

Bouteloua gracilis Competition with *Salsola iberica* in
Shortgrass Prairie Rangelands

By

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Abstract

Invasive annual species are a major concern in rangelands, especially in areas such as the shortgrass prairie, where patches of bare soil are common. Competition between blue grama (*Bouteloua gracilis*), a dominant grass, and various invasive species has been studied with regard to nutrient availability and temperature regimes, but very few studies have been conducted focusing on weed density. This thesis reports on research exploring the effect of Russian thistle (*Salsola iberica*) density on *B. gracilis* biomass in the Southern Great Plains Shortgrass Prairie. This relationship was explored via a glasshouse experiment and a field experiment. Density ratios of *B. gracilis* to *S. iberica* were 1:0, 1:1, 1:2, 1:3, 1:4, and 0:1 individuals of *B. gracilis* to *S. iberica*, respectively. In the glasshouse study, *S. iberica* presence reduced *B. gracilis* biomass from 12.13g to 2.31g-2.80g, while varying density had no effect. *Salsola iberica* also displayed higher intraspecific competition than interspecific. In the field study, neither *S. iberica* presence nor density affected *B. gracilis* biomass. However, *B. gracilis* reduced average individual *S. iberica* biomass by 65.9%. In addition, *S. iberica* did not display intraspecific competition. Future research should continue to study the effect of *S. iberica* density on *B. gracilis* to identify the *S. iberica* density level at which *B. gracilis* is affected and should focus on *S. iberica* establishment and dispersion cycles in *B. gracilis* dominant rangelands on a landscape scale.

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Chapter I

Introduction

In the Southern High Plains, as well as much of the shortgrass prairie, blue grama (*Bouteloua gracilis*) is a dominant species and a major source of forage for livestock, especially cattle (Harlan 1958; Anderson 2003; Wynia 2007). It occurs throughout the Great Plains, thriving even in drought prone areas, and while it is known to have a high drought tolerance (Dormaar et al. 1994; USDA 2002; Anderson 2003; Wynia 2007), little is known about how *B. gracilis* competes with other species, such as introduced annuals. Areas like the Texas high plains and the shortgrass prairies of the US are continually in or recovering from drought (Dunn et al. 2013). Many times, the years of average precipitation are far enough apart that the land does not have time to recover before plunging into another stretch of drought. Frequent droughts cause such systems to be ideal for annual invasive species such as Russian thistle (*Salsola iberica*) (Eck and Sims 1984). Invasives like *S. iberica* tend to accumulate during droughts when competition with other species is low, and then can cause problems for post-drought recovery (Allen 1982b). Because the high plains experiences frequent drought and because annual weeds can be plentiful in native rangelands during and immediately after drought, it is important to know how *B. gracilis* competes with these plants. By having a greater knowledge of *B. gracilis* and invasive annual competitive interactions, rangeland managers can better predict the condition and proper use of an area.

BOUTELOUA GRACILIS BACKGROUND

Distribution

Bouteloua gracilis is a warm-season native perennial C₄ species that acts as a bunchgrass in arid and semi-arid prairie regions and as a sod forming grass in mountain

areas, under heavy grazing, and in Northern regions (Fisher and Marion 1951; Hyder et al. 1971; Allen 1892a and 1982b; Lowe et al. 2002; USDA 2002). It is found throughout North America as far south as Mexico and as far north as Canada, and occurs in a wide variety of systems including woodlands and riparian habitats, as well as sagebrush and salt-desert scrub communities. It is, however, most iconic of the short- and mixed-grass prairies of the Great Plains (Hyder et al. 1971; USDA 2002; Anderson 2003; Wynia 2007). In fact, *B. gracilis* is a dominant species in shortgrass prairies and a major producer throughout the Great Plains and southwestern US, making up as much as 75-90% of all net primary production of sites in the Southern and Central Great Plains (Hyder et al. 1971; Coffin and Laurenroth 1988; Samuel and Hart 1992; Lowe et al. 2002; Anderson 2003). The grass thrives in arid and semi-arid regions with fairly saline, moderately alkaline soils, and prefers sparse, open areas with no litter (Dormaar et al. 1994; USDA 2002; Anderson 2003; Wynia 2007). It has a low tolerance of shade, acidic soil, and flooding or continuous submergence (Dormaar et al. 1994; USDA 2002; Anderson 2003; Wynia 2007). It prefers mostly spring and summer precipitation, and requires about 20.3-38.1 cm annually with an optimum range near 30.5-35.6 cm, but also does well even at slightly higher levels such as 45.7-50.8 cm (Brown and Schuster 1969; Eck et al. 1975; Anderson 2003; Wynia 2007).

Physical Characteristics

This relatively short-statured plant ranges in height from 15-61 cm at maturity (Dormaar et al. 1994; USDA 2002; Anderson 2003; Wynia 2007). Growth begins in mid-April to June and maximum leaf height is reached within 2 months, usually around mid-June to late-July, depending on weather conditions (Anderson, 2003). Flowering occurs from July to August, and seeds ripen and are dispersed from August to October after which leaf growth continues until first frost (Anderson, 2003). Its dense fibrous root

system is shallow with the majority of its root mass being in the upper 13 cm of the soil profile (Dormaar et al. 1994; Anderson 2003; Wynia 2007). Such a shallow rooting system allows it to respond rapidly to moisture events, giving it an advantage over neighboring species (Anderson 2003). Also, *B. gracilis* has a high water use efficiency (WUE) and excellent water up take even in extremely low soil moisture conditions (Dormaar et al. 1994; Anderson 2003; Wynia 2007). During drought conditions, it can not only increase water uptake, but also reduce total transpiration and adjust leaf area (Wynia 2007).

Reproduction and Establishment

Reproduction occurs by seed production and tillering (USDA 2002).

Inflorescences are eyebrow-shaped with relatively low seed production: 112.1-201.8 kg/ha in natural stands have been reported (USDA 2002; Anderson 2003). Seed dispersal is by wind, insects, clinging to animal hides, and by large herbivore ingestion (Anderson 2003). *Bouteloua gracilis* seeds have a very shallow planting depth of 0.6 to 0.9 cm (Hyder et al. 1971; Dormaar et al. 1994; USDA 2002; Anderson 2003; Wynia 2007). Germination requires warm, moist soils in a firm, but not solid seedbed (Hyder et al. 1971; Samuel and Hart 1992; Dormaar et al. 1994; USDA 2002; Wynia 2007). Under such conditions, germination is rapid (Hyder et al. 1971; Allen 1982b). Though dominant, the grass can be hard to establish from seed as its seedlings are in danger of desiccation due to their panicoid growth form (Hyder et al. 1971; Ries and Svejcar 1991; Samuel and Hart 1992; Wynia 2007). In panicoid growth, the coleoptile is elevated by sub-coleoptile internode elongation which causes the delicate adventitious roots to be very near the soil surface, usually in the upper 2-6 mm for *B. gracilis* (Hyder et al. 1971; Ries and Svejcar 1991). To insure good adventitious root development, the soil surface must remain constantly moist for the first 2-4 days (Wynia 2007). Without this ideal

development, the grass dies within 6-10 weeks (Hyder et al. 1971; Anderson 2003; Wynia 2007). Fortunately, *B. gracilis* seeds have an excellent water absorption ability to initiate germination and thus can germinate and establish in drier conditions better than other species (Dormaar et al. 1994; Anderson 2003). Germination requires high temperatures with optimum germination temperatures around 29°C during the day and 18 °C during the night (Dormaar et al. 1994; Allen 1982a; Anderson 2003). Once established, the species is very hardy and creates stable communities that resist change (Dormaar et al. 1994; Anderson 2003; Wynia 2007).

Forage Value

Bouteloua gracilis is good forage for all classes of domestic livestock as well as bison, elk, and bighorn sheep, and is even grazed by pronghorn and mule deer (Anderson 2003). It is not only highly palatable, but also nutritious and can be grazed year-round (USDA 2002; Anderson 2003; Wynia 2007). In fact, Currie et al. (1977) found that it is important in cattle diets even late in the season, from August to November. The leaves are low in fiber, high in protein, and can retain up to 50% of their nutritional value in dormant season (Anderson 2003). Fudge and Fraps (1945) found that protein content ranged from 3.3-9.8% in Texas, ranking it fair to good for cattle. Therefore, no nutritional supplementation is needed for *B. gracilis* grasslands except in winter when some nutritional value may decline due to frost (Eck et al. 1975; Wynia 2007). Furthermore, it responds well to grazing and can thrive even when grazed closely (Eck et al. 1975; Eck and Sims 1984; Dormaar et al. 1994; Wynia 2007). Eck et al. (1975) found that clipping to 1 inch every 2 weeks resulted in higher biomass yields of *B. gracilis* grass-mix as compared to other less frequent clipping regimes. They also found that when 50% of this grass and buffalograss (*Buchloe dactyloides*) growth was removed by early November, the range was still healthy and could maintain a

satisfactory condition. While Eck et al. (1975) found that clipped *B. gracilis* biomass did not increase compared to unclipped plots, other studies have found that grazing does indeed increase its biomass compared to ungrazed sites (Eck and Sims 1984; Dormaar et al. 1994). This discrepancy could be due to the fact that grass response to grazing is slightly different than to clipping, as cattle stimulate growth by more than just simple biomass removal such as salivary reactions, nitrogen imputation, and other factors associated with large ungulate presence (Reardon et al. 1974; Wallace 1990).

SALSOLA IBERICA BACKGROUND

Origin and Morphology

Bouteloua gracilis often occurs in communities containing invasive annual plants such as *Salsola iberica* (Allen 1982b). Accidentally introduced from Eurasia as a flaxseed contaminant (Dewy 1893), *S. iberica* is an annual invasive forb, and like *B. gracilis*, is a warm-season, C₄ species (Allen 1982a and 1982b; Young et al. 1988; Howard 1992; Schillinger 2007). It is an erect and highly branched forb in the Chenopodiaceae family, with a height ranging from 0.3-0.9 m, and a diameter from 0.3-1.5 m (Howard 1992). The forb has a very broad temperature range (Allen 1982a; Howard 1992). However, optimum growing temperature is between 23-30 °C (Nord et al. 1999). Leaves are awl-shaped with a spiny tip and irregular flowers at leaf axils (Howard 1992). It has an aggressive taproot system that can range in length from a several centimeters to several meters, with extensive lateral roots (Dewy 1893; Howard 1992; Schillinger 2007). Schillinger (2007) reported a rooting system that had a diameter over 5 m and ran over 2 m deep. *Salsola iberica* can produce a large amount of seeds at maturity, with one plant being capable of producing up to 250,000 seeds (Howard 1992; Schillinger 2007). Seeds germinate poorly in compacted soils or at depths greater than 5 inches (Howard

1992). Germination can occur under a wide range of temperatures from as low as 0°C at night to day temperatures as high as 50°C (Allen 1982a; Howard 1992). In fact, temperature seems to only affect rate of germination, but not percent of seeds that germinate (Allen 1982a; Howard 1992). Under favorable conditions, seeds can germinate within minutes (Howard 1992). Although seeds can germinate as late as August, they typically start germinating in April (Mid-March in some Northwestern areas), and plants begin flowering in June -August (Howard 1992; Schillinger 2007). Seeds mature in August through November, and plants die after the first frost, with seeds disseminating in late fall (Howard 1992; Schillinger 2007).

Distribution

Salsola iberica thrives in a variety of ecosystems and thus has a large distribution across North America (Howard 1992; Zwenger et al. 2010). It ranges from as far North as British Columbia to as far South as Northern Mexico, and is found across the US from Atlantic to Pacific coasts (Howard 1992). It flourishes in disturbed sites such as roadside areas, overgrazed lands, agricultural lands, prairies, construction sites, oil extraction sites, ditches, and housing areas (Allen 1982a; Young 1988; Howard 1992; Zwenger et al. 2010). Commonly found in arid and semi-arid regions, *S. iberica* does well in high temperatures with saline, alkaline soils (Howard 1992; Nord et al. 1999; Zwenger et al. 2010). It is shade intolerant and does not perform well in crowded communities (Howard 1992; Schillinger 2007). Because this forb prefers sparsely vegetated sites with low moisture, it does extremely well in drought, even increasing in density and biomass compared to normal precipitation years (Wiese and Vandiver 1970; Allen 1982b; Young 1988; Howard 1992; Patterson 1995). In fact, Wiese and Vandiver (1970) found that it produced more biomass under dry than moderate moisture conditions, and 50% more biomass under dry than wet conditions. Allen (1982b) found that *S. iberica* increased in

dry conditions, while western wheatgrass (*Elymus smithii*) and even *B. gracilis* decreased under the same conditions.

Problems and Benefits

Salsola iberica is widely recognized as a problematic weed. Because it thrives in disturbed sites and well-drained soils, it has long been a major problem in croplands, particularly in spring and summer seasons in Northern states (Young 1988; Howard 1992; Schillinger 2007; Zwenger et al. 2010). The forb is most recognized for being a problematic nuisance because the mature plant breaks off at the crown and is blown by the wind across the landscape, piling against fences and houses, in ditches, and across roadways (Howard 1992; Zwenger et al. 2010). Its morphology, tumbling nature, and accumulative habits which increase fuel load and litter in prairies, make this forb a major fire hazard (Dewy 1893; Howard 1992; Zwenger et al. 2010). Control is usually handled by herbicide or mechanical removal (Howard 1992; Schillinger 2007). Studies also show that grazing reduces *S. iberica* presence compared to ungrazed sites (Eck and Sims 1984). Aside from being a nuisance species, *S. iberica* can be useful as forage (Hageman et al. 1988; Howard 1992). In fact, it is credited as saving the livestock industry during the Dust Bowl of the 1930s (Howard 1992; USU 2016). Nutritionally, young plants are high in protein (11.5%) and even have a fair nutritional value in winter when it is dead and dry (Howard 1992). Pronghorn antelope actually prefer it during the summer, fall, or year-round in wet years; cattle and sheep graze it from early spring until it produces spines, and if winter moisture occurs, spines soften making it a good forage source again (Howard 1992). While it is a minor food source for bison, mule deer, and elk, it is an important forage for prairie dogs (Howard 1992). Not only does the plant itself make a good forage source, but its seeds are eaten by small mammals and many bird species including Gambel's quail (Howard 1992). *Salsola iberica* also provides

good cover for numerous bird species and small and large mammals depending on region, and also provides nesting sites for small mammals and many different bird species including blue quail (Howard 1992; Cantu et al. 2006). In spite of these benefits, however, the plant is considered a problematic weed on most rangelands, as it can become dominant and thus may compete with more desirable species (Allen 1982a; Howard 1992).

RESEARCH OBJECTIVES

Because *B. gracilis* is an important forage source for the livestock industry, it is important to know how this grass responds to the presences of annual invasives such as *S. iberica*. Other studies have indicated that *B. gracilis* competition varies at differing densities of invasive species (Samuel and Hart 1992; Lowe et al. 2003), however, such density specific experiments have not been conducted using *S. iberica*. The objectives of this research were to 1) determine the effect of *S. iberica* density on *B. gracilis* biomass, and 2) examine *S. iberica* intraspecific competition. In order to accomplish these objectives, I conducted a glasshouse experiment and a field experiment. Chapter II reports on results of a glasshouse study in which I grew *B. gracilis* in pots with *S. iberica* at 5 different density levels, varying from 0-4. This experiment generated data on both above- and belowground competition as well as competition among *S. iberica* individuals. Chapter III discusses a field study where I thinned *B. gracilis* and *S. iberica*, growing in the field together, to the same pre-determined ratios used in the glasshouse study. Because no belowground biomass was collected, this experiment focused only on aboveground competition. This research provides a better understanding of plant community dynamics within the shortgrass prairie ecosystem and contributes to the current knowledge of plant species relations within those systems. It is applicable to the

fields of range ecology and management, cattle and livestock industries, wildlife management, and related fields, and will help land owners, habitat ecologists, rangeland specialists, and others in similar positions to better predict plant community responses in shortgrass prairies and related systems from season to season.

LITERATURE CITED

- Allen, E.B. 1982a. Germination and competition of *Salsola kali* with native C₃ and C₄ species under three temperature regimes. *Bulletin of the Torrey Botany Club*. 109:39-46.
- Allen, E.B. 1982b. Water and nutrient competition between *Salsola kali* and two native grass species (*Agropyron smithii* and *Bouteloua gracilis*). *Ecology*. 63:732-741.
- Anderson, M.D. 2003. *Bouteloua gracilis*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available at <http://www.fs.fed.us/database/feis/> Accessed 26 January 2015.
- Brown, J.W. and J.L. Schuster. 1969. Effects of grazing on a hardland site in the southern high plains. *Journal of Range Management*. 22:418-423.
- Cantu, R., D. Rollins, and S.P. Lerich. 2006. Scaled quail in Texas: their biology and management. *Texas Parks and Wildlife Department*.
- Coffin, D.P. and W.K. Laurenroth. 1988. The effects of disturbance size and frequency on a shortgrass plant community. *Ecology*. 69:1609-1617.
- Currie, P.O., D.W. Reichert, J.C. Malechek, and O.C. Wallmo. 1977. Forage selection comparisons for mule deer and cattle under managed ponderosa pine. *Journal of Range Management*. 30:352-356.
- Dewy, L.H. 1893. Russian thistle: the Russian thistle and other troublesome weeds in the wheat region of Minnesota and North and South Dakota. *U.S. Department of Agriculture Farmers' Bulletin No. 10*.1-18.
- Dormaar, J.F., B.W. Adams, and W.D. Willms. 1994. Effect of grazing and abandoned cultivation on a Stipa-Bouteloua community. *Journal of Range Management*. 47:28-32.
- Dunn, G.H., M. Gutwien, T.R. Green, A. Menger, and J. Printz. 2013. The drought calculator: decision support tool for predicting forage growth during drought. *Rangeland Ecology and Management*. 66:570-578.

- Eck, H.V., W.G. McCully, and J. Stubbendieck. 1975. Response of shortgrass plains vegetation to clipping, precipitation, and soil water. *Journal of Range Management*. 28:194-197.
- Eck, H.V. and P.L. Sims. 1984. Grass Species adaptability in the southern high plains – a 36-year assessment. *Journal of Range Management*. 37:211-217.
- Fisher, C.E. and P.T. Marion. 1951. Continuous and rotation grazing on buffalo and tobosa grassland. *Journal of Range Management*. 4:48-51.
- Fudge, J.F. and G.S. Fraps. 1945. The chemical composition of grasses of northwestern Texas as related to soils and to requirements for range cattle. *Bulletin No. 669. [Lubbock, TX]: Texas Agricultural Experiment Station*. 56 p.
- Hageman, J.H., J.L. Fowler, M. Suzukida, V. Salas, and R. Lecaptain. 1988. Analysis of Russian thistle (*Salsola* species) selections for factors affecting forage nutritional value. *Journal of Range Management*. 41:155-158.
- Harlan, J.R. 1958. Blue grama types from west Texas and eastern New Mexico. *Journal of Range Management*. 11:84-87.
- Howard, J.L. 1992. *Salsola kali*. In: Fire Effects Information Systems, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available at <http://www.fs.fed.us/database/feis/>. Accessed 26 January 2015.
- Hyder, D.N., A.C. Everson, and R.E. Bement. 1971. Seedling morphology and seedling failures with blue grama. *Journal of Range Management*. 24:287-292.
- Lowe, P.N., W.K. Lauenroth, and, I.C. Burke. 2002. Effects of nitrogen availability on the growth of native grasses exotic weeds. *Journal of Range Management*. 55:94-98.
- Lowe, P.N., W.K. Lauenroth, and, I.C. Burke. 2003. Effects of nitrogen availability on competition between *Bromus tectorum* and *Bouteloua gracilis*. *Plant Ecology*. 167:247-254.
- Nord, C.A., C.G. Messersmith, and J.D. Nalewaja. 1999. Growth of *Kochia scoparia*, *Salsola iberica*, and *Triticum aestivum* varies with temperature. *Weed Science*. 47:435-439.
- Patterson, D.T. 1995. Effects of environmental stress on weed/crop interactions. *Weed Science*. 43:483-490.
- Reardon, P.O., C.L. Leinweber, and L.B. Merrill. 1974. Response of sideoats grama to animal saliva and thiamine. *Journal of Range Management*. 27:400-401.
- Ries, R.E. and T.J. Svejcar. 1991. The grass seedling: when is it established? *Journal of Range Management*. 44:574-576.

- Samuel, M.J. and R.H. Hart. 1992. Survival and growth of blue grama seedlings in competition with western wheatgrass. *Journal of Range Management*. 45:444-448.
- Schillinger, W.F. 2007. Ecology and control of Russian thistle (*Salsola iberica*) after spring wheat harvest. *Weed Science*. 55:381-385.
- USDA NRCS Plant Martials Program. 2002. Plant fact sheet: Blue gama *Bouteloua gracilis* (Willd. Ex Kunth) Lag. Ex Griffiths. Natural Resources Conservation Service. United States Department of Agriculture.
- USU. 2016. Russian thistle: *Salsola turgus* (*Salsola iberica*, *Salsola kali*). *The Great Basin and Invasive Weeds*. Utah State University.. Available at http://www.usu.edu/weeds/plant_species/weedspecies/russianthis.html. Accessed 5 Sept 2016.
- Wallace, L.L. 1990. Photosynthetic response of big bluestem to clipping versus grazing. *Journal of Range Management*. 43:58-61.
- Wiese, A.F., and C.W. Vandiver. 1970. Soil moisture effects on competitive ability of weeds. *Weed Science*. 18:518-519.
- Wynia, R. 2007. Plant fact sheet: Blue gama *Bouteloua gracilis* (Willd. Ex Kunth) Lag. Ex Griffiths. *USDA NRCS Plant Martials Center, Manhattan, Kansas*. Natural Resources Conservation Service. United States Department of Agriculture.
- Young, F.L. 1988. Effect of Russian thistle (*Salsola iberica*) interference on spring wheat (*Triticum aestivum*). *Weed Science*. 36:594-598.
- Zwenger, S.R., R. Alsaggaf, and C. Basu. 2010. Does an expressed sequence tag (EST) library of *Salsola iberica* (tumbleweed) help to understand plant responses to environmental stresses?. *Plant Signaling and Behavior*. 5:1330-1335.

Chapter II

***Bouteloua gracilis* Response to Varying Densities of *Salsola iberica* in a Glasshouse Setting**

ABSTRACT

Invasive annuals are a continuing problem in shortgrass prairie rangelands and can compete with more desirable native perennial grasses. This study explores the competitive relationship between the native grass blue grama (*Bouteloua gracilis*) and the invasive Russian thistle (*Salsola iberica*) at varying densities of the invasive in a glasshouse experiment. The experiment was established as a randomized block design (RBD) with 2 sets of 8 blocks containing 6 pots each with randomly assigned density ratio treatments. Density ratio treatments of *B. gracilis* to *S. iberica* were 0:1, 1:1, 1:2, 1:3, 1:4, and 0:1. *Salsola iberica* presence lowered *B. gracilis* biomass by 76.4%, though density of *S. iberica* had no effect on *B. gracilis* or itself. Overall, *S. iberica* biomass explained 54.9% of the variation in *B. gracilis* biomass. Also, *S. iberica* demonstrated high intraspecific competition as the forb's average individual biomass significantly declined by 45.9% and 43.6% as its own density increased.

INTRODUCTION

Importance of *Bouteloua gracilis*

Blue grama (*Bouteloua gracilis*) is an important grass in rangeland ecosystems of the shortgrass prairie. It is classified as a short-shoot plant, meaning its growing points remain compressed at the base of the plant during the vegetative stage and then a few, but not all, growing points are elevated during reproductive stage (Wynia 2007). This allows *B. gracilis* to quickly recover from defoliation without using an excessive amount of resources which gives it the ability to withstand even heavy grazing for an extended

period of time. In addition, it has relatively high nutrient retention in the dormant season, which can reduce the quantity of supplementation needed in grazing situations (Eck et al. 1975; Wynia 2007). These factors make *B. gracilis* excellent forage for cattle and other ungulates.

Because *B. gracilis* forage production is so important in prairie rangelands, it is important to know how it functions within such systems and factors that can affect its production. One factor that has the potential to greatly influence *B. gracilis* production is competition with other species. Competition has major effects on ecosystem structure and function as it contributes to species' presence, density, and on a local level, community diversity as a whole (Tilman 1997; Mangla et al. 2011); therefore it is important to understand how competition influences species of interest. Within shortgrass prairies, competition can be heightened by frequent disturbances that lead to bare patches of ground. Bare patches increase opportunity for competition within the system by providing optimal entry sites for opportunistic invasive annuals (Dormaar et al. 1994; Kostivkovsky and Young 2000). One such problematic invasive species in prairie rangelands is Russian thistle (*Salsola iberica*).

Origin and Impacts of *Salsola iberica*

Originally from Eastern Europe/Western Asia, *S. iberica* was introduced to North America in the 1800s; it is thought to have been a contaminant in flaxseed from Russia (Dewey 1983). It quickly became major problem in crop lands in the Northern US as it thrived in plowed fields and spread rapidly into pastures. By the tone of reports from the late 1800s, this plant was feared as if it were a medical epidemic or even human as it spread across the Great Plains and westward (Dewey 1893; Young, J.A. 1988). One North Dakota farmer proposed to the state legislature that they build a fence across the entire state to keep *S. iberica* from entering (Young ,J.A. 1988). In the 1890s, a few

hoped that the invasive plant would eventually die out (Dewey 1893); however, over 100 years later, it still remains a problematic weed. In fact, *S. iberica* causes farmers in the Pacific Northwest alone annual losses of over \$50 million due to reduced crop quality, crop loss, and herbicide costs (Young 2006). While *S. iberica* continues to be a problem in crop lands, it is also a concern in rangelands. Since its introduction, rangelands have become fragmented by roads, burned less often, and overgrazed - a problem that is compounded by frequent droughts. Such disturbances have led to an increase in *S. iberica* presence in shortgrass prairie systems, (Allen 1982a; Kostivkovsky and Young 2000), which has raised the crucial question as to how these systems respond.

Competition Studies

Studies looking at *B. gracilis*' response to competition are few. Most studies dealing with *B. gracilis* have focused on forage production, establishment, successional processes after disturbance, and grazing effects (Fisher and Marion 1951; Ries and Svejcar 1991; Domaar et al. 1994). However, a few studies have considered competition between *B. gracilis* and other grass species such as cheatgrass (*Bromus tectorum*: Lowe et al. 2002 and 2003) and western wheatgrass (*Elymus smithii*: Samuel and Hart 1992). Lowe et al. (2003) conducted a study looking at the effect of *Bromus tectorum* density on *B. gracilis* biomass and found that different densities of *B. tectorum* created different biomass responses in *B. gracilis*. In their study, Lowe et al. (2003) grew the two grass species at five different nitrogen levels and five density treatments. They found that at the two medium nitrogen levels, *B. gracilis* biomass dropped significantly with the introduction of one *B. tectorum* plant, yet subsequent *B. tectorum* individuals did not further reduce *B. gracilis* biomass. At the highest nitrogen level, *B. gracilis* biomass dropped significantly with the introduction of one and three *B. tectorum* plants.

Many studies have looked at *S. iberica* competition with other species. Since its introduction, *S. iberica* has been a major concern in agriculture, generating several studies observing competition with crop species such as wheat (*Triticum aestivum*), sorghum (*Sorghum vulgare*), and corn (*Zea mays*) (Wiese and Vandiver 1970; Young, F.L. 1988; Patterson 1995; Blackshaw and Brandt 2008). These studies have looked at specific drivers that cause *S.iberica* to thrive in its environment such as light, nutrients, nitrogen, and water availability. Nord et al. (1999) tested the effect of temperature on competition between *S. iberica* or kochia weed (*Kochia scoparia*) and spring *T. aestivum*, and found that both forbs had greater biomass at warmer temperatures. Many studies have focused on how to control *S. iberica* by chemicals, or farm management practices (Blackshaw 1990; Young 2006; Schillinger 2007). In some cases, herbicide resistance has occurred; therefore, herbicide rotation methods have been developed and some biological controls are beginning to be tested (Stallings et al. 1994; Young 2006; Berner et al. 2014).

Few studies have been conducted investigating competition between *B. gracilis* and *S. iberica*. Allen (1982b) conducted a glasshouse study looking at nitrogen and watering effects on *S. iberica* competition with *B. gracilis* and *E. smithii*. She found that *S. iberica* out-competed both grasses under dry conditions; however, under wet conditions, *E. smithii* was unaffected by competition, and *B. gracilis* actually had greater biomass than *S. iberica*. Allen (1982a) in another study, tested *B. gracilis* competition with *S. iberica* under different temperature regimes and found that the grass is an inferior competitor to the forb under warm temperature regimes, but under both cool and hot regimes, the presence of *S. iberica* had no significant effect on *B. gracilis* growth. No studies to date have looked at the effect of density on competition between these two species. By knowing how *S. iberica* density effects *B. gracilis*, land managers can make

informed decisions on when to actively control the invasive's numbers and when such measures would be a waste of resources because the grass would not produce any more biomass at a lower *S. iberica* density.

Research Objectives

To explore this competitive relationship, I conducted a controlled glasshouse experiment with the following objectives: 1) determine the effect of *S. iberica* density and biomass on *B. gracilis* biomass in a controlled setting, and 2) observe *S. iberica* intraspecific competition while in competition with another species. Results from this glasshouse study will generate conclusions about competition between *B. gracilis* and *S. iberica* and the role density plays in that competition. Such conclusions, in turn, will provide land owners and managers a better understanding of how rangeland communities operate allowing them to assign better plans and systems to help meet their goals.

METHODS

Design

I designed this experiment as an additive design, drawing from guidelines by Freckleton and Watkinson (2000), and aspects of designs used by Allen (1982a and 1982b) and Wiese and Vandiver (1970). The experiment took place in the Texas Tech University Horticulture Glasshouse, Lubbock Texas, and was arranged as a Randomized Block Design (RBD) with 8 blocks to account for possible temperature changes caused by distance from the fan and windows within the glasshouse. The RBD was replicated in 2 sets for a total of 16 blocks with 6 pots in each block; thus there were 96 pots. Blocks were arranged on corner benches which ran perpendicular to the Glasshouse wall-fan so that the blocks themselves were arranged parallel to the fan and

perpendicular to the window (figure 2.1). The experiment tested competition by growing *B. gracilis* with varying densities of *S. iberica* in the following ratios: 1:0, 1:1, 1:2, 1:3, 1:4, and 0:1. The ratios 1:0, 1:1, 1:2, 1:3, and 1:4 served to test the density effect, while the 0:1 ratio served as a control for *S. iberica* growth.

Materials and Procedure

Plastic pots 30.5 cm in diameter were filled with top soil purchased from Back to Nature (5407 E Highway 84, Slaton, Texas). Native American Seed (3791 US 377, Junction, Texas 76849) donated *B. gracilis* seeds for this experiment. Although *B. gracilis* seeds had a germination rate of 21%, seeds were sown at a seeding rate of 25-30 seeds per pot which was much higher than the recommended rate of 5-6 to ensure ample germination. *Salsola iberica* seeds were gathered from the field in Garza County, Texas in late fall. Seeds were cleaned in the lab using a standard seed blower (Hoffman Manufacturing Inc. OSB 15727 Oregon Seed Blower); from each batch blown, 5 seeds were randomly selected, dissected, and viewed under a microscope to check seed endosperm viability. To calculate germination rate, seeds were plated on germination plates with blotter medium, placed in a germination chamber (Hoffman Manufacturing Inc. SG30SC Controlled Environment Chamber) and allowed to germinate for 1 week (Wester 1991). Germination rate for *S. iberica* in this study was 62%. In the glasshouse, pots were filled with soil 27.9 cm deep, resulting in approximately 20,369 cm³ of soil per pot, and saturated to field capacity prior to planting. Individual pots were seeded with ample seeds and then thinned to the aforementioned pre-determined ratios (Allen 9182a and 1982b; Nord et al. 1999; Lowe et al. 2002 and 2003). Fans were set to maintain a temperature of 28.3°C ± 3. Each morning, pots were watered by hand before 10:00 am. Pots were generously watered with 1200 ml for the first month of the experiment to ensure establishment and then daily watering was cut to 150 ml for the

		Outside Wall with Fan												Outside Facing Window			
		Set A						Set B									
Pot #	BG:SI	Block 1		Block 2		Block 3		Block 4		Block 5		Block 6			Block 7		Block 8
		Pot 5	Pot 3	Pot 1	Pot 2	Pot 4	Pot 6	Pot 2	Pot 4	Pot 6	Pot 1	Pot 3	Pot 5				
		1:1	1:0	1:4	1:3	1:1	1:2	1:4	1:3	0:1	1:0	1:1	0:1				
		Pot 6	Pot 4	Pot 2	Pot 5	Pot 3	Pot 1	Pot 1	Pot 3	Pot 5	Pot 2	Pot 4	Pot 6				
		0:1	1:3	1:2	1:1	1:0	1:4	1:0	1:1	1:2	1:3	1:4	0:1				
		Pot 5	Pot 3	Pot 1	Pot 2	Pot 4	Pot 6	Pot 2	Pot 4	Pot 6	Pot 1	Pot 3	Pot 5				
		1:1	1:2	1:0	1:3	1:1	1:4	1:3	1:1	0:1	1:0	1:1	0:1				
		Pot 6	Pot 4	Pot 2	Pot 5	Pot 3	Pot 1	Pot 1	Pot 3	Pot 5	Pot 2	Pot 4	Pot 6				
		0:1	1:3	1:4	1:1	1:0	1:4	1:0	1:4	1:2	1:3	1:4	0:1				
		Pot 5	Pot 3	Pot 1	Pot 2	Pot 4	Pot 6	Pot 2	Pot 4	Pot 6	Pot 1	Pot 3	Pot 5				
		1:1	0:1	1:4	1:4	0:1	1:0	1:4	0:1	1:0	1:3	1:2	1:1				
		Pot 6	Pot 4	Pot 2	Pot 5	Pot 3	Pot 1	Pot 1	Pot 3	Pot 5	Pot 2	Pot 4	Pot 6				
		1:0	1:3	1:2	1:1	1:0	1:4	1:3	1:2	1:1	1:0	1:2	1:1				
		Pot 5	Pot 3	Pot 1	Pot 2	Pot 4	Pot 6	Pot 2	Pot 4	Pot 6	Pot 1	Pot 3	Pot 5				
		1:3	1:0	0:1	1:1	1:0	1:1	1:1	1:2	0:1	1:0	1:3	1:4				
		Pot 6	Pot 4	Pot 2	Pot 5	Pot 3	Pot 1	Pot 1	Pot 3	Pot 5	Pot 2	Pot 4	Pot 6				
		1:2	1:4	1:1	1:3	1:4	1:1	1:0	1:3	1:4	1:0	1:3	1:4				
		Pot 5	Pot 3	Pot 1	Pot 2	Pot 4	Pot 6	Pot 2	Pot 4	Pot 6	Pot 1	Pot 3	Pot 5				
		1:1	0:1	1:4	1:4	1:1	1:0	1:4	1:1	1:0	1:3	1:0	1:0				
		Pot 6	Pot 4	Pot 2	Pot 5	Pot 3	Pot 1	Pot 1	Pot 3	Pot 5	Pot 2	Pot 4	Pot 6				
		1:3	1:0	1:2	1:2	0:1	1:3	1:2	0:1	1:3	1:2	1:0	1:0				
		Pot 5	Pot 3	Pot 1	Pot 2	Pot 4	Pot 6	Pot 2	Pot 4	Pot 6	Pot 1	Pot 3	Pot 5				
		1:4	1:1	0:1	1:1	0:1	1:0	1:4	0:1	1:0	1:1	1:3	1:2				
		Pot 6	Pot 4	Pot 2	Pot 5	Pot 3	Pot 1	Pot 1	Pot 3	Pot 5	Pot 2	Pot 4	Pot 6				
		1:2	1:3	1:0	1:1	1:3	1:0	1:1	1:3	1:2	1:1	1:3	1:2				
		Pot 5	Pot 3	Pot 1	Pot 2	Pot 4	Pot 6	Pot 2	Pot 4	Pot 6	Pot 1	Pot 3	Pot 5				
		1:3	0:1	1:0	1:3	0:1	1:0	1:3	1:1	1:2	1:3	1:1	1:2				
		Pot 6	Pot 4	Pot 2	Pot 5	Pot 3	Pot 1	Pot 1	Pot 3	Pot 5	Pot 2	Pot 4	Pot 6				
		1:1	1:2	1:4	1:1	1:2	1:4	1:4	0:1	1:0	1:4	0:1	1:0				

Figure 2.1 Glasshouse Layout. Experiment layout for glasshouse study analyzing competition of *Bouteloua gracilis* (BG) at varying density levels of *Salsola iberica* (SI).

last month. The 150 ml amount corresponds to the summer monthly average from the year 2014 which was the year the field season was conducted (Chapter III). Additional artificial light was added to create a 14 hour photoperiod. Information for summer conditions was gathered from a weather station located on the TTU NRM Rangeland (West Texas Mesonet 2015).

Bouteloua gracilis seeds were planted on the 23rd of February, 2016 at a seeding rate of 25-30 seeds per pot using a seed-drill type planting method. In each pot, I dug two furrows 1.3 cm deep and 12.7 cm long, funneled the seeds into the trenches, and lightly pressed the soil back over seeds. After seeding, 0.3 cm of sand was placed over soil in each pot to help maintain soil surface moisture during germination and establishment. Seeds were watered after receiving the sand cap. On the 30th of March 2016, *B. gracilis* was thinned to one individual per pot and *S. iberica* seeds were planted in each pot at the seeding rates of 7, 9, 10, and 12 seeds per pot to insure that pots would contain 1, 2, 3, and 4 individuals, respectively. On the 11th of April 2016, *S. iberica* plants were transplanted from pots with ample plants into pots that contained less than the ratio assigned to that pot. On the 15th of April 2016, transplants were considered strong enough to survive, and *S. iberica* in all pots were thinned to the pre-determined ratios. Thus, on the 15th of April, all pots contained the proper ratios and the experiment was fully established (see figure 2.1 for setup of the glasshouse experiment and what ratios were assigned to each pot).

The experiment ran for two months, starting on the 15th of April 2016 and running through the 15th of June 2016. Other studies have used a similar experimental growing season when testing competition between these two species, and other plant species including *Kochia scoparia*, *Triticum aestivum*, *Elymus smithii*, *Amaranthus retroflexus*, and other common weed species (Wiese and Vandiver 1970; Allen 1982a and 1982b; Nord et al. 1999; Blackshaw and Brandt 2008). On the 16th of June, all aboveground biomass from all pots was harvested by clipping, weighed using a spring scale, and then bagged and labeled. For the *S. iberica* samples, individual plants from all pots were weighed and dried separately to allow competition between individuals to be tested. Belowground biomass was also harvested by washing all soil from root systems, and

separated by species; samples were then bagged and labeled. All samples were dried for two months in the TTU Range Barn Drying Room and weighed again.

Analysis

To analyze these data, I conducted Two-way Analysis of Variance (ANOVA) tests with treatment (density ratios) and block as the main effects (Sokal and Rohlf 2012; Zar 1999). Treatments for *B. gracilis* were the following *B. gracilis*:*S. iberica* density ratios: 1:0, 1:1, 1:2, 1:3, and 1:4. Treatments for *S. iberica*, were 0:1, 1:1, 1:2, 1:3, and 1:4. Prior to any ANOVA tests, data were tested for normality and heteroscedasticity using Shapiro-Wilk and Brown-Forsythe tests, respectively (table 2.1; Shapiro and Wilk 1965; Brown and Forsythe 1974). Because ANOVA is robust to the assumption of normality given that the data are homoscedastic, I proceeded to run the ANOVAs. Prior to running the Two-way ANOVA, I ran a One-way ANOVA to test whether "Set" had an effect on biomass. As no significant effect of Set was observed (table 2.1), I ran Two-way ANOVAs with replication using 8 blocks with 2 replicates each to test for treatment differences in the following: aboveground biomass of *B. gracilis*, aboveground biomass of *S. iberica*, belowground biomass of *B. gracilis*, belowground biomass of *S. iberica*, and total biomass of each species. To calculate *S. iberica* aboveground biomass, I summed individual plant biomass within each pot. To test intraspecific competition of *S. iberica*, I took the average biomass of the individual plants within a pot and ran a Two-way ANOVA to test the effect of treatment on average individual *S. iberica* biomass per pot. After running the ANOVAs, I applied Tukey's HSD post hoc tests for mean separation (Day and Quinn 1989). To further explore the relationship between these two species, I also ran simple regression on *B. gracilis* and *S. iberica* biomass for comparison of aboveground, belowground, and total biomass. All statistics were run in the program JMP 12.2 (JMP 2012 and 2014).

Table 2.1 P-values from Assumption Tests and Set Effect ANOVAs. P-values from tests of normality and homoscedasticity, and from ANOVAs testing for the effect of Set on all biomass types of *Bouteloua gracilis* (BG) and *Salsola iberica* (SI). *denotes a significant value at $\alpha=0.05$

Biomass Type	Assumption Test		ANOVA testing for Set Effect
	Normality	Homoscedasticity	
BG aboveground	0.0030*-0.6466	0.9942	0.6959
BG belowground	0.0151*-0.8351	0.6570	0.1384
SI aboveground	0.0082*-0.9856	0.5191	0.6303
SI belowground	0.0454*-0.9989	0.8786	0.0725
Average Individual SI /pot	0.0610-0.8762	0.8976	0.8261
Total BG	0.0045*-0.9624	0.9892	0.9194
Total SI	0.0075*-0.9996	0.5076	0.7921

RESULTS

Response of *Bouteloua gracilis* Biomass

On average, *B. gracilis* aboveground biomass for this study was 4.77g and ranged from 0.21g to 21.84g. Belowground biomass ranged from 0.31g to 4.04g and averaged 1.48g. For both above- and belowground *B. gracilis* biomass, there was no block-by-treatment interaction (table 2.2). Treatment had a significant effect on *B. gracilis* aboveground biomass ($P = <0.0001$; table 2.2 and figure 2.2A) such that treatment 1:0 (only *B. gracilis*), (12.13g), was significantly higher than all other treatments which averaged 3.51g, 2.31g, 2.80g, and 2.5g, respectively; there was no significant difference between all other treatments (table 2.3 and figure 2.2A). Belowground biomass of *B. gracilis* yielded the same result (table 2.2 and figure 2.2B); treatment 1:0, (2.42g) was significantly higher than all other treatments, which averaged 1.44g; 1.22g, 1.12g, and 1.17g, respectively ($P = <0.0001$; table 2.3 and figure 2.2B). Total *B. gracilis* biomass ranged from 0.95g to 25.24g with averages of 6.26g. There was also no block-by-treatment interaction, and treatment had a significant effect on total biomass for *B. gracilis* ($P = <0.0001$; table 2.2 and figure 2.2C). Treatment 1:0 (only *B. gracilis*) (12.13g) was significantly higher than all other treatments, but no significant

Table 2.2 Results of Two-way ANOVAs Testing Effect of *Salsola iberica* Density on *Bouteloua gracilis* Biomass.*denotes a significant value at $\alpha=0.05$.

Aboveground					
Source of Variation	df	SS	MS	F Ratio	P-value
Block	7	96.9886	13.8555	2.0068	0.0796
Treatment	4	1106.9744	276.7436	40.0838	<0.0001*
Block-Treatment	28	135.6099	4.8432	0.7015	0.8339
Error	38	262.3569	6.9041		
Total	77	1601.9298			

Belowground					
Source of Variation	df	SS	MS	F Ratio	P-value
Block	7	3.6944	0.5278	0.9731	0.4646
Treatment	4	18.7066	4.6767	8.6229	<0.0001*
Block-Treatment	28	8.3397	0.2978	0.5492	0.9489
Error	38	20.6095	0.5424		
Total	77	51.3501			

Total					
Source of Variation	df	SS	MS	F Ratio	P-value
Block	7	130.2042	18.6006	1.9283	0.0918
Treatment	4	1409.1377	352.2844	36.5217	<0.0001*
Block-Treatment	28	193.8056	6.9216	0.7176	0.8179
Error	38	366.5445	9.6459		
Total	77	2099.692			

Table 2.3 Tukey Post Hoc Results for *Bouteloua gracilis* Biomass. Tukey HSD All Pairwise Comparison results from a two-way ANOVA testing for Treatment's of effect on *B. gracilis* biomass. Treatments are the density ratios of *B. gracilis* to *S. iberica* (BG:SI).*denotes a significant value at $\alpha=0.05$

Treatment Comparison	Aboveground		Belowground		Total	
	t ratio	P-value	t ratio	P-value	t ratio	P-value
1:0 1:1	9.28	<0.0001*	3.75	0.0050*	8.74	<0.0001*
1:0 1:2	10.31	<0.0001*	4.49	0.0006*	9.79	<0.0001*
1:0 1:3	9.70	<0.0001*	4.92	0.0002*	9.37	<0.0001*
1:0 1:4	10.21	<0.0001*	4.79	0.0002*	9.77	<0.0001*
1:1 1:2	1.31	0.6876	0.85	0.9146	1.31	0.6882
1:1 1:3	0.70	0.9553	1.28	0.7071	0.89	0.8971
1:1 1:4	0.93	0.8833	1.03	0.8389	1.03	0.8390
1:2 1:3	-0.59	0.9755	0.42	0.9933	-0.40	0.9943
1:2 1:4	-0.41	0.9940	0.16	0.9999	-0.31	0.9980
1:3 1:4	0.20	0.9996	-0.27	0.9987	0.11	1.0000

difference existed between the other treatments (3.51g, 3.00g, and 2.65g, respectively; table 2.9 and figure 2.2C).

Response of *Salsola iberica* Biomass

Salsola iberica aboveground biomass ranged from 5.21g to 32.24g with an average of 18.73g. Belowground biomass ranged from 0.38g to 3.23g and averaged 1.60g. Like *B. gracilis*, there was no treatment-by-block interaction for either above- or belowground biomass of *S. iberica* (table 2.4). For aboveground *S. iberica* biomass, there was no significant difference between treatments ($P= 0.0591$) and treatment averages were 21.49g, 17.21g, 18.61g, 17.45g, and 18.78g, respectively (table 2.4 and figure 2.2B). However, for belowground biomass, treatment 0:1 (only *S. iberica*), (2.05g) was significantly greater ($P=0.0036$; table 2.4) than treatment 1:1 (1.37g; $P=0.0078$) and treatment 1:3 (1.32g; $P=0.0047$); treatments 1:2 and 1:4 were not significantly different from any treatments (table 2.5 and figure 2.2F) and had averages of 1.56g and 1.68g, respectively. Total *S. iberica* biomass ranged from 5.59g to 35.36g with an average of 20.32g, and there was no block-by-treatment interaction. Like belowground biomass, treatment had a significant effect on total biomass of *S. iberica* ($P= 0.0323$; table 2.4 and figure 2.2F); treatment 0:1 (only *S. iberica*) (23.54g) was significantly higher than treatments 1:1 (18.58g) and 1:3 (18.77g) (table 2.5 and figure 2.2F). Treatments 1:2 (20.17g) and 1:4 (20.45g) were not significantly different from each other or any other treatments (table 2.5 and figure 2.2F).

Table 2.4 Results of Two-way ANOVAs Testing Effect of *Salsola iberica* Density on *Salsola iberica* Biomass.

*denotes a significant value at $\alpha=0.05$

Aboveground					
Source of Variation	df	SS	MS	F Ratio	P-value
Block	7	226.3658	32.3380	1.6824	0.1428
Treatment	4	191.6993	47.9248	2.4933	0.0591
Block-Treatment	28	446.2929	15.9390	0.8292	0.6939
Error	38	730.4115	19.2214		
Total	77				

Belowground					
Source of Variation	df	SS	MS	F Ratio	P-value
Block	7	2.6717	0.3817	1.3063	0.2739
Treatment	4	5.4666	1.3666	4.6775	0.0036*
Block-Treatment	28	4.4025	0.1572	0.5382	0.9543
Error	38	11.1025	0.2922		
Total	77	23.6433			

Total					
Source of Variation	df	SS	MS	F Ratio	P-value
Block	7	273.6695	39.0956	1.7677	0.1226
Treatment	4	261.0435	65.2609	2.9507	0.0323*
Block-Treatment	28	499.7474	17.8481	0.8070	0.7199
Error	38	840.4494	22.1171		
Total	77	1874.9099			

Table 2.5 Tukey Post Hoc Results for *Salsola iberica* Belowground and Total Biomass. Tukey HSD All Pairwise Comparison results from a two-way ANOVA testing for treatment effect on *S. iberica* biomass. Treatments are the density ratios of *B. gracilis* to *S. iberica* (BG:SI).

*denotes a significant value at $\alpha=0.05$

Treatment Comparison		Belowground		Total	
		t ratio	P-value	t ratio	P-value
0:1	1:1	3.59	0.0078*	2.98	0.0377*
0:1	1:2	2.50	0.1112	1.84	0.3688
0:1	1:3	3.77	0.0047*	2.93	0.0423*
0:1	1:4	1.97	0.2988	1.86	0.3582
1:1	1:2	-0.98	0.8624	-1.06	0.8271
1:1	1:3	0.29	0.9984	0.04	1.0000
1:1	1:4	-1.62	0.4950	-1.13	0.7918
1:2	1:3	1.23	0.7322	1.07	0.8220
1:2	1:4	-0.59	0.9757	-0.04	1.0000
1:3	1:4	-1.86	0.3562	-1.13	0.7878

Average individual *S. iberica* biomass ranged from 2.61g to 32.24g with an average of 11.81g. Treatment had a highly significant effect on *S. iberica* biomass ($P < 0.0001$; table 2.6 and figure 2.6). Treatments 0:1 (21.49g), 1:1 (17.21g), and 1:2 (9.31g) were significantly different from each other as well as treatments 1:3 (5.82g) and 1:4 (4.69g); however, treatments 1:3 and 1:4 were not significantly different from each other ($P = 0.9016$; table 2.7 and figure 2.6).

Table 2.6. Results of Two-way ANOVA Testing Effect of *Salsola iberica* Density on Average Individual *Salsola iberica* Biomass per Pot.

*denotes a significant value at $\alpha = 0.05$

Source of Variation	df	SS	MS	F Ratio	P-value
Block	7	226.3658	32.3380	3.0966	0.0110*
Treatment	4	3381.3051	845.3263	80.9475	<0.0001*
Block-Treatment	28	231.7935	8.2783	0.7927	0.7363
Error	38	396.8301	10.4429		
Total	77	4236.2945			

Table 2.7 Tukey Post Hoc Results for Average Individual *Salsola iberica* Biomass. Tukey HSD All Pairwise Comparison results from a two-way ANOVA testing for treatment effect on average individual *S. iberica* biomass.

Treatments are the density ratios of *B. gracilis* to *S. iberica* (BG:SI).

*denotes a significant value at $\alpha = 0.05$

Treatment Comparison		t ratio	P-value
0:1	1:1	3.74	0.0052*
0:1	1:2	10.25	<0.0001*
0:1	1:3	13.38	<0.0001*
0:1	1:4	14.70	<0.0001*
1:1	1:2	6.62	<0.0001*
1:1	1:3	9.75	<0.0001*
1:1	1:4	10.96	<0.0001*
1:2	1:3	3.04	0.0328*
1:2	1:4	4.01	0.0024*
1:3	1:4	0.88	0.9016

Relationship between *Bouteloua gracilis* and *Salsola iberica* Biomass

Bouteloua gracilis aboveground biomass, belowground biomass, and total biomass were each inversely related to *S. iberica* aboveground, belowground, and total biomass, respectively with R^2 values of 0.576132, 0.091507, and 0.549048 for each.

DISCUSSION AND CONCLUSIONS

Response of *Bouteloua gracilis* to Density and Presence of *Salsola iberica*

Salsola iberica density did not significantly affect *B. gracilis* biomass. However, its presence did significantly reduce *B. gracilis* biomass as *B. gracilis* grown at any density of *S. iberica* produced less biomass than when grown alone. In fact, *S. iberica* presence reduced *B. gracilis* biomass both above and belowground by 77.1% and 48.8 %, respectively (figure 2.2A, B). Overall, presence of *S. iberica* reduced total *B. gracilis* biomass by 76.4% (figure 2.2C). In addition to greatly reducing *B. gracilis* aboveground biomass; *S. iberica* aboveground biomass explained 57.6% of the variation in *B. gracilis* biomass in this study (figure 2.3). *Salsola iberica* belowground biomass had a lesser effect as it only explained 9.15% of the variation in *B. gracilis* belowground biomass (figure 2.4), which indicates that these species are competing differently above- and belowground, a phenomenon documented by other studies (Wilson and Tilman 1993). Total *S. iberica* biomass explained 54.9% of the variation in total *B. gracilis* biomass (figure 2.5). Because over half the variation in *B. gracilis* biomass can be explained by *S. iberica* biomass, reducing *S. iberica* biomass should cause an increase *B. gracilis* biomass.

These findings are similar to results generated from other studies. Lowe et al. (2003) found similar results in their study of *B. gracilis* competition with *B. tectorum* at varying nitrogen levels. They found that at their two middle nitrogen levels (4 and 7 g

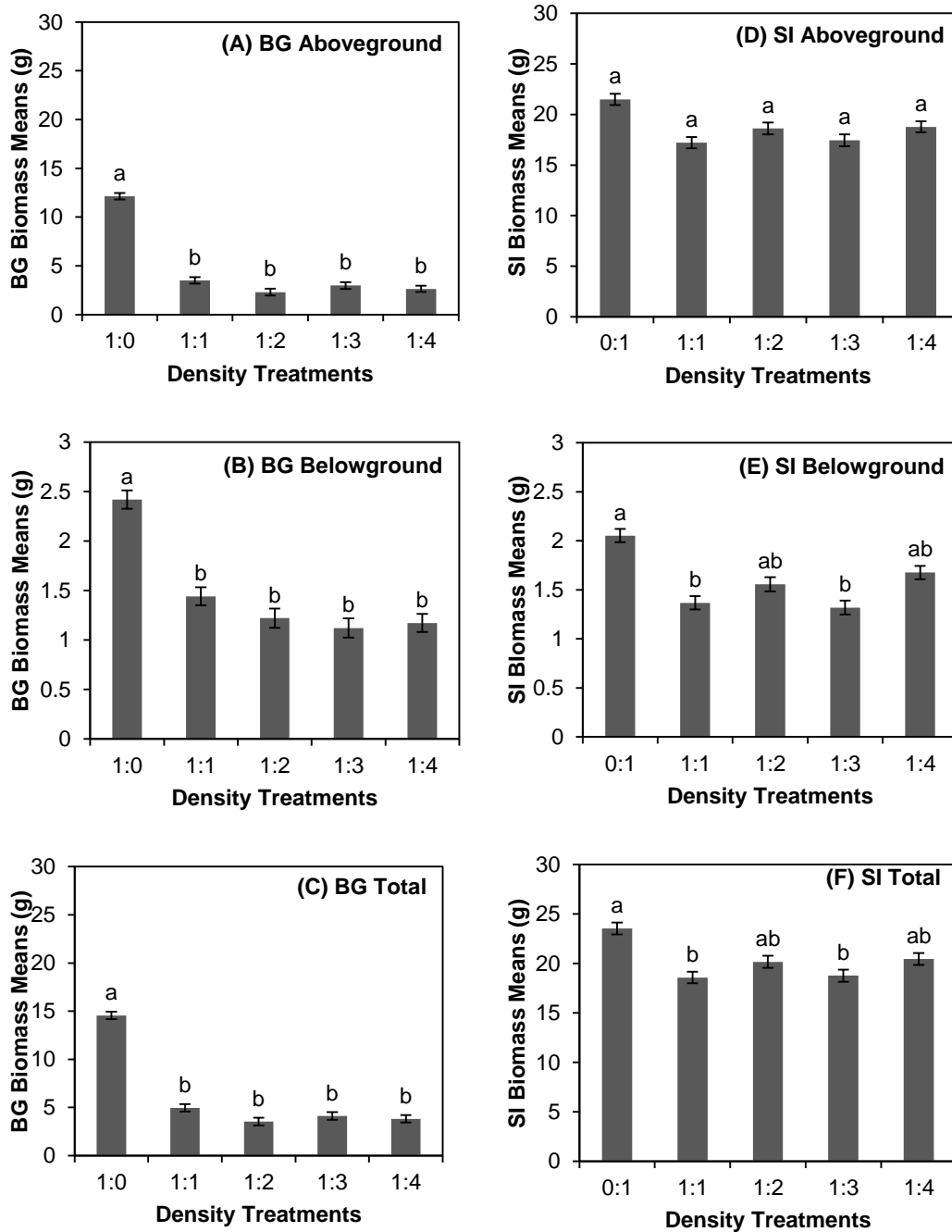


Figure 2.2 Means of *Bouteloua gracilis* and *Salsola iberica* Biomasses. Means of *B. gracilis* (BG) and *S. iberica* (SI) biomasses for each density treatment. Biomass Means are in grams. Density Treatments are ratios of *B. gracilis* individuals to *S. iberica* individuals per pot. Within each graph, columns marked with same letters are not significantly different at $\alpha=0.05$

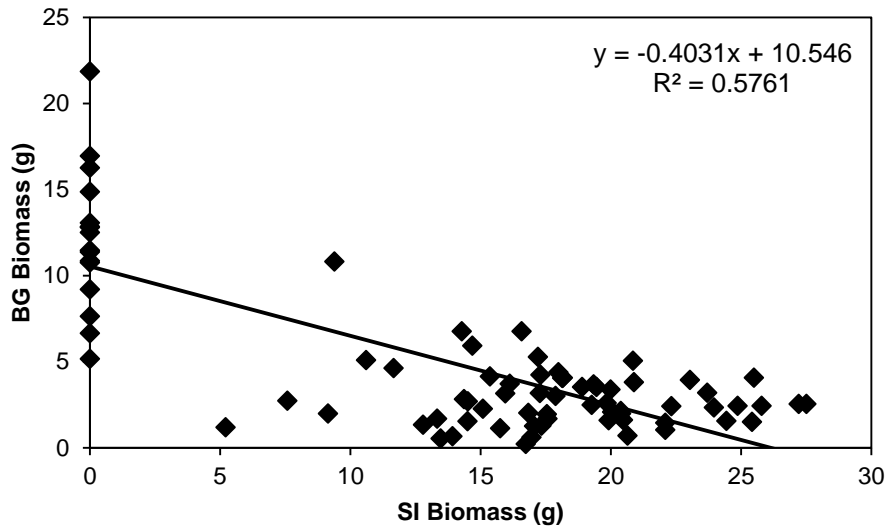


Figure 2.3 Aboveground Biomass Regression. Regression showing the relationship of *Bouteloua gracilis* (BG) aboveground biomass to *Salsola iberica* (SI) aboveground biomass. Biomass values are in grams.

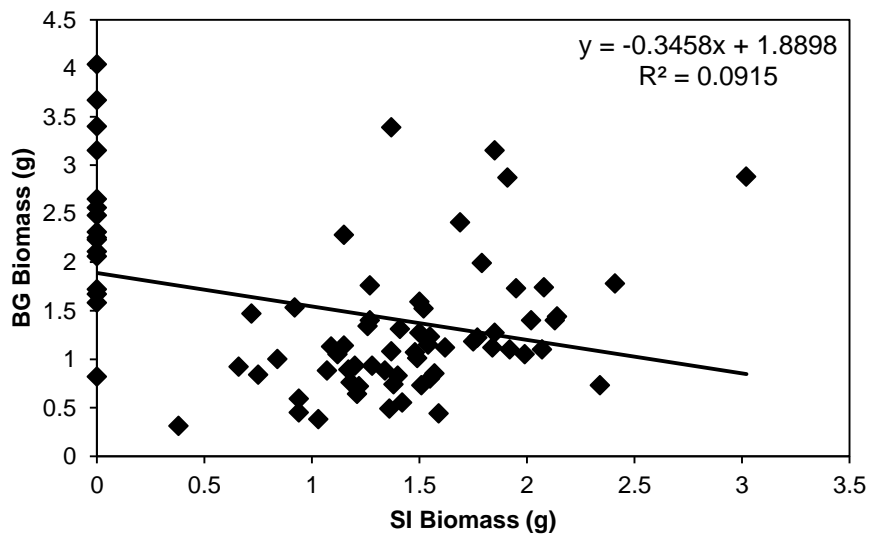


Figure 2.4 Belowground Biomass Regression. Regression showing the relationship of *Bouteloua gracilis* (BG) belowground biomass to *Salsola iberica* (SI) belowground biomass. Biomass values are in grams.

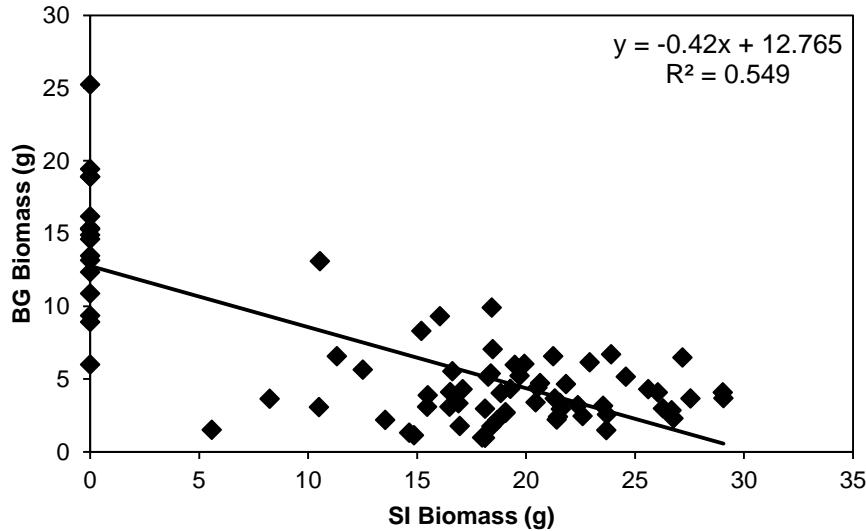


Figure 2.5 Total Biomass Regression. Regression showing the relationship of *Bouteloua gracilis* (BG) total biomass to *Salsola iberica* (SI) total biomass. Biomass values are in grams.

/m²N), *B. gracilis* biomass was reduced by any density of *B. tectorum*, but there was no significant difference in biomass between each treatment grown with the annual grass, except at the highest level of nitrogen tested (10 g /m²N). At the lowest nitrogen levels (0 and 1 g /m²N), density of *B. tectorum* had no effect on *B. gracilis* whatsoever.

***Salsola iberica* Response to Density and Intraspecific Competition**

Even though *S. iberica* aboveground biomass was not significantly affected by density treatments, belowground biomass was significantly reduced by density and competition with *B. gracilis* (figure 2.2D, E). *Salsola iberica* had more root mass when grown by itself (2.05g) compared to when grown with *B. gracilis* (1.37g), or *B. gracilis* and 3 individuals of its own species (1.32g). Yet there was no difference between growing it by itself, and growing it with *B. gracilis* and 2 of its own species (1.56g), and with *B. gracilis* and 4 of its own species (1.68g; figure 2.2E). This indicates that density can affect *S. iberica*, at least its root system, and this effect is larger than the state of no-effect from aboveground biomass because, when added together, total *S. iberica*

biomass shows this same significant pattern (figure 2.2F). This is important because it shows that interspecific competition was more severe belowground than aboveground for *S. iberica* (Wilson and Tilman 1993).

Because all four treatments contained the same amount of *B. gracilis*, it is obvious that competition with the grass is not the only force at play. The average individual biomass per pot significantly decreased by 19.9% going from one *S. iberica* plant grown by itself to one grown with *B. gracilis*, decreased another 45.9% going to two grown with *B. gracilis*, and then decreased a final 43.6% going to three and four each grown with *B. gracilis*; there was no significant difference between the last two treatments (figure 2.6). Thus, *S. iberica* competes better against *B. gracilis* than it does against itself, which corroborates Allen's (1982b) results looking at the effect of moisture regimes on competition of these same species. However in order to explore this intraspecific relationship further, an experiment must be designed in such a way to make sure that *S. iberica* biomass is not constricted by pot size. Because *S. iberica* produced

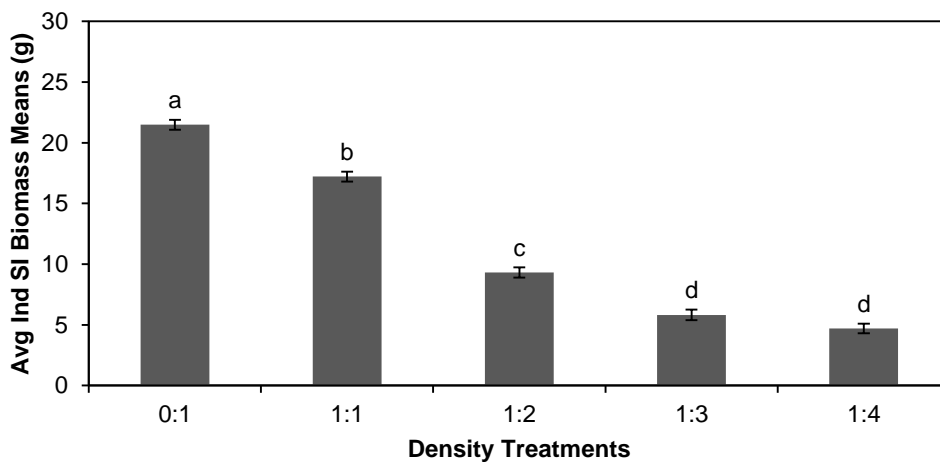


Figure 2.6 Average Individual *Salsola iberica* Aboveground Biomass. Means of average individual *S. iberica* (Avg Ind SI) biomass for each density treatment. Biomass Means are in grams. Density Treatments are ratios of *B. gracilis* individuals to *S. iberica* individuals per pot.

Columns marked with same letters are not significantly different at $\alpha=0.05$.

the same amount of biomass regardless of density, it could be that the plants will use the available resources to generate a certain amount of aboveground biomass regardless of how many individuals are within a constricted area. A good way to eliminate this potential lurking variable would be to either sample above- and belowground biomass in a field study or design experimental plot sizes large enough to ensure that space is not a limiting resource. From this experiment, it appears that *S. iberica* generates a similar amount of biomass regardless of species density. How this happens, what causes this phenomenon, and confirmation of this occurrence in nature needs to be explored before any management practices can be derived. If this does occur in nature and is driven by resource availability, managers could possibly control or at least predict *S. iberica* growth from season to season based on resource abundance and availability.

Summary and Further Study

This study demonstrates that *S. iberica* presence lowers *B. gracilis* biomass, and also that *B. gracilis* and *S. iberica* compete differently for above- and belowground resources (figure 2.2). This variation brings into question the resources for which these species are competing. Aboveground, the main resource these species are more than likely competing for is light (Dybzinski and Tilman 2007). In the glasshouse, I observed that *S. iberica* grew taller than the grass and shaded it. Thus, in pots containing *S. iberica*, *B. gracilis* had less light for photosynthesis resulting in less biomass accumulation. When grown alone, light was likely not a limiting factor on *B. gracilis* production. Belowground, soil nutrients, especially nitrogen, are the most likely drivers of competition (Tilman et al. 1996; Dybsinski and Tilman 2007).

As mentioned previously, density specific competition between *B. gracilis* and *S. iberica* has not been well studied. The interactions between these two species, the drivers causing such competition, and the exact resources and levels of resources for

which these species are competing are still not well understood. One possible avenue for further research was addressed earlier in this section, dealing with experimental pot size creating resource restrictions. This restriction could be causing *S. iberica* to be unaffected by density, when in reality, it would be affected in nature under the same densities.

Another interesting topic for future study is the possibility of *S. iberica* density and *B. gracilis* interactive effects on *S. iberica* biomass. Belowground biomass responded significantly to density treatments, creating an “up-down-up” pattern moving from treatment to treatment (figure 2.2E). Interestingly enough, the reverse of this pattern is present in *B. gracilis* aboveground and total biomass, though not significant. This does elicit questions of whether or not there is some form of interaction between density and *B. gracilis* as they both impact *S. iberica* root growth and overall biomass production. Previous studies have looked at belowground competition and its effect on overall competition and species performance (Wilson and Tilman 1993; Casper and Jackson 1997). Future studies should look into these patterns to determine if they are reflections of this more complicated type of competitive interaction.

Finally, the effect of *S. iberica* density on *B. gracilis* biomass should continue to be studied. While density did not affect *B. gracilis* biomass in the present study, density is expected to play some role in nature. Although there was no significant difference between density treatments, *B. gracilis* produced more biomass when grown with one *S. iberica* plant than when grown with 2, 3, and 4 plants across all 16 blocks. This provides a good opportunity for future studies to look at whether or not increased densities of *S. iberica* could have a significant effect on *B. gracilis* biomass. It may be that the densities tested here are not high enough to reveal a significant effect.

This experiment demonstrated that *S. iberica* presence has a greater effect on *B.gracilis* biomass than its density does, and that density does not affect total *S. iberica* aboveground biomass, but it does reduce belowground biomass at certain levels. This experiment also contributes to the evidence that *S. iberica* has a higher intraspecific than interspecific competition; verification of this intraspecific competition is needed to ensure that experimental pot size is not a lurking variable skewing this conclusion. Future studies should give special focus to higher densities, experimental plot size, and specific competition factors such as resource availability.

LITERATURE CITED

- Allen, E.B. 1982a. Germination and competition of *Salsola kali* with native C₃ and C₄ species under three temperature regimes. *Bulletin of the Torrey Botany Club*. 109:39-46.
- Allen, E.B. 1982b. Water and nutrient competition between *Salsola kali* and two native grass species (*Agropyron smithii* and *Bouteloua gracilis*). *Ecology*. 63:732-741.
- Berner, D., A.L. Lagopodi, J. Kashefi, Z. Mukhina, T. Kolomiets, L. Pankratova. D. Kassanelly, C. Cavin, E. Smallwood. 2014. Field assessment in Greece and Russia, of facultative saprophytic fungus, *Colletotrichum salsolae*, for biological control of Russian thistle (*Salsola tragus*). *Biological Control*. 76:114-123.
- Blackshaw, R.E. 1990. Russian thistle (*Salsola iberca*) and kochia (*Kochia scoparia*) control in dryland corn (*Zea mays*). *Weed Technology*. 4:631-634.
- Blackshaw, R.E. and R.N. Brandt. 2008. Nitrogen fertilizer effects on weed competitiveness is species dependent. *Weed Science*. 56:743-747.
- Brown, M.B. and A.B. Forsythe. 1974. Robust tests for equality of variances. *Journal of the American Statistical Association*. 69:364-367.
- Casper, B.B. and R.B. Jackson. 1997. Plant competition underground. *Annual review of ecology and systematics*. 28:545-570.
- Day, R.W. and G.P. Quinn. 1989. Comparisons of treatments after an analysis of variance in ecology. *Ecological Monographs*. 59:433-463.
- Dewey, L.H. 1893. Russian thistle: the Russian thistle and other troublesome weeds in the wheat region of Minnesota and North and South Dakota. *U.S. Department of Agriculture Farmers' Bulletin No. 10*.1-18.

- Dormaar, J.F., B.W. Adams, and W.D. Willms. 1994. Effect of grazing and abandoned cultivation on a *Stipa-Bouteloua* community. *Journal of Range Management*. 47:28-32.
- Dybzinski, R. and D. Tilman. 2007. Resource use patterns predict long-term outcomes of plant competition for nutrients and light. *The American Naturalist*. 170:305-318.
- Eck, H.V., W.G. McCully, and J. Stubbendieck. 1975. Response of shortgrass plains vegetation to clipping, precipitation, and soil water. *Journal of Range Management*. 28:194-197.
- Fisher, C.E. and P.T. Marion. 1951. Continuous and rotation grazing on buffalo and tobosa grassland. *Journal of Range Management*. 4:48-51.
- Freckleton, R.P. and A.R. Watkinson. 2000. Design for greenhouse studies of interactions between plants: an analytical perspective. *Journal of Ecology*. 88: 386-391.
- JMP. 2012. One-Way ANOVA: Rev 07/2012. *jmp: Statistical Discovery*. From SAS. Available at jmp.com/learn. Accessed 31 Aug 2016.
- JMP. 2014. Two-Way (Factorial) ANOVA: Rev 1/2014. *jmp: Statistical Discovery*. From SAS. Available at jmp.com/learn. Accessed 31 Aug 2016.
- Kostivkovsky, V., and J.A. Young. 2000. Invasive exotic rangeland weeds: a glimpse at some of their naïve habitats. *Rangelands*. 22:3-6.
- Lowe, P.N., W.K. Lauenroth, and, I.C. Burke. 2002. Effects of nitrogen availability on the growth of native grasses exotic weeds. *Journal of Range Management*. 55:94-98.
- Lowe, P.N., W.K. Lauenroth, and, I.C. Burke. 2003. Effects of nitrogen availability on competition between *Bromus tectorum* and *Bouteloua gracilis*. *Plant Ecology*. 167:247-254.
- Mangla, S., R.L. Sheley, J.J. James, and S.R. Radosevich. 2011. Intra and interspecific competition among invasive and native species during early stages of plant growth. *Plant Ecology*. 212:531-542.
- Nord, C.A., C.G. Messersmith, and J.D. Nalewaja. 1999. Growth of *Kochia scoparia*, *Salsola iberica*, and *Triticum aestivum* varies with temperature. *Weed Science*. 47:435-439.
- Patterson, D.T. 1995. Effects of environmental stress on weed/crop interactions. *Weed Science*. 43:483-490.
- Ries, R.E. and T.J. Svejcar. 1991. The grass seedling: when is it established? *Journal of Range Management*. 44:574-576.

- Samuel, M.J. and R.H. Hart. 1992. Survival and growth of blue grama seedlings in competition with western wheatgrass. *Journal of Range Management*. 45:444-448.
- Schillinger, W.F. 2007. Ecology and control of Russian thistle (*Salsola iberica*) after spring wheat harvest. *Weed Science*. 55:381-385.
- Shapiro, S.S. and M.B. Wilk. 1965. An analysis of variance test for normality (complete samples). *Biometrika*. 52:591-611.
- Sokal, R.R. and F.J. Rohlf. 2012. Biometry. 4th Ed. W. H. Freeman and Company. New York, NY; Basingstoke, England. Copyright: 2012,1995,1981, and 1969.
- Stallings, G.P., D.C. Thill, and C.A. Mallory-Smith. 1994. Sulfonylurea-resistant Russian thistle (*Salsola iberica*) survey in Washington State. *Weed Technology*. 8:258-264.
- Tilman, D. 1997. Community invasibility, recruitment limitation, and grassland biodiversity. *Ecology*. 78:81-92.
- Tilman, D., D. Wedin, and J. Knops. 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. *Nature*. 22:718-720.
- Wester, D.B. 1991. A summary of range plant seed germination research. *International Center for Arid and Semiarid Land Studies*. Texas Tech University; Lubbock, TX.
- West Texas Mesonet: Texas Tech University. 2015. West Texas Mesonet Resource Database. For years 2014 and 2015. Available at www.mesonet.ttu.edu/preciphistory.html. Accessed 1 Sept 2015.
- Wiese, A.F., and C.W. Vandiver. 1970. Soil moisture effects on competitive ability of weeds. *Weed Science*. 18:518-519.
- Wilson, S.D. and D. Tilman. 1993. Plant competition and resource availability in response to disturbance and fertilization. *Ecology*. 74:599-611.
- Wynia, R. 2007. Plant fact sheet: Blue gama *Bouteloua gracilis* (Willd. Ex Kunth) Lag. Ex Griffiths. *USDA NRCS Plant Martials Center, Manhattan, Kansas*. Natural Resources Conservation Service. United States Department of Agriculture.
- Young, J.A. 1988. The public response to the catastrophic spread of Russian thistle (1880) and halogeton (1945). *Agricultural History*. 62: 122-130.
- Young, F.L. 1988. Effect of Russian thistle (*Salsola iberica*) interference on spring wheat (*Triticum aestivum*). *Weed Science*. 36:594-598.
- Young, F.L. 2006. Russian thistle (*Salsola* spp.) biology and management. 15th *Australian Weeds Conference*. p. 145-147.

Zar, J.H. 1999. *Biostatistical Analysis* 4th ed. Prentice Hall Inc.; Upper Saddle River, NJ.
Copyright: 1999, 1996, 1984, and 1974.

Chapter III

Effects of *Salsola iberica* Density on *Bouteloua gracilis*

Biomass under Field Conditions

ABSTRACT

The Texas High Plains are dominated by the native perennial grass blue grama (*Bouteloua gracilis*), but environmental conditions of the region make the landscape susceptible to invasive annuals such as Russian thistle (*Salsola iberica*), which may pose a threat to the native species in this region. This study focuses on how density of *S. iberica* affects *B. gracilis* as it competes with the invasive in the field. On the Texas Tech University Natural Resources Management Native Rangeland, an randomized block design (RBD), with 8 blocks each containing 6 quarter-meter plots, was established to test the effect of 5 different *S. iberica* density levels on *B. gracilis* and *S. iberica* biomass. Not only was *B. gracilis* not affected by *S. iberica* presence or density, but *B. gracilis* lowered average individual *S. iberica* biomass at densities of one *B. gracilis* to 2, 3, and 4 *S. iberica* plants. This research demonstrates that mature *B. gracilis* can successfully compete with *S. iberica* in the field, and that *S. iberica* is not always affected by intraspecific competition under field conditions.

INTRODUCTION

Field Environment and its Effect on *Bouteloua gracilis* and *Salsola iberica*

Blue grama (*Bouteloua gracilis*), a native perennial bunchgrass, is an important forage source for wildlife and livestock inhabiting shortgrass prairie rangelands in North America. These rangelands are also occupied by many species of invasive annuals including Russian thistle (*Salsola iberica*). Because *B. gracilis* is such an important species, it is essential to know how it competes with invasive annuals under field

conditions. In the Texas High Plains, extreme heat is common, with summertime temperatures in the lower to upper 30s°C (NOAA 2016a) and photoperiods averaging 14-15 hours (NOAA 2016b). These hot conditions are compounded by frequent drought (National Weather Service 2015). Under the definition of having annual precipitation equal to 75% of the long-term average for a given area (NDMC 2016), the Texas High Plains has been in drought every 3-4 years over the past 114 years (figure 3.1; National Weather Service 2015). Precipitation events that do occur, even in drought, are quick and hard, triggering run-off events that can cause bare ground patches and soil erosion. These variables make the landscape very susceptible to invasive annuals, like *S. iberica*, that can withstand low-moisture conditions and high temperatures.

Many plants that thrive in such environments, including *B. gracilis* and *S. iberica*, use the C₄ photosynthetic pathway. C₄ species generally have a higher heat tolerance than C₃ plants, as well as a higher water use efficiency (WUE) (Allen 1982b; Nord et al. 1999; Zwenger et al. 2010). The advantages of C₄ over C₃ species have been studied in both glasshouse and field experimentation. In all studies, *B. gracilis* and *S. iberica* gained more biomass than C₃ species under higher temperatures and lower moisture conditions (Weise and Vandiver 1970; Allen 1982a and 1982b; Nord et al. 1999). Fewer studies have been conducted looking at competition between the C₄ species *B. gracilis* and *S. iberica*

It is important to understand how *B. gracilis* and *S. iberica* behave in the field to better predict production and abundance of these species in the Texas High Plains. The bulk of field research on *S. iberica* occurs in croplands (Young 1986 and 1988; Blackshaw 1990; Patterson 1995; Nord et al. 1999; Blackshaw and Brandt 2008); however, very few tests have been conducted in a shortgrass prairie or even a rangeland setting, and even fewer deal with competition. *Bouteloua gracilis* on the

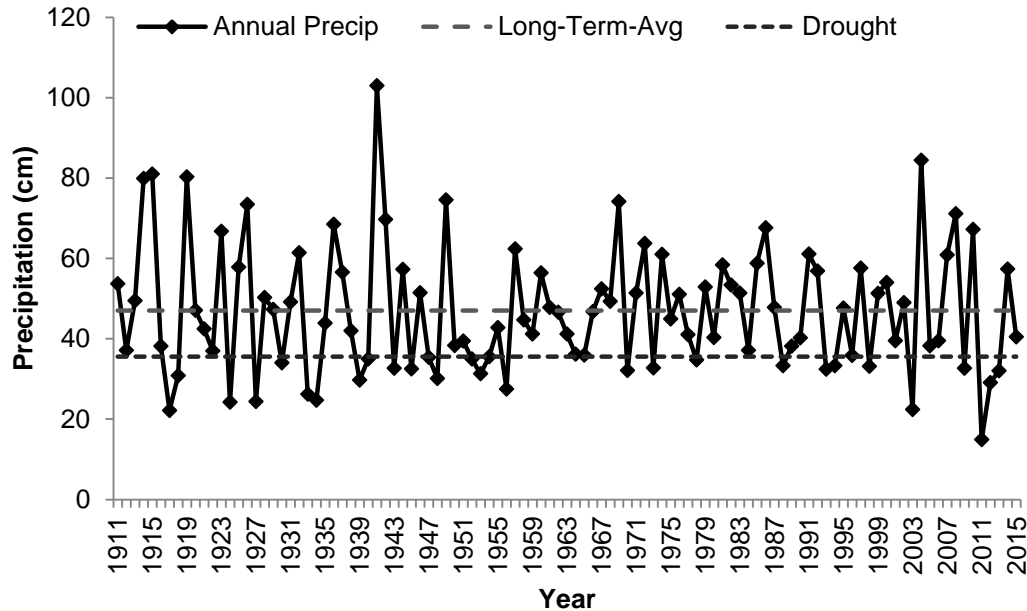


Figure 3.1 Annual Precipitation In Lubbock, Texas, over the Past 104 years. Solid black line represents annual precipitation (annual precip) Lubbock, Texas has received from 1911 to 2015. Top long-dashed line represents the long-term average (long-term avg) precipitation for Lubbock. Bottom short-dashed line represents 75% of the long-term average (drought). Precipitation is in inches (National Weather Service 2015).

other hand, has been well studied in these prairie rangeland systems. Most studies have looked at seedling survival, establishment, and distribution characteristics (Harlan 1958; Eck and Sims 1984; Ries and Svejcar 1991; Dormaar et al. 1994) or growth and production following disturbance (Stuth and Dahl 1974; Coffin and Laurenroth 1988). Special focus has also been given to grazing effects (Brown and Schuster 1969; Currie et al. 1977; Wynia 2007). While few studies have been conducted looking at *B. gracilis* competition under field conditions (Samuel and Hart 1992), even less has been done looking at competition between *B. gracilis* and *S. iberica* in the field. This gap in knowledge makes my research a pivotal study on the responses of these species.

Research Objectives

To explore this competitive relationship, I conducted a field experiment at the TTU Natural Resources Management (NRM) Native Rangeland. The NRM rangeland is

a shortgrass prairie in the High Plains ecoregion of Texas (TPWD 2016). My objectives for this experiment were to 1) determine how *S. iberica* density affects *B. gracilis* biomass in a native rangeland setting, and 2) observe intraspecific competition in *S. iberica* in the field. Findings from this experiment will add to the base knowledge of how these two species behave in a natural and non-constricted environment, and especially how they interact with one another in such environments. My field experiment will not only help land owners better understand range community dynamics, but it will also help researchers understand how *B. gracilis* and *S. iberica* should be studied moving forward and what questions should be answered next.

METHODS

Study Site

The field experiment took place on the TTU NRM Native Rangeland during the summer of 2014. Soils at my site were classified as Acuff-Urban land complex with 0-2 percent slope (WSS 2016) and the area is heavily invaded by mesquite (*Prosopis glandulosa*). During the growing season of 2014, the site received 29.4 cm of precipitation from March through August with average temperatures from March to August in the upper 20s and 30s°C (West Texas Mesonet 2015). This contributed to an abundance of *S. iberica* on the field site. However, in 2015 the site received 52 cm of precipitation over that same time period, with 28.5 cm occurring in May alone (West Texas Mesonet 2015) and, as a result, little to no *S. iberica* grew on the rangeland. Unfortunately, conditions remained unfavorable for the forb in 2016 most likely due to low recruitment from the previous year and precipitation. Therefore, I did not replicate the study in 2015 or 2016. During my 2 month growing season, the NRM Rangeland received a total of 9.32 cm of precipitation (figure 3.2) with average highs/lows of 37.94/17.06°C and 38.89/14.56°C for

each month respectively. Prior to the plots being established, the area had received 20.50 cm of precipitation, with 19.69 cm occurring in April to June (West Texas Mesonet 2015).

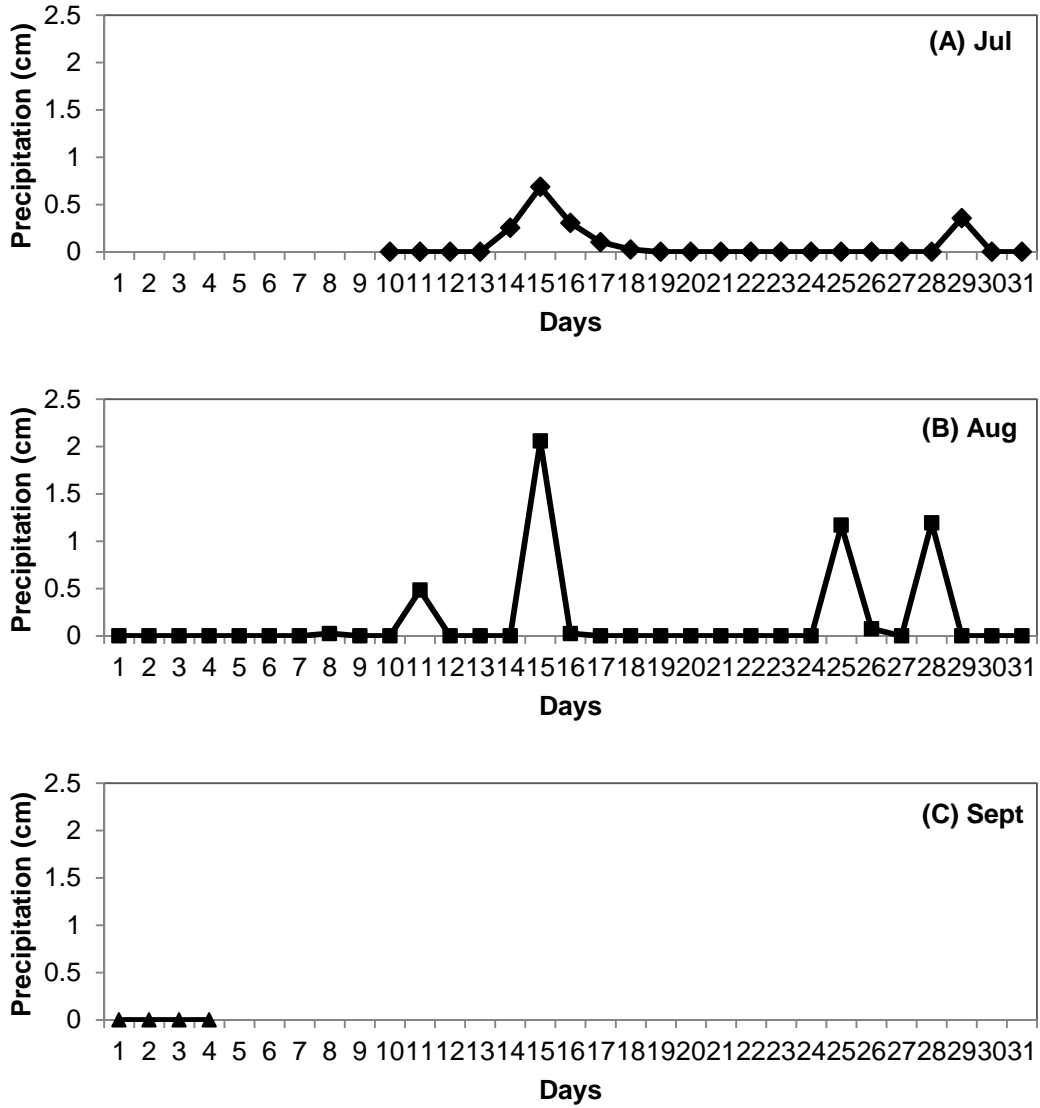


Figure 3.2 Precipitation NRM Rangeland Received over the Course of the Field Experiment. Precipitation that the NRM Rangeland received each day over the course of the 2-month field experiment. Experiment began on 10 July 2014 and ended on 4 September 2014. Precipitation is in centimeters (West Texas Mesonet 2015).

Experimental Design

Because soil and microclimatic conditions can vary across a landscape of this size, this experiment was also established as a randomized block design (RBD) with two replicated sets of blocks. Within two sections of the rangeland, I set up 2 sets of 4 blocks each containing 6 quarter-meter plots which resulted in a total of 48 plots, and each section was approximately 1.3 ha (figure 3.3). I chose areas for plots that contained *B. gracilis* and *S. iberica* and met the following criteria: for *B. gracilis*, the



Figure 3.3 Map of TTU NRM Rangeland. A map of the TTU NRM Native Rangeland depicting the locations of plots during the 2014 field season. Each section contained of a set 4 blocks with 6 quarter-meter plots in each block. Section 1 contained Set A and section 2 contain Set B.

plant's basal area needed to be between 5.1 and 7.6 cm. with new leaf-growth not exceeding 12.7 cm; for *S. iberica*, plants needed to be pliable, contain no elongated lateral stems, and have a height not exceeding 17.8 cm. After staking out plots, I thinned plots to fit the same *B. gracilis* to *S. iberica* density ratios as in the glasshouse study: 1:0, 1:1, 1:2, 1:3, 1:4, and 0:1. All other species present within plots were removed by hand, identified, allowed to dry, and their biomasses weighed and recorded. Once a week, I checked plots and performed additional weeding if needed to insure that assigned ratios remained the same. The experiment ran for approximately two months from the 10th of July until the 4th of September, 2014. On the 4th of September, I harvested aboveground biomass of all plants, bagged and weighed each sample using a spring scale, dried them, and then reweighed them and recorded biomass weights.

Analysis

Prior to formal analysis, I tested datasets for normality and heteroscedasticity using Shapiro-Wilk and Levene's tests, respectively (table 3.1; Levene 1960; Shapiro and Wilk 1965). These tests were non-significant and thus I concluded that the data met with test assumptions and proceeded with analysis. I ran a One-way ANOVA to test the effect of "set" on the data. Because set did not have a significant effect (table 3.1), I ran Two-way ANOVAs with replication, with block and treatment as main effects, on *B. gracilis* biomass, *S. iberica* biomass, and the average individual *S. iberica* biomass per plot to test the effect of density treatment (Zar 1999; Sokal and Rohlf 2012). Density treatments ratios of *B. gracilis* to *S. iberica* were 1:0, 1:1, 1:2, 1:3, and 1:4 for testing *B. gracilis*, biomass, and 0:1, 1:1, 1:2, 1:3, and 1:4 for testing *S. iberica*. I ran Tukey's HSD post hoc tests for mean separation (Day and Quinn 1989). I also ran One-way ANOVAs to test if there was a difference between *B. gracilis* and *S. iberica* biomass within each treatment as well as between *B. gracilis* and average individual *S. iberica* biomass. For

these tests, treatments 1:0 and 0:1 combined to make 1 treatment that represented each species growing without competition and was designated as 1:0/0:1. The other treatments used were 1:1, 1:2, 1:3, and 1:4. Lastly, I ran a regression on *B. gracilis* biomass and biomass of weed species removed from the plots to determine if weed biomass affected my results. Statistical analyses were run in the program JMP 12.2 by SAS (JMP 2012 and 2014).

Table 3.1 P-values from Assumption Tests and Set Effect ANOVA for Field Analysis. P-values for normality, homoscedasticity, and One-Way ANOVAs testing for Set effect for *Bouteloua gracilis* (BG), *Salsola iberica* (SI), and Average Individual SI (Avg Ind SI) biomass.

*denotes a significant value at $\alpha=0.05$

Biomass Type	Assumption Test		Set Effect ANOVA
	Normality	Homoscedasticity	
BG	0.0703-1.0000	0.3135	0.4253
SI	0.1693-1.0000	0.3642	0.4617
Avg Ind SI	0.0517-1.0000	0.3435	0.9683

RESULTS

***Bouteloua gracilis* and *Salsola iberica* Response**

Bouteloua gracilis biomass ranged from 0.47g to 6.5g with an average of 2.27g. There was no significant block-by-treatment interaction (table 3.2). Density did not have a significant effect on *B. gracilis* biomass in the field, as there was no significant difference between any of the 5 treatments for *B. gracilis* biomass (P=0.2624; table 3.2 and figure 3.4) and treatments averaged 2.59g, 2.93g, 1.54g, 2.11g, and 2.11g, respectively. Total biomass of *S. iberica* for this study averaged 2.67g with a range of 0.23g-6.65g. There was, likewise, no significant block-by-treatment interaction for *S. iberica* and treatment had no effect on total biomass of *S. iberica* in the field (P=0.1132; see table 3.2 and figure 3.5). Average individual *S. iberica* biomass per plot ranged from 4.55g to 0.22g and averaged 1.50g, and there was also no significant block-by-treatment

interaction (see table 3.2). Treatment did have a significant effect on average individual *S. iberica* biomass (P=0.0002; see table 3.2 and figure 3.6); treatment 0:1 (only *S. iberica*) (3.27g) was significantly higher than all other treatments (1.71g, 0.86g, 0.94g, and 0.95g, respectively) while all other treatments had no significant difference between them (table 3.3 and figure 3.6).

Table 3.2. Two-way ANOVA Tables Testing Effect of *Salsola iberica* Density on Biomass of *Bouteloua gracilis*, *Salsola iberica*, and Average Individual *Salsola iberica*.

*denotes a significant value at $\alpha=0.05$

		<i>Bouteloua gracilis</i>			
Source of Variation	df	SS	MS	F Ratio	P-value
Block	3	5.3474	1.7825	1.3121	0.3072
Treatment	4	7.9522	1.9880	1.4634	0.2624
Block*Treatment	12	17.0402	1.4200	1.0453	0.4602
Error	15	20.3775	1.3585		
Total	34	50.7171			

		<i>Salsola iberica</i>			
Source of Variation	df	SS	MS	F Ratio	P-value
Block	3	4.9880	1.6627	0.7889	0.5200
Treatment	4	19.1594	4.7898	2.2724	0.1132
Block*Treatment	12	20.5169	1.7097	0.8111	0.6381
Error	14	29.5101	2.1079		
Total	33	74.1743			

		Average Individual <i>Salsola iberica</i>			
Source of Variation	df	SS	MS	F Ratio	P-value
Block	3	4.9880	1.6627	4.2256	0.0253*
Treatment	4	18.5533	4.6383	11.7882	0.0002*
Block*Treatment	12	7.8771	0.6564	1.6683	0.1793
Error	14	5.5086	0.3935		
Total	33	36.9269			

Table 3.3 Tukey Post Hoc Results for Average Individual *Salsola iberica* Biomass. P-values and ratios from Tukey HSD All Pairwise Comparison of treatment effect on *S. iberica*.
*denotes a significant value at $\alpha=0.05$

Treatment Comparison		t ratio	P-value
0:1	1:1	3.30	0.0357*
0:1	1:2	5.55	0.0006*
0:1	1:3	5.78	0.0004*
0:1	1:4	5.49	0.0006*
1:1	1:2	2.49	0.01484
1:1	1:3	2.45	0.1598
1:1	1:4	2.30	0.2032
1:2	1:3	-0.29	0.9982
1:2	1:4	-0.30	0.9979
1:3	1:4	-0.03	1.0000

Differences between Species Biomass within each Treatment

There was no significant difference between *B. gracilis* and *S. iberica* total biomass in treatments 1:0/0:1, 1:1, 1:2, and 1:3 ($P=0.5071$, 0.1606 , 0.6384 , 0.3799 ; table 3.4 and figure 3.7). However, *B. gracilis* in treatment 1:4 ($P=0.0412$; table 3.4) (2.11g) was significantly lower than *S. iberica* (3.78g). Comparing *B. gracilis* biomass to average individual *S. iberica* biomass, there was no significant difference between species biomass in treatments 1:0/0:1, and 1:1 ($P=0.5071$; $P=0.1606g$), but *B. gracilis* had significantly more biomass than *S. iberica* in treatments 1:2, 1:3, and 1:4 ($P=0.0147$; $P=0.0095$; $P=0.0034$; table 3.5 and figure 3.8). Thus, there was no difference between the respective average *B. gracilis* and *S. iberica* biomasses of 2.81g and 3.27g (1:0/0:1), as well as 2.93g and 1.71g (1:1), yet 1.54g and 0.86g (1:2), 2.11g and 0.95g (1:3), and 2.11g and 0.94g (1:4), were significantly different (figure 3.8).

Table 3.4 One-Way ANOVAs Testing for Differences between Species Biomass within Each Treatment. ANOVA tables testing differences between *B. gracilis* biomass and *Salsola iberica* biomass within each treatment

*denotes a significant value at $\alpha=0.05$

Source of Variation	df	SS	MS	F Ratio	P-value
1:0/0:1					
Species	1	0.6120	0.6120	0.4734	0.5071
Error	10	12.9269	1.2927		
Total	11	13.5389			
1:1					
Species	1	5.2094	5.2094	2.2369	0.1606
Error	12	27.9456	2.3288		
Total	13	33.1550			
1:2					
Species	1	0.0972	0.0972	0.2349	0.6384
Error	10	4.1382	0.4138		
Total	11	4.2354			
1:3					
Species	1	1.9321	1.9321	0.8221	0.3799
Error	14	32.9048	2.3503		
Total	15	34.8369			
1:4					
Species	1	9.8281	9.8281	5.2269	0.0412*
Error	12	22.5636	1.8803		
Total	13	32.3917			

Table 3.5 Results from One-Way ANOVAs Testing for Differences between Species Biomass within Each Treatment Using Average Individual *Salsola iberica* Biomass. ANOVA tables testing differences between *B. gracilis* (BG) biomass and the average individual *Salsola iberica* (SI) biomass within each treatment
 *denotes a significant value at $\alpha=0.05$

Source of Variation	df	SS	MS	F Ratio	P-value
1:0/0:1					
Species	1	0.6120	0.6120	0.4734	0.5071
Error	10	12.9269	1.2927		
Total	11	13.5389			
1:1					
Species	1	5.2094	5.2094	2.2369	0.1606
Error	12	27.9456	2.3288		
Total	13	33.1550			
1:2					
Species	1	1.3906	1.3906	8.6647	0.0147*
Error	10	1.6049	0.1605		
Total	11	2.9955			
1:3					
Species	1	5.5225	5.5225	9.0294	0.0095*
Error	14	8.5626	0.6116		
Total	15	14.0851			
1:4					
Species	1	4.7561	4.7561	13.2281	0.0034*
Error	12	4.3145	0.3596		
Total	13	9.0707			

Effect of Weed Biomass on *Bouteloua gracilis*

Other than excess *S. iberica* and *B. gracilis*, 2 grass species, 18 forbs species, and 1 shrub species were removed from the plots during plot establishment (see table 3.6 for a list of species, number of each removed, average biomass, and abundance across plots). Total weed biomass per plot ranged from 1g to 32.96g with an average of 14.44g per plot. The regression of total weed biomass and *B. gracilis* biomass yielded an R² value of 0.0688 with a non-significant ANOVA (P= 0.1280).

Table 3.6 List of Species Removed from Plots. All species removed from plots to create density ratios of *Bouteloua gracilis* and *Salsola iberica*. Origin status: USDA PLANTDatabase 2016.
 *1 plot omitted; contained 207 individuals; average biomass: 0.04g; plot abundance: 58.3%

Scientific name	Common name	# of plots	# of individuals across plots	Average total biomass per plot	Total abundance	Origin status (TX)
Grass						
<i>Digitaria californica</i>	Arizona Cottontop	1	11	4.91g	22.9%	N
<i>Bouteloua gracilis</i>	Blue grama	16	127	4.25g	11.5%	N
<i>Buchloe dactyloides</i>	Buffalograss	20	249	2.72g	17.7%	N
Forb						
<i>Amaranthus blitoides</i>	Mat Amaranth	1	1	0.10g	1.4%	I
<i>Chamaesyce serpens</i>	Small Matted Sandmat	48	1082	2.32g	31.6%	N
<i>Chenopodium album</i>	Lambsquarters	17	251	1.64g	18.6%	N/I
<i>Chenopodium berlandieri</i>	Pitted Goosefoot	43	710	1.19g	21.4%	N
<i>Chenopodium leptophyllum</i>	Narrowleaf Goosefoot	1	4	0.07g	8.33%	N
<i>Croton lindheimeranus</i>	Threeseed Croton	1	1	0.14g	6.67%	N
<i>Helianthus ciliaris</i>	Texas Blueweed	5	21	3.93g	4.68%	N
<i>Kochia scoparia</i>	Kochia Weed	12	81	1.12g	7.63%	I
<i>Oenothera drummondii</i>	Beach Evening Primrose	2	8	2.07g	6.30%	N
<i>Physalis</i> spp.	Groundcherry spp.	1	1	0.08g	7.69%	-
<i>Portulaca oleracea</i>	Little Hogweed	12	17	0.7g	1.99%	N/I
<i>Portulaca pilosa</i>	Rose-flowered Purslane	7*	21	0.71g	3.15%	N
<i>Salsola collina</i>	Slender Russian Thistle	1	1	2.75g	1.54%	I
<i>Salsola iberica</i>	Russian Thistle	43	538	7.95g	17.4%	I
<i>Solanum dimidiatum</i>	Western Horsenettle	4	8	0.44g	2.44%	N
<i>Solanum elaeagnifolium</i>	Silverleaf Nightshade	3	3	0.68g	1.30%	N
<i>Sphaeralcea coccinea</i>	Scarlet Globemallow	8	13	0.38g	1.55%	N
<i>Verberna bipinnatifida</i>	Prairie Verbena	13	24	.23g	3.52%	N
Shrub						
<i>Prosopis glandulosa</i>	Honey Mesquite	2	2	0.07g	1.03%	N

DISCUSSION AND CONCLUSIONS

***Bouteloua gracilis* Response**

This research demonstrates that *B. gracilis* is a strong competitor in the field against *S. iberica* because *S. iberica* density did not impact *B. gracilis* biomass (see figure 3.4). Furthermore, *S. iberica* presence had no significant effect on *B. gracilis* either, as there was no significant difference in *B. gracilis* biomass when grown by its self or when grown with any level of *S. iberica* (figure 3.4). The reason *S. iberica* had no effect on *B. gracilis* in this study could be linked to the grass's life cycle. *Bouteloua gracilis* is a perennial species and as an established perennial, it is likely that *B. gracilis* is robust to single season changes, especially as changes in weed density levels may not be felt until the following growing season. If this is true, then *B. gracilis* would be less affected by *S. iberica* after one growing season and possibly even from season to season. Because it is an annual, *S. iberica* is less likely to come back each season at

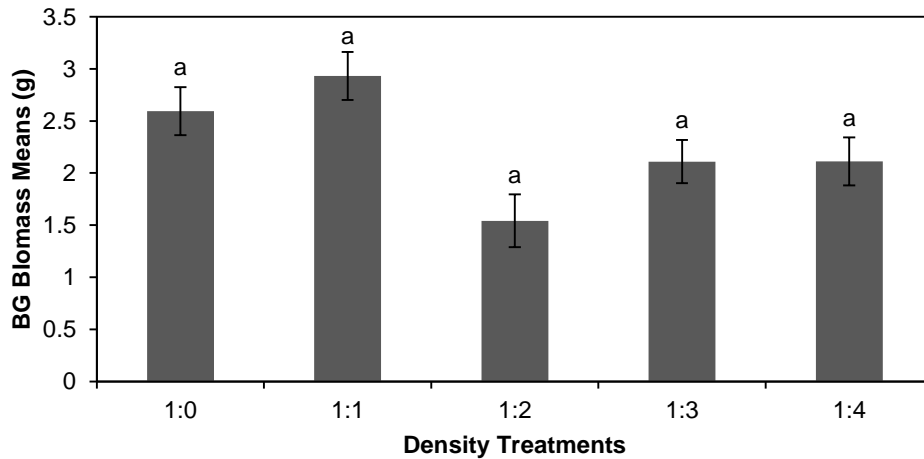


Figure 3.4 Differences in *Bouteloua gracilis* Biomass Means by Treatment. Means for *B. gracilis* (BG) biomass within each treatment. Bars represent Standard Error for Means within a treatment. Density Treatments are ratios of *B. gracilis* individuals to *S. iberica* individuals per plot. Biomass Means are in grams. Columns marked by same letters are not significantly different at $\alpha=0.05$

the same levels, thus the density levels are less likely to remain the same each growing season. This would give the perennial the advantage in that it would be less likely to suffer long-term effects of continuous density levels. These results correspond to previous work that showed that *B. gracilis* is resistant to community changes and further validates the hardy nature already documented for the species (Dormaar et al 1994; Anderson 2003; Wynia 2007).

***Salsola iberica* and Average Individual *Salsola iberica* Responses**

Total *S. iberica* biomass was also unaffected by density as it generate the same total biomass from treatment to treatment (figure 3.5). However, when grown alone, average individual *S. iberica* plants had significantly greater biomass than individuals grown with *B. gracilis* or any other density of *S. iberica* (figure 3.6). When *B. gracilis* or another *S. iberica* plant was present, individual *S. iberica* biomass was reduced by 65.9%. It is apparent that competition with *B. gracilis* can reduce *S. iberica* biomass, which seems rather counter intuitive, because *S. iberica* is an extremely aggressive weed species, growing well in variety of ecosystems (Dewy 1893; Evens and Young 1970; Howard 1992). A possible reason the slower growing *B. gracilis* can outcompete the aggressive forb is that the grass's fibrous root system is better at obtaining water. While both are C₄ species and thus have excellent WUE (Allen 1982a and 1982b; Zwenger et al. 2010), the majority of the grass's root mass in the upper part of the soil column (Hyder et al. 1970), and therefore would be more likely to take advantage of a precipitation event than the tap-rooted *S. iberica* (Anderson 2003). This difference between rooting systems is magnified in areas where run-off is frequent, like at the NRM rangeland where soils are hard. While many studies show that *S. iberica* is more competitive under dry conditions, these studies were either against a C₃ crop species

(Young, F.L. 1988) or were carried out in a glasshouse study where run-off was not a factor (Wiese and Vandiver 1970; Allen 1982b).

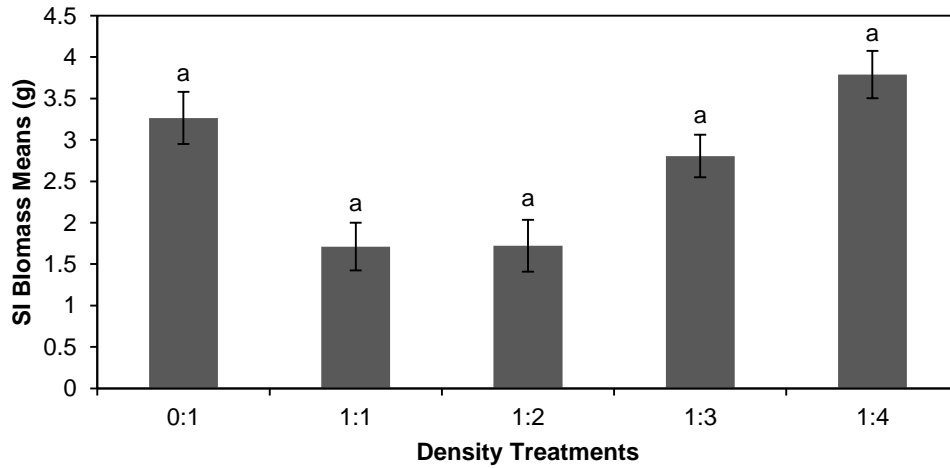


Figure 3.5 Differences in *Salsola iberica* Biomass Means by Treatment. Means for *S. iberica* (SI) biomass within each treatment. Bars represent Standard Error for Means within a treatment. Density Treatments are ratios of *B. gracilis* individuals to *S. iberica* individuals per plot. Biomass Means are in grams. Columns marked by same letters are not significantly different at $\alpha=0.05$

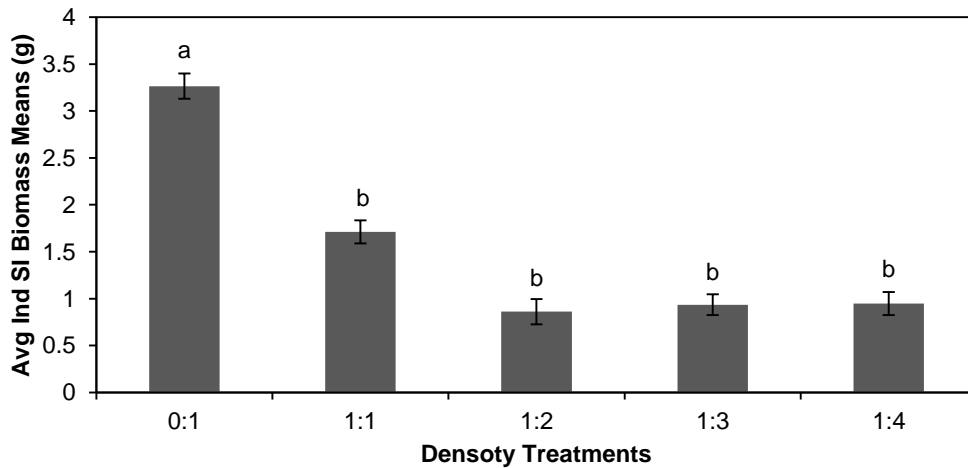


Figure 3.6 Differences in Average Individual *Salsola iberica* Biomass Means by Treatment. Means for average individual *S. iberica* (Avg Ind SI) biomass per plot within each treatment. Bars represent Standard Error for Means within a treatment. Density Treatments are ratios of *B. gracilis* individuals to *S. iberica* individuals per plot. Biomass Means are in grams. Columns marked by same letters are not significantly different at $\alpha=0.05$

Other studies have documented that *S. iberica* has a high intraspecific competition (Chapter II; Allen 1982b; Stallings et al. 1994), yet that was not observed in this field study. In fact, average individual *S. iberica* biomass was not significantly affected by density at all (figure 3.6). This could have also been caused by a difference in water availability. Studies that show intraspecific interactions are either in the glasshouse where water is more readily delivered to the roots, or in field studies conducted in wetter regions, such as Washington State (Chapter II; Allen 1982b; Stallings et al. 1994). In this experiment, the NRM rangeland received 9.32 cm of precipitation over the course of the 2 month field season with temperatures in the lower and upper 30s °C (West Texas Mesont 2015). With little water available, the plants might not have been able to accumulate a sufficient amount of biomass to force detectable competition.

Differences between Species Biomass within each Treatment

Bouteloua gracilis and *S. iberica* generated the same amount of biomass whether grown by themselves or at densities of 1:1, 1:2, and 1:3 (figure 3.7). However, at the density of 1:4, *S. iberica* had 79.1% more biomass than *B. gracilis*. More interesting is the lack of difference at treatments 1:0/0:1 through 1:3. Because there are 2, 3, and 4 *S. iberica* individuals compared to 1 grass, one would expect that *S. iberica* would have more biomass, yet this was not the case. In fact, it only had higher biomass when there were 4 plants. Comparing *B. gracilis* to average individual biomass of *S. iberica* gives a better demonstration of how these species affect each other as individuals. When looking at average individual *S. iberica* biomass compared to *B. gracilis* biomass within each treatment, both species had equal biomass when grown by themselves or with each other at 1:1 (figure 3.8). However, *B. gracilis* actually had 79.1%, 125.7%, and 122.1% more biomass than individual *S. iberica* plants at densities

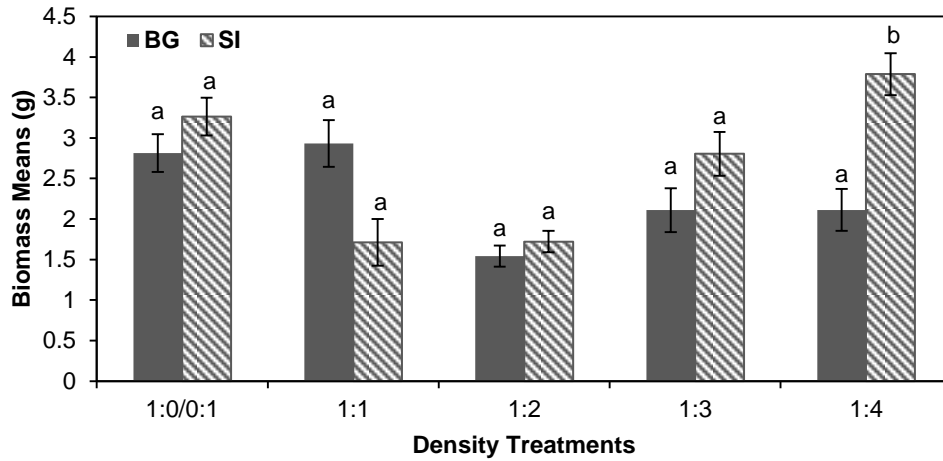


Figure 3.7 Differences between *Bouteloua gracilis* and *Salsola iberica* Biomass within a Treatment. Biomass Means of *B. gracilis* (BG) and *S. iberica* (SI) biomass compared within each treatment. Bars represent Standard Error for Means of each species within a treatment. Density Treatments are ratios of *B. gracilis* individuals to *S. iberica* individuals per plot. Biomass Means are in grams. Columns within a treatment marked by same letters are not significantly different at $\alpha=0.05$

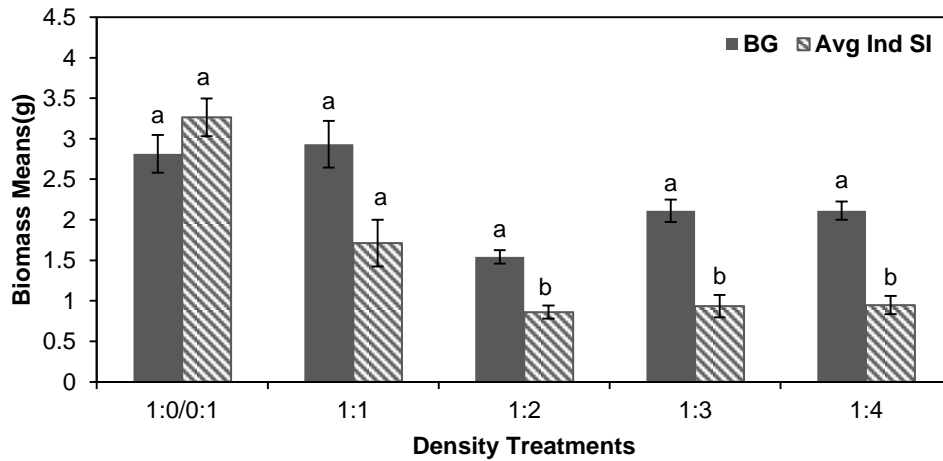


Figure 3.8 Differences between *Bouteloua gracilis* and Average Individual *Salsola iberica* Biomass within a Treatment. Means of *B. gracilis* (BG) and *S. iberica* (Avg Ind SI) biomass compared within each treatment. Bars represent Standard Error for Means of each species within a treatment. Density Treatments are ratios of *B. gracilis* individuals to *S. iberica* individuals per plot. Biomass Means are in grams. Columns with in a treatment marked by same letters are not significantly different at $\alpha=0.05$

of 1:2, 1:3, and 1:4 respectively (figure 3.8). Thus *B. gracilis* out competed the forb in 3 out of the 5 treatments. Although it is easy to suppose that *S. iberica* was impacted by intraspecific competition, which caused the significant effect instead of competition with *B. gracilis*, there was no significant difference in individual *S. iberica* biomass except when *B. gracilis* was present. It would seem that *B. gracilis* is not an inferior competitor in field conditions, but rather, can perform well against the invasive species.

Effect of Weed Biomass on *Bouteloua gracilis*

Biomass of weed species had every little impact on *B. gracilis* biomass as the relationship between these variables was very weak (figure 3.9). This regression also demonstrates *B. gracilis*' resilience to competitive disturbances in rangelands.

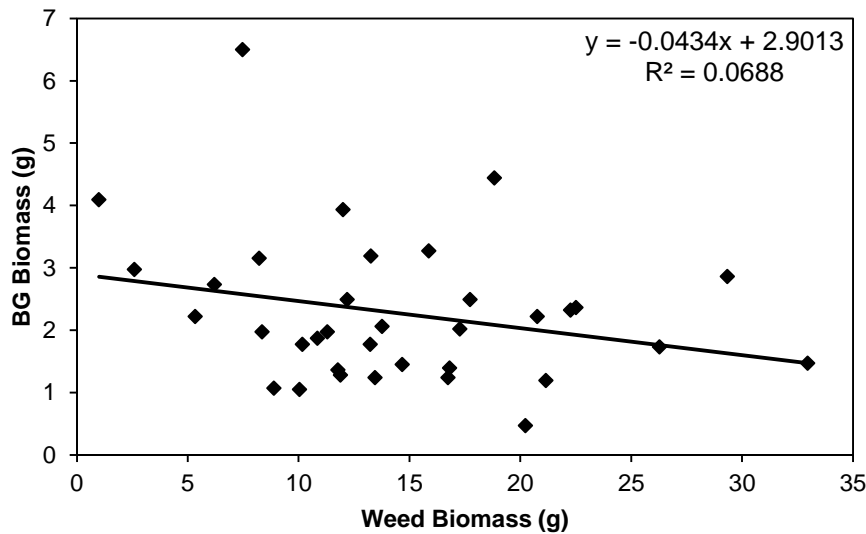


Figure 3.9 *Bouteloua gracilis* and Weed Species Regression. Regression model for *B. gracilis* (BG) biomass and the biomass of all weed species removed from plots. Biomasses are in grams.

Summary and Future Research

This research demonstrates that *B. gracilis* is a strong competitor in the field against *S. iberica*. Not only is its biomass not harmed by the invasive's presence, but it

actually lowered individual *S. iberica* plants' biomass under certain densities. It also shows that *S. iberica* intraspecific competition can be absent under field conditions. Other studies show that *S. iberica* lowers *B. gracilis* biomass under dry conditions (Chapter II; Allen 1982b); however, these studies were typically conducted in a glasshouse setting. These glasshouse studies show how important a role environmental variability plays in the field, and what could happen in the field under certain conditions. Under different weather conditions, such as a difference in precipitation amount, timing, and duration of an event, *S. iberica* might become more competitive. Likewise, soil conditions make a difference in water availability and nutrient uptake, and this is greatly affected by ground cover of neighboring species. Land managers should be less concerned about *S. iberica* competing with *B. gracilis* in rangelands as the grass can produce the same amount of biomass regardless of the invasive's presence. While these results offer practical application for land managers and ecologists, they also provide direction for future research.

Future research should focus on increased density levels, going beyond the 5 levels used here, to determine at what level density does effect *B. gracilis*, or if these results hold true for the grass at any level. Long-term effects on the same area should also be studied. Although it can be aggressive and has remarkable seed production and dispersion ability, *S. iberica* does not persist as a dominant species in plant communities for very long (Howard 1992). Therefore, studies should be conducted looking at how *B. gracilis* is affected by *S. iberica* from year to year, taking special note of *S. iberica* densities within that area each year. Furthermore, research should be conducted at a landscape scale between these two species, and focus on how *S. iberica* seeds enter *B. gracilis* dominated areas, how long the annual is present in that area, where it moves to and how it survives exiting that area, and how *B. gracilis* responds to all these changes.

LITERATURE CITED

- Allen, E.B. 1982a. Germination and competition of *Salsola kali* with native c_3 and c_4 species under three temperature regimes. *Bulletin of the Torrey Botany Club*. 109:39-46.
- Allen, E.B. 1982b. Water and nutrient competition between *Salsola kali* and two native grass species (*Agropyron smithii* and *Bouteloua gracilis*). *Ecology*. 63:732-741.
- Anderson, M.D. 2003. *Bouteloua gracilis*. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available at <http://www.fs.fed.us/database/feis/> Accessed 26 January 2015.
- Blackshaw, R.E. 1990. Russian thistle (*Salsola iberca*) and kochia (*Kochia scoparia*) control in dryland corn (*Zea mays*). *Weed Technology*. 4:631-634.
- Blackshaw, R.E. and R.N. Brandt. 2008. Nitrogen fertilizer effects on weed competitiveness is species dependent. *Weed Science*. 56:743-747.
- Brown, J.W. and J.L. Schuster. 1969. Effects of grazing on a hardland site in the southern high plains. *Journal of Range Management*. 22:418-423.
- Coffin, D.P. and W.K. Laurenroth. 1988. The effects of disturbance size and frequency on a shortgrass plant community. *Ecology*. 69:1609-1617.
- Currie, P.O., D.W. Reichert, J.C. Malechek, and O.C. Wallmo. 1977. Forage selection comparisons for mule deer and cattle under managed ponderosa pine. *Journal of Range Management*. 30:352-356.
- Day, R.W. and G.P. Quinn. 1989. Comparisons of treatments after an analysis of variance in ecology. *Ecological Monographs*. 59:433-463.
- Dewy, L.H. 1893. Russian thistle: the Russian thistle and other troublesome weeds in the wheat region of Minnesota and North and South Dakota. *U.S. Department of Agriculture Farmers' Bulletin No. 10*. 1-18.
- Dormaar, J.F., B.W. Adams, and W.D. Willms. 1994. Effect of grazing and abandoned cultivation on a *Stipa-Bouteloua* community. *Journal of Range Management*. 47:28-32.
- Eck, H.V. and P.L. Sims. 1984. Grass Species adaptability in the southern high plains – a 36-year assessment. *Journal of Range Management*. 37:211-217.
- Evans, R.A. and J.A. Young. 1970. Plant litter and establishment of alien annual weed species in rangeland communities. *Weed Science*. 18:697-703.
- Harlan, J.R. 1958. Blue grama types from west Texas and eastern New Mexico. *Journal of Range Management*. 11:84-87.

- Howard, J.L. 1992. *Salsola kali*. In: Fire Effects Information Systems, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available at <http://www.fs.fed.us/database/feis/>. Accessed 26 January 2015.
- Hyder, D.N., A.C. Everson, and R.E. Bement. 1971. Seedling morphology and seedling failures with blue grama. *Journal of Range Management*. 24:287-292.
- JMP. 2012. One-Way ANOVA: Rev 07/2012. *jmp: Statistical Discovery. From SAS*. Available at jmp.com/learn. Accessed 31 Aug 2016.
- JMP. 2014. Two-Way (Factorial) ANOVA: Rev 1/2014. *jmp: Statistical Discovery. From SAS*. Available at jmp.com/learn. Accessed 31 Aug 2016.
- Levene, H. 1960. Robust tests for equality of variances. In: I. Olkin [ED.]. Contributions to probability and statistics: essays in honor of Harold Hotelling. Stanford, CA, USA: Stanford University Press. p. 278-292.
- National Weather Service. 2015. *National Weather Service Lubbock, TX Weather Forecast Office*.
- NDMC. 2016 National Drought Mitigation Center. University of Nebraska-Lincoln. Available at <http://drought.unl.edu/DroughtBasics/WhatisDrought.aspx>. Accessed 24 Aug 2016.
- NOAA. 2016a. Average Temperatures by Month and Year. National Oceanic Atmospheric Agency. Available at <http://www.srh.noaa.gov/lub/?n=climate-klbb-03>. Accessed 23 Aug 2016.
- NOAA. 2016b. Duration of daylight/darkness table for one year. National Oceanic Atmospheric Agency. Available at http://aa.usno.navy.mil/data/docs/Dur_OneYear.php. Accessed 23 Aug 2016.
- Nord, C.A., C.G. Messersmith, and J.D. Nalewaja. 1999. Growth of *Kochia scoparia*, *Salsola iberica*, and *Triticum aestivum* varies with temperature. *Weed Science*. 47:435-439.
- Patterson, D.T. 1995. Effects of environmental stress on weed/crop interactions. *Weed Science*. 43:483-490.
- PLANTSDatabase. 2016. Plant species database. Natural Resource Conservation Services: United States Department of Agriculture. Available at <http://plants.usda.gov/core/profile>. Accessed 26 Sept 2016.
- Raven, P.H., R.F. Evert, and S.E. Eichhorn. 2005. The carbon-fixation reaction. Photosynthesis, light, and life. Biology of plants. 7th ed. New York, NY, USA: W.H. Freeman and Company. p. 130-132.
- Ries, R.E. and T.J. Svejcar. 1991. The grass seedling: when is it established? *Journal of Range Management*. 44:574-576.

- Samuel, M.J. and R.H. Hart. 1992. Survival and growth of blue grama seedlings in competition with western wheatgrass. *Journal of Range Management*. 45:444-448.
- Shapiro, S.S. and M.B. Wilk. 1965. An analysis of variance test for normality (complete samples). *Biometrika*. 52:591-611.
- Sokal, R.R. and F.J. Rohlf. 2012. Biometry. 4th ed. W. H. Freeman and Company. New York, NY; Basingstoke, England. Copyright: 2012, 1995, 1981, and 1969.
- Stallings, G.P., D.C. Thill, and C.A. Mallory-Smith. 1994. Sulfonylurea-resistant Russian thistle (*Salsola iberica*) survey in Washington State. *Weed Technology*. 8:258-264.
- Stuth, J.W. and B.E. Dahl. 1974. Evaluation of rangeland seedings following mechanical brush control in Texas. *Journal of Range Management*. 27:146-149.
- TWPD. 2016. Texas Ecoregions. *Texas Parks and Wildlife Department*. Available at <https://tpwd.texas.gov/education/hunter-education/online-course/wildlife-conservation/texas-ecoregions>. Accessed 25 Sept 2016.
- West Texas Mesonet: Texas Tech University. 2015. West Texas Mesonet Resource Database. For years 2014 and 2015. Available at www.mesonet.ttu.edu/preciphistory.html. Accessed 1 Sept 2015
- West Texas Mesonet: Texas Tech University. 2016. West Texas Mesonet Resource Database. For the year 2016. Available at www.mesonet.ttu.edu/preciphistory.html. Accessed 22 Sept 2016
- Wiese, A.F., and C.W. Vandiver. 1970. Soil moisture effects on competitive ability of weeds. *Weed Science*. 18:518-519.
- WSS 2016. Web Soil Survey: Area of Interest Soils Report. Natural Resource Conservation Service. Available at <http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx>. Accessed 25 Sept 2016.
- Wynia, R. 2007. Plant fact sheet: Blue grama *Bouteloua gracilis* (Willd. Ex Kunth) Lag. Ex Griffiths. *USDA NRCS Plant Materials Center, Manhattan, Kansas*. Natural Resources Conservation Service. United States Department of Agriculture.
- Young, F.L. 1986. Russian thistle (*Salsola iberica*) growth and development in wheat (*Triticum aestivum*). *Weed Science*. 34: 901-905.
- Young, F.L. 1988. Effect of Russian thistle (*Salsola iberica*) interference on spring wheat (*Triticum aestivum*). *Weed Science*. 36:594-598.
- Zar, J.H. 1999. Biostatistical Analysis 4th ed. Prentice Hall Inc.; Upper Saddle River, NJ. Copyright: 1999, 1996, 1984, and 1974.

Zwenger, S.R., R. Alsaggaf, and C. Basu. 2010. Does an expressed sequence tag (EST) library of *Salsola iberica* (tumbleweed) help to understand plant responses to environmental stresses?. *Plant Signaling and Behavior*. 5:1330-1335.

Chapter IV

Conclusion

Salsola iberica density had no effect on *B. gracilis* biomass or total aboveground *S. iberica* biomass in either of the experiments reported in this thesis. In the glasshouse, *S. iberica* generated the same biomass regardless of density. One possible explanation of this phenomenon was that the pot size could have restricted growth in such a way that it generated the same biomass. However, total aboveground *S. iberica* biomass in the field was also unaffected by density, thus it is unlikely that pot size contributed to that result in the glasshouse.

The glasshouse and field experiments yielded differing results in other aspects as well. For example, in the glasshouse, *S. iberica* presence significantly reduced *B. gracilis* biomass. In the field *S. iberica* presence did not significantly affect *B. gracilis* biomass production. *Salsola iberica* intraspecific competition was detected in the glasshouse, but not in the field. These differences could be attributed to water availability, *B. gracilis* maturity, and pot/plot size. While glasshouse conditions attempted to mimic field conditions, plants in the glasshouse still had more water available than those in the field. For example, the pots in the glasshouse received an excess of water to ensure establishment of each species, which is a common practice in glasshouse studies (Weise and Vandiver 1970; Allen 1982b). While watering was cut to more natural conditions the last month of the experiment, the previous watering likely improved the root systems of *S. iberica* beyond what would have been present in the field during 2014. Thus, overall competition would have been altered.

Evapotranspiration was likely lower in the glasshouse than in the field due to lack of wind, increased humidity, and the presence of the enclosed structure itself. This would allow the water given the plants time to remain in the soil longer and be absorbed

by the plants before evaporating. Also, the pots were able to hold water until it penetrated the root zone; in the field, especially when the ground is hardened, run-off can cause what little moisture that does occur to be unavailable to plants' systems roots. Thus, even though the field received 9.32 cm of precipitation, this full amount was more than likely unavailable to the plants, where as in the glasshouse, plants are able to use much of the water given to them. Furthermore, plants were watered daily in the glasshouse, where in the field, precipitation occurred sporadically over the 2 month period (figure 3.2). These differences in watering regimes demonstrate the importance of moisture and its effect on these two species and their competitive abilities.

Another major difference between these experiments is that of *B. gracilis* maturity level. In the glasshouse, *B. gracilis* was competing as newly established plants, but in the field, I used mature stands of *B. gracilis* that had endured many previous growing seasons. *Bouteloua gracilis* likely performed better against *S. iberica* in the field because it had more root mass, and a larger crown for resource storage. Therefore, my results indicate that *S. iberica* could be of special concern in newly established *B. gracilis* stands. In mature stands, however, it appears that *B. gracilis* can successfully compete against *S. iberica*.

COMPARISON BETWEEN THIS STUDY AND CURRENT LITERATURE

Studies looking directly at *S. iberica* density effects on *B. gracilis* are practically nonexistent in the literature, which makes my study a valuable addition to our current knowledge. However, the findings presented here are similar to those in several previous studies that investigated *B. gracilis* competition with other plants. Lowe et al. (2003) found a similar reaction to density when considering *B. gracilis* competition with cheatgrass (*Bromus tectorum*), an invasive annual grass. In their glasshouse study,

densities were maintained at a constant of 5 plants per pot as they manipulated the ratio of *B. gracilis* to the invasive grass. They found that at intermediate nitrogen levels (4 and 7 g /m²N), *B. tectorum* density did not have an effect on *B. gracilis* biomass, but *B. tectorum* presence did. At low levels of nitrogen (0 and 1 g /m²N), *B. gracilis* was not affected by the invasive grass at all. In my study, *B. gracilis* behaved the same way; *S. iberica* presence reduced *B. gracilis* biomass, yet density had no effect.

Allen (1892b) conducted a glasshouse study looking at the effect of moisture regimes on *B. gracilis* and *S. iberica* competition. She found that when grown together, the *S. iberica* had higher aboveground biomass than *B. gracilis* under dry conditions, though under wet conditions, *B. gracilis* actually had higher biomass. In my glasshouse study, I recorded similar results. In the same study, Allen found that individual *S. iberica* plants had a higher aboveground biomass when grown with *B. gracilis* than when grown by itself, suggesting that *S. iberica* has a greater intraspecific competition than interspecific. This too was echoed in my findings in the glasshouse experiment.

Several other field studies looking at *B. gracilis* competition vary slightly from the results found here. Samuel and Hart (1992) conducted a study looking at *B. gracilis* competition with western wheatgrass (*Elymus smithii*) under field conditions. In that study, they inserted *B. gracilis* seedlings into openings of varying sizes in *E. smithii* dominated sod fields. They found that *B. gracilis* had a higher survival rate and higher biomass in lower competition treatments. In my study, I found that *B. gracilis* was unaffected by *S. iberica* competition; this difference is more than likely caused by differing competitor species, and perhaps, maturity level of *B. gracilis*. Comparing *S. iberica* results from my field study with others is a hard task as most *S. iberica* studies look at competition against C₃ crop species. In such studies, *S. iberica* reduces crop

biomass, especially in dry years (Young 1988; Schillinger 2007). In this study, *S. iberica* was an inferior competitor in the field against *B. gracilis*, a hardy C₄ grass.

APPLICATION AND FUTURE STUDY

Land managers do not need to expend additional resources to remove *S. iberica* from mature *B. gracilis* dominated rangelands because *B. gracilis* can thrive in areas occupied by *S. iberica*. In areas newly planted to *B. gracilis*, *S. iberica* could be more problematic and should be considered for control. Yet even then, the forb's transient nature makes it less threatening to a dominant perennial like *B. gracilis*. On rangelands where grazing occurs, *S. iberica* is even less of a problem as grazing has been shown to effectively reduce *S. iberica* and increase *B. gracilis* (Eck and Sims 1984). In years of above-average precipitation, *S. iberica* is inconsequential in rangelands as it can have remarkably reduced germination and establishment in such areas under wet conditions (Howard 1992), which I observed in 2015 and 2016. Management plans should also take into account the amount of precipitation received, the season in which it came, and the duration of those precipitation events.

Moving forward from this study, research should continue to look at *S. iberica* density and its impact on *B. gracilis*. While increasing densities did not harm *B. gracilis* growth in this study, obviously *S. iberica* density will eventually have an effect on *B. gracilis* if the forbs numbers persistently increase. Future research should identify that density threshold and determine if such density levels could be reached in a natural setting. Studies should also explore how *S. iberica* establishes and disperses its seeds on a landscape scale, and how *B. gracilis* is impacted by these cycles from season to season. The intraspecific competitive nature of *S. iberica* should also be researched to determine how environmental conditions impact this process. Furthermore, future

studies need to encompass multiple growing seasons. My research serves as an exploratory study to begin understanding how these species interact during a single growing season. Multiple growing seasons need to be studied to investigate the interactions between *B. gracilis* and *S. iberica* and determine if my results hold true across time.

LITERATURE CITED

- Allen, E.B. 1982b. Water and nutrient competition between *Salsola kali* and two native grass species (*Agropyron smithii* and *Bouteloua gracilis*). *Ecology*. 63:732-741.
- Eck, H.V. and P.L. Sims. 1984. Grass Species adaptability in the southern high plains – a 36-year assessment. *Journal of Range Management*. 37:211-217.
- Lowe, P.N., W.K. Lauenroth, and, I.C. Burke. 2003. Effects of nitrogen availability on competition between *Bromus tectorum* and *Bouteloua gracilis*. *Plant Ecology*. 167:247-254.
- Samuel, M.J. and R.H. Hart. 1992. Survival and growth of blue grama seedlings in competition with western wheatgrass. *Journal of Range Management*. 45:444-448.
- Schillinger, W.F. 2007. Ecology and control of Russian thistle (*Salsola iberica*) after spring wheat harvest. *Weed Science*. 55:381-385.
- Wiese, A.F., and C.W. Vandiver. 1970. Soil moisture effects on competitive ability of weeds. *Weed Science*. 18:518-519.
- Young, F.L. 1988. Effect of Russian thistle (*Salsola iberica*) interference on spring wheat (*Triticum aestivum*). *Weed Science*. 36:594-598.