forage kochia with other potential perennial native or nonnative species. Our study investigated whether forage kochia could compete with *Bromus tectorum* (cheatgrass), an invasive annual weed, better than potential perennial grasses such as *Agropyron cristatum* (crested wheatgrass; nonnative) and *Elymus lanceolatus* (thickspike wheatgrass; native). Although forage kochia seedlings moderately competed with *B. tectorum*, perennial grass seedlings reduced *B. tectorum* growth more than forage kochia at the seedling stage. There is a concern that forage kochia may compete with native perennials. To address this, we also conducted a greenhouse experiment and observed that forage kochia has little to no effect on the growth of native perennial grass seedlings. On the contrary, native grass seedlings negatively influenced the growth of forage kochia seedlings. This is important, because it shows that forage kochia seedlings compete with *B. tectorum*, but not with native grass seedlings. Forage kochia has been considered a potentially important forage and reclamation species, and our study shows the potential for future field-based research to more fully explore forage kochia and its competitive ability against *B. tectorum* and its compatibility with native perennials.

C. A. Mey.] (Stevens and McArthur 1990), *B. tectorum* (McArthur et al. 1990; Monsen and Turnipseed 1990), and saltwort (*Salsola kali* L.) (Koch and Asay 2001). Generally, it can be seeded either in late fall, winter, or early spring. Forage kochia emerges in the early spring and competes with invasive weeds such as *B. tectorum* for soil moisture (Monaco 2004).

In spite of the benefits of forage kochia, there is a concern that it may outcompete native plants and spread into native rangelands, perhaps because nonnative plants establish and spread in new areas by acquiring resources faster than native plants (Levine et al. 2003; Rees et al. 2001). Forage kochia spreads in most unseeded areas adjacent to seeded areas (Blauer et al. 1993; Gray and Muir 2013; Harrison et al. 2000). However, many researchers have suggested forage kochia is not invasive in perennial plant communities (Harrison et al. 2000, 2002; Monaco et al. 2003; Pendleton et al. 1992; Waldron et al. 2010). Nevertheless, there is limited information available on its competitiveness with native species (Harrison et al. 2000; Monaco et al. 2003). Further investigations of potential interactions of forage kochia with native perennial grasses will augment the existing literature and help land managers decide whether to use it for reclamation or as a forage species. Therefore, the specific objectives of this study were: (1) to compare the effect of forage kochia versus perennial cool-season grasses on *B. tectorum* seedling growth and (2) to evaluate the effect of forage kochia on native perennial cool-season grasses during the seedling stage.

Materials and Methods

Greenhouse experiments were conducted at the Laramie Research and Extension Center greenhouse complex, Laramie, WY, from January 2014 to February 2015. The air temperature was maintained at approximately 24 C during daytime and 18 C during nighttime. There was no supplemental lighting.

Bromus tectorum Study

The target-neighbor design (Gibson et al. 1999; Goldberg and Fleetwood 1987) was used to determine competitive ability of neighbor species against a target species. In this study, the target species was *B. tectorum* and neighbor species included 'Immigrant' forage kochia (nonnative perennial subshrub), 'Critana' thickspike wheatgrass [*Elymus lanceolatus* (Scribn. & J. G. Sm.) Gould; native perennial grass], and 'Hycrest' crested wheatgrass [*Agropyron cristatum* (L.) Gaertner × *A. desertorum* (Fisch. Ex Link) Schultes; nonnative perennial grass].

Bromus tectorum and three neighbor species were sown into black plastic propagation trays (53-cm length by 28-cm width by 5-cm height) with drainage holes on January 11, 2014. Before seeding, trays were filled to within 2.5 cm of the rim with the greenhouse potting media (mixture of one part sand and two parts media containing peat moss, vermiculite, and rice hulls). Seedlings were transplanted into 1.5-L pots (15-cm deep) at 2 wk after seeding. Each neighbor species was transplanted in increasing densities (0, 1, 2, 3, 4, or 5 seedlings pot^{-1}) equidistant around 1 target seedling planted in the center of the pot. Before transplanting, pots were filled with greenhouse potting media (Table 1). During the first week of transplanting, dead seedlings were replaced by new seedlings of the same age. Eighteen treatments (3 neighbor species by 6 densities), each replicated six times, were arranged in a completely randomized design (CRD). Pots were given approximately 150 ml water on alternate days, but no fertilizer was applied. The pots were rearranged biweekly to minimize microenvironmental effects in the greenhouse. Tiller number and height of *B. tectorum* plants were measured at 2 wk after transplanting and before harvesting. Grass shoots with at least 3 leaves were counted as tillers. The plant height was taken from the soil surface to the extended tip of the longest live grass leaf. The difference between initial values (2 wk after transplanting) and final values (before harvesting) for tiller number and plant height were response variables. Aboveground plant parts were harvested on March 23, 2014, oven-dried for 48 h at 60 C, and weighed to determine *B. tectorum* dry biomass.

The same design and methods were used for the repeated study conducted during fall 2014; however, Laramie field soil (fine-loamy, mixed, Borollic Haplargids; Table 1) was used instead of greenhouse potting media. All species were seeded on September 28, 2014, and transplanted into 1.5-L pots at 2 wk after seeding. Aboveground shoots were harvested on January 13, 2015.

Statistical analyses were conducted separately for each study using SAS software (SAS institute 2014). For testing the relationships between *B. tectorum* growth parameters and neighbor

Table 1. Properties of potting media used in greenhouse experiments.

	Soil type	
Soil properties	Greenhouse potting media	Laramie field soil
pH	6.0	7.3
Soluble salts (mmho cm^{-1})	0.92	0.32
Organic matter (%)	10.1	2.3
Nitrate-nitrogen (mg kg^{-1})	113	0.5
Phosphorus (mg kg^{-1})	76	15.9
Potassium (mg kg^{-1})	187	452

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density within each neighbor species, regression analysis (r^2) was determined using PROC REG, and linear-regression models were fit based on residual plots (scatter plot of residuals vs. neighbor density variable). An analysis of covariance (ANCOVA) was used to compare slopes of three regression lines using PROC GLM.

Native Grass Study

Four native perennial grasses: 'Anatone' bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) Á. Löve], 'Magnar' basin wildrye [*Leymus cinereus* (Scribn. & Merr.) Á. Löve], 'Critana' *E. lanceolatus*, and 'Rosana' western wheatgrass [*Pascopyrum smithii* (Rydb.) Á. Löve] were used to study their interaction with Immigrant forage kochia. In this study, treatments consisted of forage kochia grown alone, each of four native grasses grown alone, and one individual of each native species grown with one individual forage kochia seedling. Treatments were arranged in a CRD with five replicates. All treatments were established by sowing seeds in respective pots on June 13, 2014, and seedlings in individual pots were thinned to the desired number of plants for each treatment on June 28, 2014. Pot arrangement, watering, and fertilization were done following the same procedures described earlier. Plant height, number of branches (forage kochia), and tiller number (grass) were measured after thinning (June 28, 2014) and before harvesting. Plant height was measured from the pot soil surface to the top of forage kochia main stem or the extended tip of longest live grass leaf. A tiller was a grass shoot with at least 3 leaves. The differences between initial (after thinning) and final data (before harvesting) were considered as response variables for respective parameters. No mortality was observed during the study period. Aboveground biomass was harvested on October 28, 2014, oven-dried for 48 h at 60 C, and weighed to determine dry biomass. The study was repeated using the same design. Planting was done on November 1, 2014, and thinning occurred on November 15, 2014. Laramie field soil was used instead of greenhouse potting media in the second study period (Table 1). The study was harvested on February 16, 2015.

Statistical analyses were conducted separately for each study using PROC GLM in SAS software (SAS institute 2014). Forage kochia plant characteristics and aboveground biomass data were subjected to statistical analysis using a CRD. A two-group t test ($\alpha = 0.05$) was conducted for comparison within each native species when grown with and without the forage kochia companion.

Results and Discussion

Bromus tectorum Study

Results from Study 1 showed that change in height of *B. tectorum* (Δheight) was significantly influenced by different neighbor densities of forage kochia and *E. lanceolatus*, but not by neighbor densities of *A. cristatum* (Figure 1A1). However, ANCOVA analysis showed that the slopes of three regression lines were not significantly different ($P > 0.05$), and there were no differences in *B. tectorum* Δheight among these three neighbor species. In Study 2, *B. tectorum* Δheight was reduced by increasing density of *A. cristatum* and *E. lanceolatus*, but not forage kochia Figure 1A2). The slopes differed ($P < 0.05$) across three regression lines. *Agropyron cristatum* and *E. lanceolatus* appeared more effective in reducing *B. tectorum* height than forage kochia. Linear regression analyses showed that increase in *B. tectorum* tiller number (Δtiller) was negatively related to neighbor density of all neighbor species (Figure 1B1 and B2). However, the slopes of three regression lines were not significantly different ($P > 0.05$) in Study 1, but were different ($P = 0.05$) across three regression lines in Study 2. The change in *B. tectorum* tiller number was lower when grown with each perennial grass than when grown with forage kochia. In both studies, regression analyses showed that the effect of neighbor density on *B. tectorum* shoot biomass was significant for all neighbor species (Figure 1C1 and C2). These three slopes were not different ($P > 0.05$), and pairwise comparisons among neighbor species showed that forage kochia was not as effective in reducing *B. tectorum* shoot biomass as the two grasses.

These two greenhouse experiments used different potting media (potting soil in Study 1 and field soil in Study 2). Any differences in plant growth responses between these two studies may be attributed to differences in soil characteristics of these potting media, especially nitrogen availability (Table 1). Overall, the results from the two greenhouse experiments indicate that increasing density of each neighbor species (up to 5 seedlings pot^{-1}) around a *B. tectorum* seedling reduced *B. tectorum* seedling growth. However, no mortality of *B. tectorum* seedlings was observed in any case during this period (8 wk in Study 1 and 13 wk in Study 2) under regular watering conditions. *Bromus tectorum* has relatively rapid shoot and root growth with many fine rootlets that give it a competitive advantage over slow-growing seedlings of perennial plants (Aguirre and Johnson 1991; Cline et al. 1977; Evans 1961; Harris 1977). The greater neighbor density likely resulted in more rapid depletion of water and nutrients from the soil compared with when *B. tectorum* was grown alone. The results of this study indicate that these neighbor species in their initial growth stages slightly reduced *B. tectorum* seedling growth in the greenhouse. However, established or mature stands of these perennial species may have long-term or even greater ability to suppress *B. tectorum* seedling growth in field conditions (Buman et al. 1998; Humphrey and Schupp 2004; McGlone et al. 2011). Davies and Johnson (2017) reported that established perennial vegetation was effective in limiting reinvasion by exotic annual grasses.

Forage kochia has been considered a candidate for competing with aggressive exotic weeds such as *B. tectorum* (McArthur et al. 1990; Monaco 2004; Monaco et al. 2003; Stevens et al. 1985; Young and Clements 2004). Forage kochia seedlings can form a small rosette of leaves and accelerate root growth by preferentially partitioning energy into the root system (Harrison et al. 2000), thereby being able to survive in stressful environmental conditions such as weed competition or water stress. The results from the greenhouse studies indicate that presence of forage kochia, even in its seedling stage, tends to negatively affect *B. tectorum* seedling growth. However, the effect of forage kochia seedlings on *B. tectorum* was less than that of *E. lanceolatus* and *A. cristatum*, likely due to greater interference of the fibrous root system of neighbor grass species compared with the single taproot of forage kochia seedlings. Moreover, relatively small forage kochia seedlings were more likely to be influenced by the shading effect of lateral tillers of *B. tectorum* (Evans 1961). Davies and Johnson (2017) also reported that established *A. cristatum* limited exotic annual grasses more than forage kochia. Previous studies also found that native or nonnative perennial cool-season grasses were effective for *B. tectorum* control (Davies and Johnson 2017; Rose et al. 2001; Whitson and Koch 1998). In field conditions near Riverside, WY, Whitson and Koch (1998) found that *E. lanceolatus* was not as effective for *B. tectorum* control as Hycrest *A. cristatum*.

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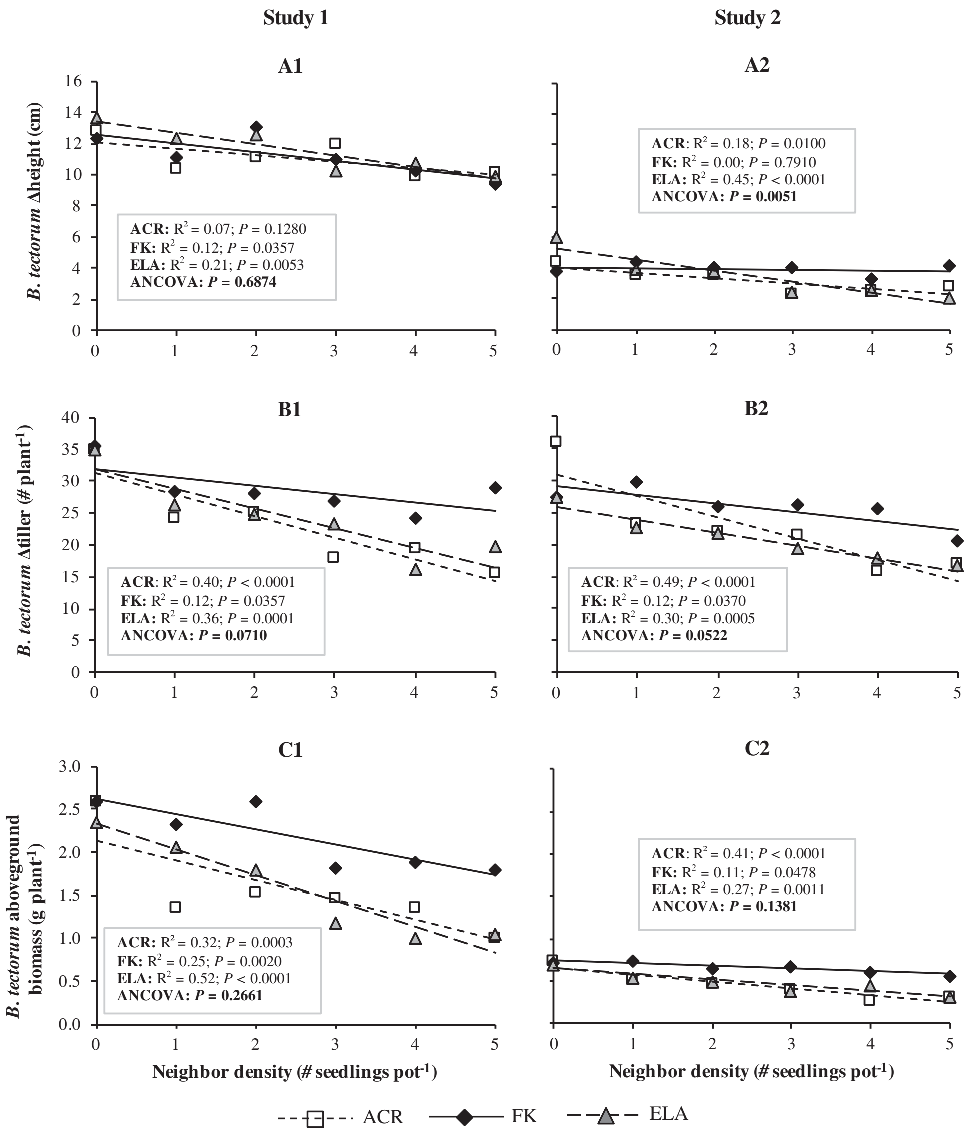

Figure 1. Regression analyses to determine the effects of neighbor species and neighbor densities on growth parameters of *Bromus tectorum* (change in height [Δheight], change in tiller number [Δtiller], and aboveground biomass) in two greenhouse studies. ACR, *Agropyron cristatum*; FK, forage kochia; ELA, *Elymus lanceolatus*. ANCOVA P-values (for equality of slopes) are also included.

While aggressive *A. cristatum* was shown to be strongly competitive against *B. tectorum*, it also has the tendency to reduce native plant diversity and form monotypic stands (Asay et al. 2001; Henderson and Naeth 2005; Hull and Klomp 1967; Nafus et al. 2015). In the present greenhouse studies, the overall effects of *E. lanceolatus* and *A. cristatum* on *B. tectorum* seedling growth did not seem to differ from each other.

Native Grass Study

There were no significant ($P > 0.05$) effects of a forage kochia seedling on the growth parameters (change in height, tiller, shoot biomass) of any native species in Study 1 (Figure 2). In Study 2, change in grass height and biomass of *P. spicata* and only biomass of *L. cinereus* were reduced when grown with forage kochia, but forage kochia seedlings did not influence the tiller number of any grasses. Overall results indicate that forage kochia seedlings did not interfere with seedling growth of these native perennial grasses during the study period (12 wk in Study 1 and 16 wk in Study 2). Previous reports also support that forage kochia can be sown in a mixture with perennials (Stevens et al. 1985; Stevens and McArthur 1990) and does not preclude reestablishment of native perennials in rangelands (Clements et al. 1997; Harrison et al. 2000). Likewise, forage kochia stands do not appear to reduce the density of established perennial species (Stevens et al. 1985) and do not demonstrate an invasive nature in perennial plant communities (Harrison et al. 2000, 2002; Monaco et al. 2003; Pendleton et al. 1992; Waldron et al. 2010).

In Study 1, there were no significant differences in forage kochia change in plant height, branching, and shoot biomass when forage kochia was grown with and without a native perennial grass companion (Figure 3). In Study 2, change in height of forage kochia was significantly lower when grown with each native grass seedling, except *P. smithii*, and the effects of *E. lanceolatus*, *L. cinereus*, and *P. spicata* on forage kochia height were similar. There was a significant effect of native grass on forage kochia branching. Branching was greatest when forage kochia was grown alone, followed by when it was grown with *P. smithii*.

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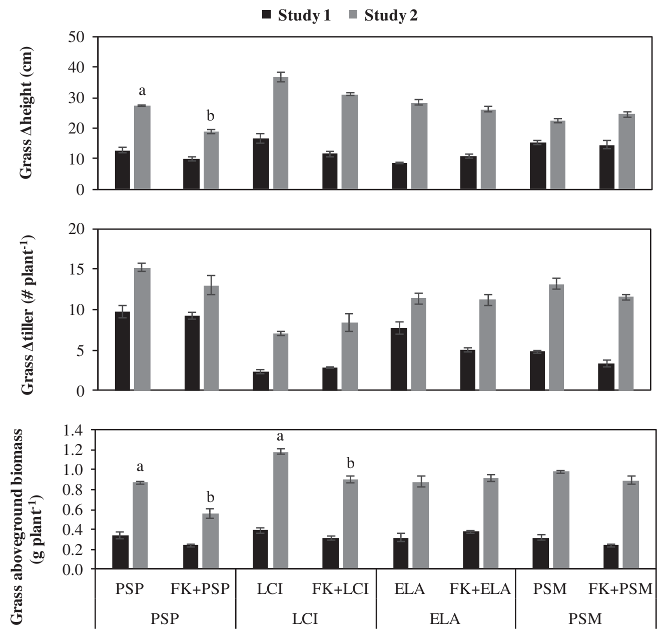

Figure 2. Effects of forage kochia companion on growth parameters of grasses (change in height [Δheight], change in tiller number [Δtiller], and aboveground biomass) in two greenhouse studies. For each native grass species within a study, means (±SEs) with different letters are significantly different ($P < 0.05$). PSP, *Pseudoroegneria spicata*; LCI, *Leymus cinereus*; FK, forage kochia; ELA, *Elymus lanceolatus*; PSM, *Pascopyrum smithii*.

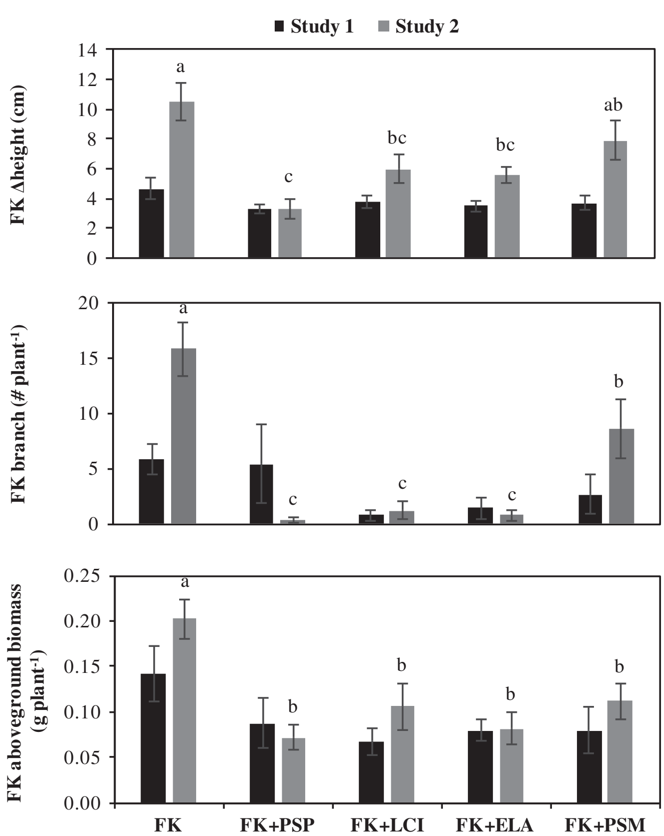

Figure 3. Effects of native grass companion on growth parameters of forage kochia (change in height [Δheight], branching, and aboveground biomass) in two greenhouse studies. Means (±SEs) with different letters within a study are significantly different ($P < 0.05$). PSP, *Pseudoroegneria spicata*; LCI, *Leymus cinereus*; FK, forage kochia; ELA, *Elymus lanceolatus*; PSM, *Pascopyrum smithii*.

The other three native grasses drastically reduced the branching of forage kochia. Similarly, forage kochia shoot biomass was also significantly lower when grown with each native grass seedling than when grown alone. All native grasses were similar in reducing forage kochia shoot biomass.

The results from this study indicate that these native grasses negatively affect forage kochia branching and shoot biomass. In general, perennial grasses develop a fibrous root system that is likely able to occupy more soil volume and thus acquire more moisture and nutrients within the pot environments compared with the single slender taproot system of forage kochia in its early growth stage. In the present studies, competition for light was unlikely because of the relatively small seedling size. Although the mechanism of competition was not directly examined, seedlings within each pot were likely competing for nutrients, because the pots were not fertilized during the experiment and watering may have leached existing nutrients from the soil. In a study by Aerts et al. (1991), a major proportion of biomass of a perennial grass, moorgrass [*Molinia caerulea* (L.) Moench], was allocated to its roots, and this extensive root system gave it a competitive advantage over two evergreen shrubs [*Calluna vulgaris* (L.) Hull and *Erica tetralix* L.]. According to Li et al. (2006), the extent of root distribution and density of a species influence the ability of other species to take up resources from the soil. Rate of nutrient uptake of a plant can influence its competitive ability in different soil environments (Casper and Jackson 1997). However, root growth and comparative ability of roots to take up soil moisture or nutrients were not studied in the current experiments. Overall, forage kochia did not appear to compete with native grasses at the seedling stage.

Forage kochia has been considered a potential perennial species to control *B. tectorum* in semiarid rangelands. The greenhouse studies showed that the seedlings of forage kochia and cool-season grasses have a negative impact on *B. tectorum* growth parameters, and the presence of high densities of these species increases the negative impact on *B. tectorum*. The native grass *E. lanceolatus* in its seedling stage also showed promise for reducing *B. tectorum* seedling growth. Reduction of forage kochia growth in the presence of native perennial grasses indicates that forage kochia seedlings are unlikely to limit the growth of native seedlings. Although these studies used two types of potting media (greenhouse potting mixture and actual field soil), detailed field experiments should be conducted to better elucidate the effectiveness of forage kochia and *E. lanceolatus* or other desirable perennial species in annual weed–dominated areas.

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