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Title: The Impact of Fuel Load and Burn Season on the Growth and Reproductive Capacity of an Invasive Legume, *Lespedeza cuneata*.

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Sericea lespedeza is an invasive plant expanding its range through the grasslands of the Great Plains, displacing native grasses and reducing plant diversity. Invasive species cost the US economy billions of dollars each year. Given the historical loss of grasslands and the economic cost of invasive species, it is important to find sustainable management options. I evaluated the effect of burn season in conjunction with other common management strategies on the reduction of sericea lespedeza. We burned plots in spring, fall or unburned control, which were divided into four subplots receiving a secondary treatment of herbicide, mowing, fuel load addition, or burn only. In each subplot, biomass, stem height, stem count, and seed production were measured. Results indicate that fall burning in conjunction with mowing results in the greatest reduction of stem height, seed weight, and plant biomass. Mowing after a fall fire appears to have the greatest impact on reducing seed production. The investment in seed production was reduced from 2014 to 2015, with plants that experienced fall fire and no fire having significantly less investment in seed production than plants experiencing spring fire regardless of secondary treatment. Because sericea lespedeza is a prolific seed producer, the reduced investment in seed production is important for its control. This study shows that fall fire in conjunction with mowing treatments can significantly reduce seed production of sericea lespedeza without the use of harmful herbicides.

THE IMPACT OF FUEL LOAD AND BURN SEASON ON THE GROWTH AND REPRODUCTIVE CAPACITY OF AN INVASIVE LEGUME, *LESPEDEZA CUNEATA*

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PREFACE

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INTRODUCTION

Biological invasions of non-indigenous species have been happening since humans have been moving across the landscape, resulting in displacement of native species and threatening ecosystems around the world (Eddy and Moore 1998). An invasive plant is described by Foy and Inderjit (2001) as an introduced species that becomes established and spreads outside of the native range, with potential to alter ecosystem function and reduce biodiversity. Many invasive species have been deliberately introduced for various reasons, such as forage species, and have become invasive after they escape cultivation. These species are unique because they are selected for traits that promote establishment and persistence in monocultures, which also facilitates their success as invaders into native ecosystems (Cummings et al. 2007). These invasions have serious ecological and economic consequences and can affect biodiversity, ecosystem structure and function, and agricultural production (Smith and Knapp 2001; Allred et al. 2010).

Sericea lespedeza (*Lespedeza cuneata*) is an invasive legume expanding its range in the grasslands of the Great Plains, and thereby displacing native grasses and reducing native plant diversity. Sericea lespedeza was introduced to the United States from China and Japan in the 1930s for forage and soil conservation (McGraw and Hoveland 1985). Sericea lespedeza has expanded its range partly due to intentional plantings, but has also unintentionally spread due to its invasive qualities (Wong et al. 2012) (Figure 1). It is now a common invasive legume throughout the eastern United States (McGraw and Hoveland 1985) that threatens to destroy the quality and productivity of the tallgrass prairie (Eddy and Moore 1998). Sericea lespedeza has altered the prairie's vegetation composition and density by reducing genetic diversity of native plants and may severely inhibit restoration of native biodiversity and habitat (Eddy and Moore 1998; Foy and Inderjit 2001).

Several factors that contribute to the invasiveness of sericea lespedeza include the ability to thrive in poor soil, multiple fertilization methods, drought tolerance, stress tolerance, ability of nitrogen fixation, prolific seed production, low palatability to livestock, and allelopathic qualities (Logan, Hoveland and Donnelly 1969; McGraw and Hoveland 1985; Young 2000; Brandon, Gibson and Middleton 2004; Allred et al. 2010). Invasive success depends on the traits of individual species as well as the invasibility of the plant community (Smith and Knapp 2001). No single trait or group of traits can explain the success of invasive species (Smith and Knapp 2001). Rather than focus on methods of invasion, it may be more useful to focus on life stages at which invaders are most vulnerable to control (Wong et al. 2012).

Sericea lespedeza has been listed as a county option noxious weed in Kansas since 1988 and was declared a noxious weed in 52 out of 105 Kansas counties by 1995 (Eddy and Moore 1998), becoming a state-wide noxious weed in Kansas in 2000 (Eddy, Davidson and Obermeyer 2003). The number of hectares infested with sericea lespedeza in Kansas increased from 3,200 in 1988 to 187,492 in 2001, and the plant had infested 72 of the 105 counties by 2002, an increase of approximately 14,000 hectares per year (Eddy, Davidson and Obermeyer 2003). The current invasion rate of sericea lespedeza is approximately a 2% increase in vegetative cover per year (Cummings, Fuhlendorf and Engle 2007).

The spread of sericea lespedeza has had a dramatic effect on native grasses in the Flint Hills, as well as grasses currently used for crops and grazing, with reduced grass forage leading to reduced grazing income (Eddy, Davidson and Obermeyer2003; Brandon, Gibson and Middleton 2004; Cummings, Fuhlendorf and Engle 2007). The 1995 Pest Risk Analysis indicated that the annual economic impact would approach $29 million per year, assuming a 75% reduction in quality forage available to livestock (Eddy and Moore 1998). Invasive species, including sericea lespedeza, are estimated to cost U.S. agricultural production approximately $33 billion dollars a year with a total cost of $314 billion per year on the U.S. economy (Cummings, Fuhlendorf and Engle 2007).

Sericea lespedeza can reduce grass production in native tallgrass prairie by as much as 92%, reduce species richness from 27 species to 8 species (Eddy and Moore 1998), and reduce grass and forb species by 66% and 70%, respectively, which drastically changes the biodiversity and ecology of the grassland ecosystem (Eddy, Davidson and Obermeyer 2003). Sericea lespedeza density significantly affects species richness in tallgrass prairies and is inversely related to forb species richness (Baldwin-Blocksome 2006). Sericea lespedeza has the potential to dominate the native grasslands (Eddy, Davidson and Obermeyer 2003). Grasslands once accounted for over 40% of global plant cover. With estimates of only 10% of the original North American tallgrass prairie remaining, conservation and restoration efforts are critical in preserving the remaining tracts of this ecologically and economically valuable biome (Samson and Knopf 1996). Given the historical loss of grasslands and the economic cost of invasive species, it is especially important to find successful management options.

Current control methods of herbicide treatment and mowing are costly and are relatively ineffective in the long term (Wong et al 2012). Currently, only a few herbicides are effective at controlling sericea lespedeza; however, they also kill native non-target plants and are ineffective at killing seeds stored in the seedbank, making permanent eradication with herbicide highly unlikely (Eddy, Davidson and Obermeyer 2003; Cummings, Fuhlendorf and Engle 2007). Repeated applications of herbicides are expensive and do not have a worthwhile long-term effect on control of sericea lespedeza (Eddy, Davidson and Obermeyer 2003; Cummings, Fuhlendorf and Engle 2007). In addition, herbicide use to reduce dominance of sericea lespedeza has not resulted in any increase in grass or forb biomass (Cummings, Fuhlendorf and Engle 2007). Mowing sericea lespedeza infestations has some success if under three inches of stem is left in place; however, this is not possible with most mowing or haying machinery because of difficult terrain (Young 2000).

Annual spring fires commonly used in the Flint Hills to increase forage production have been found to increase germination and spread of sericea lespedeza (Cummings et al. 2007). Traditionally, burning pastures has been used to increase grass production and decrease tree and shrub overgrowth. However, these burns likely encourage spread of sericea lespedeza by scarifying the seed coat, promoting germination, and are therefore unlikely to control the invasive weed (Young 2000; Wong et al. 2012). Soil surface temperatures during annual spring grassland burns often do not reach high enough temperatures for sufficient durations to decrease seed viability, especially for seeds in the seed bank (250˚ is the minimum temperature for seed mortality) (Young 2000, Bell 2012). While fuel load and fire temperatures are greater in burned pastures under a 3-year patch burn fire management plan compared to annual full burn pastures, the fire temperature was often below the lethal threshold to effectively reduce seedling density (Bell 2012). Additionally, a full spring burn once every three years failed to control sericea lespedeza after a six year time period had elapsed, and resulted in large increases in sericea lespedeza compared to patch burn treatments under which only a small part of the pasture was burned on a rotational schedule (Cummings, Fuhlendorf and Engle 2007). Much money and effort is put into the control of sericea lespedeza each year with little to no effect on its spread.

The addition of fuel load to fires has been shown to increase maximum fire temperature, increase damage and mortality rate of shrubs, and decrease re-sprout density (Thaxton and Platt 2006). However, the above-ground severity of fire is not indicative of below-ground temperature increases. The maximum temperature below the soil surface is influenced by moisture content during fire, with dry soil attaining temperatures much higher compared to moist soil (Hartford and Frandsen 1992; Busse et al. 2005). Seed viability of sericea lespedeza drops significantly at 225˚ C and seeds are inviable at 250˚ C. A typical prairie burn reaches 350˚ C - 400˚ C at ground level, but sub-surface temperature (5 cm) rarely reach even 80° C, so fires have little effect on seeds already in the seedbank (Bell 2012).

This project was designed to evaluate the impact of fire season on sericea lespedeza both independently and in conjunction with other commonly used management strategies. I evaluated the control of sericea lespedeza by measuring vegetative performance as individual plant mean stem count, mean stem height, mean aboveground standing biomass, and by reproductive performace as mean total seed mass and the ratio of seed mass to biomass after treatment with herbicide, mowing, fuel load addition, and fire only in conjunction with spring fire, fall fire, and no fire. The objective of this experiment was to manipulate fire season with secondary treatments in hopes to provide land managers with additional tools to control sericea lespedeza while preserving the integrity of the tallgrass prairie ecosystem. Using targeted burning at vulnerable points within the plant's life cycle, prescribed fall fire has potential to reduce the growth and reproductive capacity of sericea lespedeza. Fall fire with supplemental fuel load addition will likely have a higher fire temperature; therefore, I expected this treatment to have the greatest impact on sericea lespedeza growth and seed production. By burning in the fall, that season's seed set would be more likely to be destroyed by the fire, compared to spring burns when seeds have had several months to work their way into the seed bank or become scarified to promote germination.

MATERIALS AND METHODS

Study Site

The study site is located within the Marais des Cygnes National Wildlife Refuge near Pleasanton, Kansas (38.2250° N, 94.6500° W) and is a prairie restoration planted with native tallgrass species and native forb species approximately 25 years ago. The site has a widespread and evenly dispersed sericea lespedeza infestation with sericea stem densities up to 353 stems / m^2. Growing season precipitation went from 44.4 cm in 2014 to 76.3 cm in 2015, which equates to a 72% increase in growing season precipitation (Western Region Climate Center, 2016) (Table 1). A baseline burn was administered across the entire study site in March 2014 before treatments began.

Burn Treatments

The site was divided into 50-m by 50-m burn plots (Figure 2). Burn treatments were randomly assigned to each plot as spring annual, fall annual, and unburned with four replicate plots of each burn treatment. Triennial burn treatments are also occurring at the site, but are not used in this study. Spring burns occurred between March and April, fall burns occurred in October. Plots designated as unburned controls did not receive any burning treatment. The first year of the study is considered pre-burn treatment (2014) and the second year post-burn (2015), with no triennial data to be collected in 2016.

Secondary Treatments

Each 50-m by 50-m burn treatment was divided into four subplots receiving an additional treatment at random of fuel load, herbicide addition, or mowing, with the fourth section receiving fire only (except in unburned plots). Fuel load addition was administered by broadcasting approximately 500 pounds of prairie hay (½ hay bale), by hand throughout each subplot 1-2 weeks before the burn to allow it to settle. This application rate approximates a doubling of annual productivity. It was checked for sericea lespedeza before being allowed on the site. No sericea lespedeza was found in the hay used for fuel load addition or the site that the hay was cut from. No secondary treatment of fuel load addition was applied to unburned plots, but unburned plots did receive secondary treatments of herbicide and mowing. Herbicide treatment involved spraying mid-summer of 2014 with triclopyr (Dow Remedy® EC) using an ATV with boom sprayers. Mowing of designated sub-plots was done mid-summer (late-July) with a tractor and mowing attachment. Plots designated as burn-only received no secondary treatment of herbicide, mowing, or fuel load addition, but did receive the assigned burn unless the burn treatment was an unburned control.

Plant Selection and Tagging

Individual sericea lespedeza plants were monitored with 5 plants in each subplot tagged and monitored each year. Plants were no less than 5 m from the sub plot boundaries. Only plants with obvious crowns were selected, so there would be no question the following year which stems were counted with that crown. Plant size was also taken into consideration, by visually judging plant size and picking plants that were average size for each sub-plot. Plants that were much larger or smaller than other plants from the same sub-plot were avoided. Plants were assigned a number based on the diagram shown in figure 2, with the plant closest to that spot being marked with a permanent post. The same individuals were measured each year unless plants were destroyed by wildlife.

Sericea Lespedeza Growth and Reproductive Performance

Sericea lespedeza was evaluated by both vegetative performance and reproductive performance. Vegetative growth parameters measured included number of stems per crown, stem height, and aboveground standing biomass. Reproductive performance was evaluated by seed mass per plant and the ratio of seed mass to biomass. The number of stems per crown was counted manually and recorded each year in September. The tallest and shortest mature stem of each plant was measured in September after seasonal growth concluded and an average of the tallest and shortest stem was recorded for each plant. New growth that was far shorter than other stems was counted in stem count, but not used as the shortest stem for averaging stem height. By doing this, I hoped to get a more accurate average of mature stems that would not be skewed with new growth. Each individual plant was clipped at ground level after seeds had matured (mid-October), and seeds were brown, rounded, and hard rather than green, shriveled, and soft. Care was taken to clip plants carefully, to lose as few seeds as possible from the stems, as they naturally drop easily. It was not noted whether plants had cleistogamous or chasmogamous flowers. Plants within fall burn fuel load addition treatment plots were harvested approximately one week before hay was spread, and the rest of the plants within fall burn plots were harvested approximately one week before the scheduled burn date. Aboveground standing biomass was determined for each plant after being dried at 60˚ C for 48 hours. Aboveground standing biomass included the dried weight of the stems and leaves. Seed mass was not included in aboveground standing biomass. After drying, leaves and seeds were stripped from the stems and bagged. The leaves and seeds were then separated from each other using a Model 757 South Dakota Seed Blower (Seedburo Equipment Co., Chicago, IL), and seeds were weighed. Seed mass to aboveground standing biomass ratio was determined to evaluate investment in seed production.

Data Analysis

I evaluated the effectiveness of our manipulated variables of fire season, along with secondary treatments of fuel load addition, herbicide use, and mowing on the stem count, height, aboveground standing biomass, and seed production (seed mass and seed mass : biomass ratio) of individual sericea lespedeza plants with a split-plot analysis of variance (ANOVA) (α=0.05). A least-significant means separation test with Tukey conservative adjustment was used to determine the significant effects within fire season or secondary treatment. Interactions between fire and other treatments were also evaluated using a split-plot ANOVA (α=0.05). All split-plot tests were performed using a generalized linear mixed model (PROC GLIMMIX). Least-significant means separations tests were done with a general linear model (PROC GLM) in SAS 9.1 (SAS Institute Inc. Cary, NC). The relationship between seed mass and aboveground standing biomass was evaluated through regression analysis (PROC REG) in SAS 9.1 (SAS Institute Inc. Cary, NC).

RESULTS

Stems per Crown

Year and secondary treatment significantly impacted the number of stems per crown, and the interaction between year and treatment also significantly affected the number of stems per crown (Table 2). The number of stems per crown did not differ between burn seasons treatments; however, they did significantly increase after the burn treatments across all burn treatments, including the unburned treatment, with 2014 data being pre-burn treatment, and 2015 data being post burn treatment (Table 3, Fig. 4). The number of stems per crown increased in each secondary treatment group within each burn treatment after the first set of burn treatments except for the herbicide treatment, which resulted in 100% mortality for each individual plant monitored (Table 4, Fig. 4). The number of stems ranged from 2 to 33, with an average of 6.5 stems per crown in 2014, and an average of 10.1 stems per crown in 2015 (likely due to the increase in precipitation).

Stem Height

Year, burn season, and secondary treatment significantly affected stem height. All interactions between year, burn season, and secondary treatments significantly effected sericea lespedeza stem heights (Table 2). Burn season treatments only significantly impacted height in combination with the fuel load addition (Table 3), with spring burning significantly reducing heights compared to absence of burning but not fall burning (Fig. 5). Across all burn treatments, herbicide treatments resulted in full mortality of monitored plants, therefore resulting in significantly shorter stems than plants receiving other secondary treatments (Table 4, Fig. 5). Mowing treatments also resulted in significantly shorter stems at the end of the growing season compared to plants receiving burn only and fuel load addition treatments (Table 4, Fig. 6).

Aboveground Standing Biomass

Standing aboveground biomass does not include seed mass, and plants in fall fire treatment were harvested prior to the prescribed fall fire. Year and secondary treatment significantly impacted the aboveground standing biomass, and the interaction between year and fire season, and year and treatment also significantly affected aboveground standing biomass (Table 2). Aboveground standing biomass significantly increased after the first year of prescribed burn treatments (Fig. 7). Within each secondary treatment, burn season did not affect aboveground standing biomass of sericea lespedeza (Table 3, Fig. 7). When sericea lespedeza is burned in fall with or without a fuel load addition, plants produced significantly more aboveground biomass than ones receiving a mowing treatment or herbicide treatment (Table 4, Fig. 7). Similarly, when burning was absent, only herbicide treatments significantly reduced aboveground standing biomass (Table 4, Fig. 7). Following a spring prescribed burn, a mowing treatment significantly reduced aboveground standing biomass more than burning with a fuel load addition, but not fire only. Herbicide treatment again had 100% mortality for all plants monitored (Table 4, Fig. 7).

Seed Mass

Seeds for plants that were scheduled to receive a prescribed burn treatment were collected 1-2 weeks prior to the scheduled date of the burn. Plants in other burn treatments were collected approximately 2 weeks later when seeds were more likely to be mature. Secondary treatments as well as the interaction between burn season and secondary treatment significantly impacted seed mass of sericea lespedeza (Table 2). Sericea lespedeza seed mass was significantly affected by secondary treatments post burn in all burn seasons (Table 4) but not by burn treatment alone (Table 3). Herbicide treatment again had 100% mortality for all plants monitored. While stem count, height, and aboveground standing biomass of sericea lespedeza increased from pre- to post-burn treatment, the mass of seed produced per plant did not increase (Table 2). Fall fire had a stronger impact on reducing sericea lespedeza seed production in combination with the secondary treatments than spring fire or absence of fire (Fig. 8). Under fall burning, secondary treatments of mowing and herbicide significantly reduced seed production compared to burning only (Table 4, Fig. 8). Spring burns in conjunction with mowing or herbicide treatments significantly reduced seed production compared to seed production in plants receiving fuel load addition treatment or burning only (Table 4, Fig. 8). In absence of fire, mowing and herbicide treatments significantly reduced seed production compared to no treatment (fire only, and fuel load addition categories) (Table 4, Fig. 8).

Seed Mass : Aboveground Standing Biomass

The seed mass to plant mass ratio removes the effect of plant size on seed production and shows the relative investment of resources in seed production. Year, fire season, and secondary treatment significantly impacted the ratio of seed mass to aboveground standing biomass of sericea lespedeza. The interaction between fire season and secondary treatment, year and secondary treatment, and year, fire season, and secondary treatment all significantly impacted the ratio of seed mass to aboveground standing biomass of sericea lespedeza (Table 2). The relative investment in seed production was reduced from 2014 to 2015, with sericea lespedeza that experienced fall fire and no fire having significantly less investment in seed production than plants experiencing spring fire regardless of secondary treatment (Table 3, Table 4). The relationship of seed mass to aboveground standing biomass was significant for each treatment and burn season, but the strength of that relationship declined under fall burning especially when plants are also mowed mid-summer (Fig. 9). Spring fire showed a tendency for sericea lespedeza to increase its investment in seed production (Fig. 9). As a secondary treatment to any of the fire season treatments, mowing resulted in a significant reduction in the investment in seed production (Fig. 9).

Relationship of Seed Mass to Aboveground standing biomass

Mowing treatments consistently had the weakest relationship between seed mass and aboveground standing biomass with r^2 values of 0.22 or less (other than herbicide, which could not be measured due to mortality of each plant being monitored) (Table 5). Prior to the burn treatment, all secondary treatments except herbicide had a significant dependence of seed mass on the amount of aboveground standing biomass, but the strength of the relationship varied. Post burn treatment, the dependence of seed production on aboveground standing biomass declined under fall burning, especially in combination with mowing ($r^2 = 0.0028$). In contrast, the dependence of seed production on aboveground standing biomass remained high (up to 93%) under spring burning. Because herbicide resulted in mortality of all plants monitored, this treatment had an r^2 value that was undetermined regardless of burn season treatment (fall, spring, or unburned). Regardless of burn treatment, mowing reduces the dependence of sericea lespedeza seed production on aboveground standing biomass. Fall burn season in conjunction with secondary mowing treatment has the largest impact on breaking down the seed mass to aboveground standing biomass relationship.

DISCUSSION

By shifting burning season from spring to fall, with secondary treatment of mowing, land managers are able to utilize all available tools to control sericea lespedeza while preserving the tallgrass prairie ecosystem by reducing herbicide expenditure. Overall, fall burning in combination with mowing resulted in the greatest reduction in sericea lespedeza stem height, seed weight, and aboveground standing biomass. Burning in the fall not only reduces the investment in seed production, but also likely kills that year's seed set before seeds are able to be embedded in the seed bank through multiple freezing and thawing episodes over the winter season.

Only herbicide effectively reduced stem count and resulted in complete mortality for each monitored plant (n=60). While herbicide treatment had great impact on mean stem count, mean stem height, mean seed mass, and mean aboveground standing biomass, it is expensive (Wong et al. 2012) and harmful to the native grasses and forbs as well as to the people using it regularly for control (Eddy and Moore 1998).

Increasing fuel load significantly reduced sericea lespedeza height in spring burn plots compared to not burning but did not significantly reduce height with fall burning. Fall burn stem heights were not significantly different from spring or unburned plots stem heights. However, there was also a 72% increase in precipitation from April-August between 2014 and 2015 at the research site (Western Region Climate Center, 2016), which may contribute to the differences between years as much or more than the fire treatments. These findings agree with those of Thaxton and Platt (2006), who noted that stem damage in their study was highest in fuel addition treatments, and that the addition of fuel load increased the probability of mortality by as much as 150% compared to controls. Fuel load addition treatments significantly reduced seed mass: aboveground standing biomass ratio with fall being significantly lower than unburned plots, and unburned plots being significantly lower than spring burn plots. Seed mass increased in the fuel load addition and fire only plots, but this may be attributed to the difference in precipitation. The increase in precipitation also led to an increase in stems per crown in all seasons and all treatments except herbicide treatment, which had 0% regrowth.

Aboveground standing biomass was increased in all seasons and all treatments except the spring burn in combination with mowing treatment, which was not a significant decrease. This increase is likely due to the increase in growing season precipitation. Aboveground standing biomass was not affected by fire season, especially under conditions of abundant moisture.

The relationship of seed mass to aboveground standing biomass was significant for each treatment and burn season, but the strength of that relationship declined under fall burning and also when plants were mowed mid-summer. At least in wet years, mowing after a fall fire appears to have the greatest impact in reducing seed production. Fall burning appears to break down the strength of the seed mass – plant mass relationship. Furthermore, changing from spring to fall burn season has been shown to have no negative consequences for grassland production and may result in a more diverse prairie with an increase in cool season grasses as well as less impact on wildlife (Towne and Craine 2014).

Mowing treatments kept standing aboveground biomass of sericea lespedeza at a much lower rate, despite the increase in rain, compared to litter addition or fire only treatments from preburn to postburn seasons. Seed mass of sericea plants from mowed plots was not significantly different than that of plants from herbicide addition plots, showing that mowing competes with herbicide treatments in effectiveness at reducing seed mass and does so in a safe and much more inexpensive manner. Hoveland et al. (1985) state that sericea lespedeza seed yields are highest during years that the plant is not harvested, agreeing with our findings that seed mass is reduced when mowed. Young (2000) also notes that mowing too short can severely damage the stand.

Reproductive allocation is commonly measured as a ratio of seed mass to biomass, with seed production being dependent on plant size (Bazzaz and Ackerly 1992; Zhou et al. 2015), and refers to the proportion of total biomass allocated to reproductive tissues. Zhou et al. (2015) state that a more accurate estimate of the relative contribution of each individual to the next generation is reproductive rather than vegetative. Ploschuk et al. (2005) confirms that reproductive allocation increases linearly with plant size. The seed mass to plant mass ratio removes the effect of plant size on seed production and shows the relative investment of resources in seed production. The investment in seed production was reduced from preburn to postburn, with plants that experienced fall fire and no fire having significantly less investment in seed production than plants experiencing spring fire regardless of secondary treatment. Importantly, this decrease in seed production occured despite the increases shown in biomass, which was likely due to the increase in growing season precipitation. Because sericea lespedeza is a prolific seed producer, the reduced investment in seed production is important for the control of sericea lespedeza. Each plant can produce hundreds of seeds annually that can stay dormant in the seedbank for many years, making eradication using herbicide impossible (Young 2000); therefore, any reduction in seed production is valuable.

The greatest impacts on sericea lespedeza growth and reproduction were fall burn season with a secondary treatment of mowing. Annual spring burns have been shown to increase germination and growth of sericea lespedeza (Cummings, Fuhlendorf and Engle 2007). Additionally, switching to fall burning does not reduce the native grass annual production (Towne and Craine 2014). Shifting from a spring to fall burn season may help control sericea without harmful impacts on native grass growth and production. Mowing treatments showed a decrease in seed production statistically similar to that of herbicide but without harming native grasses and forbs as well as minimizing chemical exposure to the wildlife and land managers who apply the treatments.

Large changes in growing season precipitation may mask fire season impacts for the years of this study, but this study still shows that utilizing fall fire in conjunction with mowing treatments can significantly reduce seed production of sericea lespedeza without the use of harmful herbicide treatments. This would result in reduced herbicide expenditures which would minimize environmental impact and cost of management of sericea lespedeza. Reductions in herbicide use will also lead to greater biodiversity and rangeland health as well as the health of the ranchers who frequently apply the herbicide.

From the data collected in this study, I predict the best long-term solution for the control of sericea lespedeza to be a combination of fall burning with secondary mowing treatments. Additional herbicide use may contribute to the efficiency of killing the above-ground vegetation and seeds. Additional research will be done in the next several years following an identical setup and collection strategy, with triennial burn treatments added to the burn season treatment group. This should mitigate the differences between annual precipitation rates and lend more data over a multi-year period, giving land managers a better chance at control of sericea lespedeza while also preserving the grassland ecosystem.

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Table 1. Mean air temperature (ºC) and total precipitation (cm) at the Marias des Cygnes National Wildlife Refuge, Pleasanton, Kansas. Growing season precipitation was determined from April-August. Climate data has been recorded since April 2007 (Western Region Climate Center 2016).

	2014	2015	Site Mean
Mean air temperature	11.3	13.9	13.44
Total Precipitation	95.4	116.3	103.40
Growing Season Precipitation	44.4	76.3	71.68

Table 2. Treatment and interaction effect *P* values for mean stem count, mean stem height, mean seed mass, mean standing biomass, and seed mass : biomass ratio of *Lesepdeza cuneata* for 2015 at the Marias des Cygnes National Wildlife Refuge, Pleasanton, KS. Burn seasons include Fall, Spring, and Unburned. Secondary treatments include herbicide, fuel load addition, mowing, and fire only. Significant *P* values are in bold. A.G.S. Biomass = Aboveground Standing Biomass

Variable	Treatment effects and interactions	*P* value
Stem count	Year	**<0.0001**
	Burn Season	0.7740
	Secondary Treatment	**<0.0001**
	Burn Season * Secondary Treatment	0.4085
	Year * Burn Season	0.9693
	Year * Secondary Treatment	**<0.0001**
	Year * Burn Season * Secondary Treatment	0.9134
Stem height	Year	**<0.0001**
	Burn Season	**0.0001**
	Secondary Treatment	**<0.0001**
	Burn Season * Secondary Treatment	**<0.0001**
	Year * Burn Season	**<0.0001**
	Year * Secondary Treatment	**<0.0001**
	Year * Burn Season * Secondary Treatment	**0.0056**
A.G.S. Biomass	Year	**<0.0001**
	Burn Season	0.9532
	Secondary Treatment	**<0.0001**
	Burn Season * Secondary Treatment	0.3887
	Year * Burn Season	**0.0354**
	Year * Secondary Treatment	**<0.0001**
	Year * Burn Season * Secondary Treatment	0.3523
Seed mass	Year	0.1694
	Burn Season	**0.0254**
	Secondary Treatment	**<0.0001**
	Burn Season * Secondary Treatment	**<0.0001**
	Year * Burn Season	0.6766
	Year * Secondary Treatment	0.0534
	Year * Burn Season * Secondary Treatment	0.7080
Seed:Biomass	Year	**<0.0001**
	Burn Season	**<0.0001**
	Secondary Treatment	**<0.0001**
	Burn Season * Secondary Treatment	**<0.0001**
	Year * Burn Season	0.0648
	Year * Secondary Treatment	**<0.0001**
	Year * Burn Season * Secondary Treatment	**0.0259**

Table 3. Degrees Freedom, *F* values, and *P* values for separation of means comparison by burn season for *Lespedeza cuneata* in 2015 at the Marias des Cygnes National Wildlife Refuge, Pleasanton, KS. Significant *P* values are bold. A.G.S. Biomass = Aboveground Standing Biomass.

Secondary Treatment	*df*	*F* value	*P* value	n
Fire only				
Stem count	2, 43	0.09	0.4041	46
Height	2, 34	2.15	0.1322	37
A.G.S. Biomass	2, 33	1.02	0.3725	36
Seed Mass	2, 34	2.02	0.1488	37
Seed:Biomass	2, 33	5.38	**0.0095**	36
Herbicide				
Stem count	2, 57	0.00	0.0000	60
Height	2, 57	0.00	0.0000	60
A.G.S. Biomass	2, 57	0.00	0.0000	60
Seed Mass	2, 57	0.00	0.0000	60
Seed:Biomass	2, 57	0.00	0.0000	60
Fuel Load Addition				
Stem count	2, 41	0.02	0.9763	44
Height	2, 41	3.91	**0.0279**	44
A.G.S. Biomass	2, 35	0.16	0.8488	38
Seed Mass	2, 34	2.76	0.0776	37
Seed:Biomass	2, 35	26.19	**< 0.0001**	38
Mowing				
Stem count	2, 34	0.08	0.9226	37
Height	2, 34	2.15	0.1322	37
A.G.S. Biomass	2, 33	1.02	0.3725	36
Seed Mass	2, 34	2.02	0.1488	37
Seed:Biomass	2, 33	5.38	**0.0095**	36

Table 4. Degrees Freedom, F values, and *P* values for separation of means comparison by secondary treatment for *Lespedeza cuneata* in 2015 at the Marias des Cygnes National Wildlife Refuge, Pleasanton, KS. Significant *P* values are bold. A.G.S. Biomass = Aboveground Standing Biomass.

Burn season		*df*	*F* value	*P* value	n
Fall					
	Stem count	3, 57	16.16	< **0.0001**	61
	Height	3, 45	182.98	< **0.0001**	49
	A.S.G. Biomass	3, 57	12.16	< **0.0001**	61
	Seed Mass	3, 56	6.10	**0.0011**	60
	Seed:Biomass	3, 57	7.24	**0.0003**	61
Spring					
	Stem count	3, 71	13.29	< **0.0001**	75
	Height	3, 45	116.79	< **0.0001**	49
	A.G.S. Biomass	3, 69	7.62	**0.0002**	73
	Seed Mass	3, 70	8.55	< **0.0001**	74
	Seed:Biomass	3, 69	51.83	< **0.0001**	73
Unburned					
	Stem count	3, 46	20.05	< **0.0001**	50
	Height	3, 45	182.98	< **0.0001**	49
	A.G.S. Biomass	3, 44	9.23	< **0.0001**	48
	Seed Mass	3, 44	8.66	**0.0001**	48
	Seed:Biomass	3, 44	16.66	< **0.0001**	48

Table 5. Seed mass to aboveground standing biomass coefficient of determination (r^2), significance levels, and slopes in *Lespedeza cuneata* at each treatment within each burn season from 2014-2015 at the Marias des Cygnes National Wildlife Refuge, Pleasanton, KS.

	Fall					Spring					Unburned				
	df	r^2	*P*	*F*	Slope	*df*	r^2	*P*	*F*	Slope	*df*	r^2	*P*	*F*	Slope
Pre-burn (2014)															
Fire	1, 18	0.56	0.0001	23.04	0.26	1, 18	0.91	<0.0001	182.38	0.35	1, 17	0.51	0.0006	17.80	0.24
Fuel addition	1, 16	0.67	<0.0001	32.10	0.10	1, 18	0.78	<0.0001	64.21	0.25	1, 17	0.93	<0.0001	217.22	0.35
Mowing	1, 17	0.22	0.0448	4.69	0.03	1, 18	0.52	0.0003	19.41	0.17	1, 18	0.28	0.0163	7.03	0.13
Herbicide	0, 0	0.00	0.0000	0.00	0.00	0, 0	0.00	0.0000	0.00	0.00	0, 0	0.00	0.0000	0.00	0.00
Post-burn (2015)															
Fire	1, 14	0.41	0.0073	9.82	0.08	1, 16	0.89	<0.0001	128.13	0.27	1, 10	0.10	0.3279	1.06	0.03
Fuel addition	1, 9	0.39	0.0416	5.64	0.05	1, 17	0.93	<0.0001	217.97	0.28	1, 8	0.81	0.0004	33.62	0.23
Mowing	1, 12	0.0028	0.8563	0.03	0.0053	1, 14	0.17	0.1122	2.87	0.03	1, 4	0.64	0.0549	7.22	0.02
Herbicide	0, 0	0.00	0.0000	0.00	0.00	0, 0	0.00	0.0000	0.00	0.00	0, 0	0.00	0.0000	0.00	0.00

Figure 1. a) Distribution map of *Lespedeza cuneata* in the United States

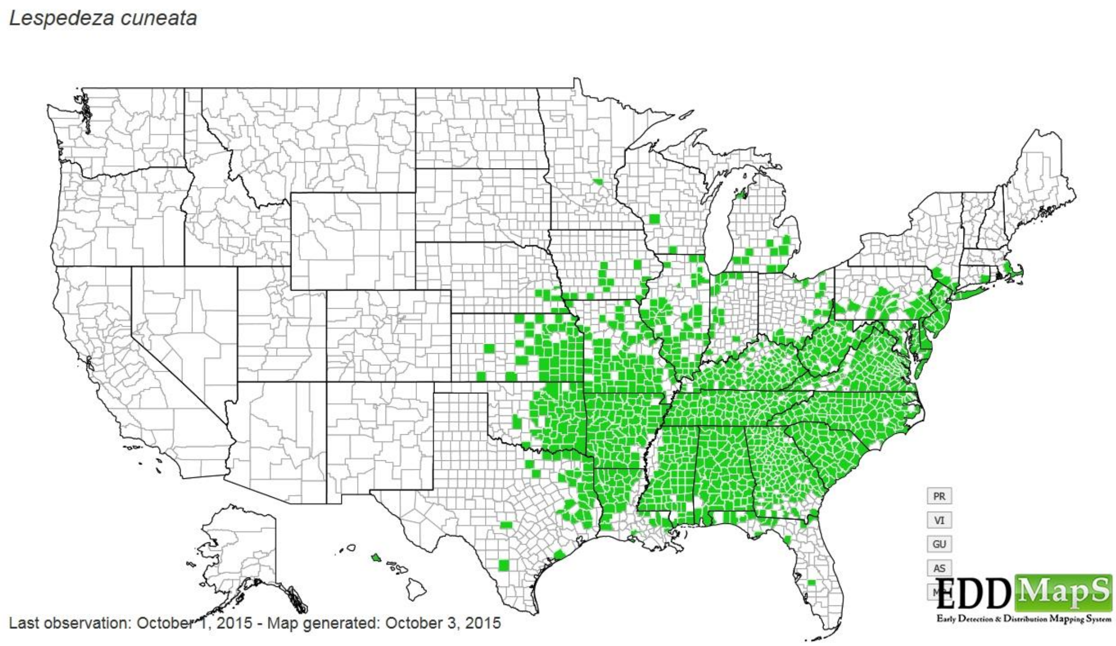
(EDDMapS. 2016. Early Detection & Distribution Mapping System.

The University of Georgia - Center for Invasive Species and Ecosystem Health)

b) Distribution map of *Lespedeza cuneata* in the state of Kansas

(http://agriculture.ks.gov/divisions-programs/plant-protect-weed-control/noxious-weed-control-program).

a)


Lespedeza cuneata
PR
VI
GU
AS
EDDMapS
Early Detection & Distribution Mapping System
Last observation: October 1, 2015 - Map generated: October 3, 2015

b)

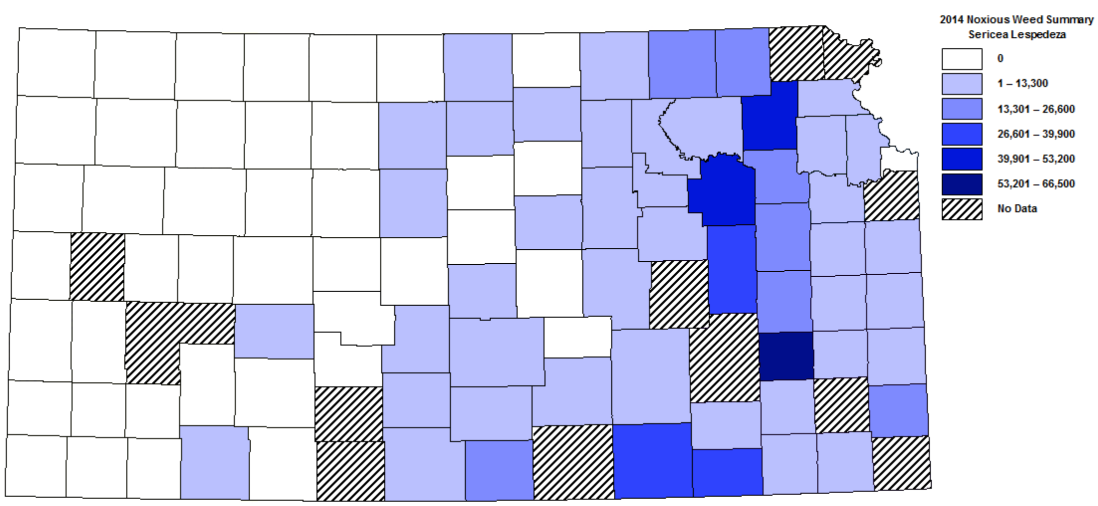

2014 Noxious Weed Summary
Sericea Lespedeza
0
1 – 13,300
13,301 – 26,600
26,601 – 39,900
39,901 – 53,200
53,201 – 66,500
No Data

Figure 2. Site map at the Marias des Cygnes National Wildlife Refuge, Pleasanton, KS. Plants were labeled and marked according to the burn season, secondary treatment, and plant number.

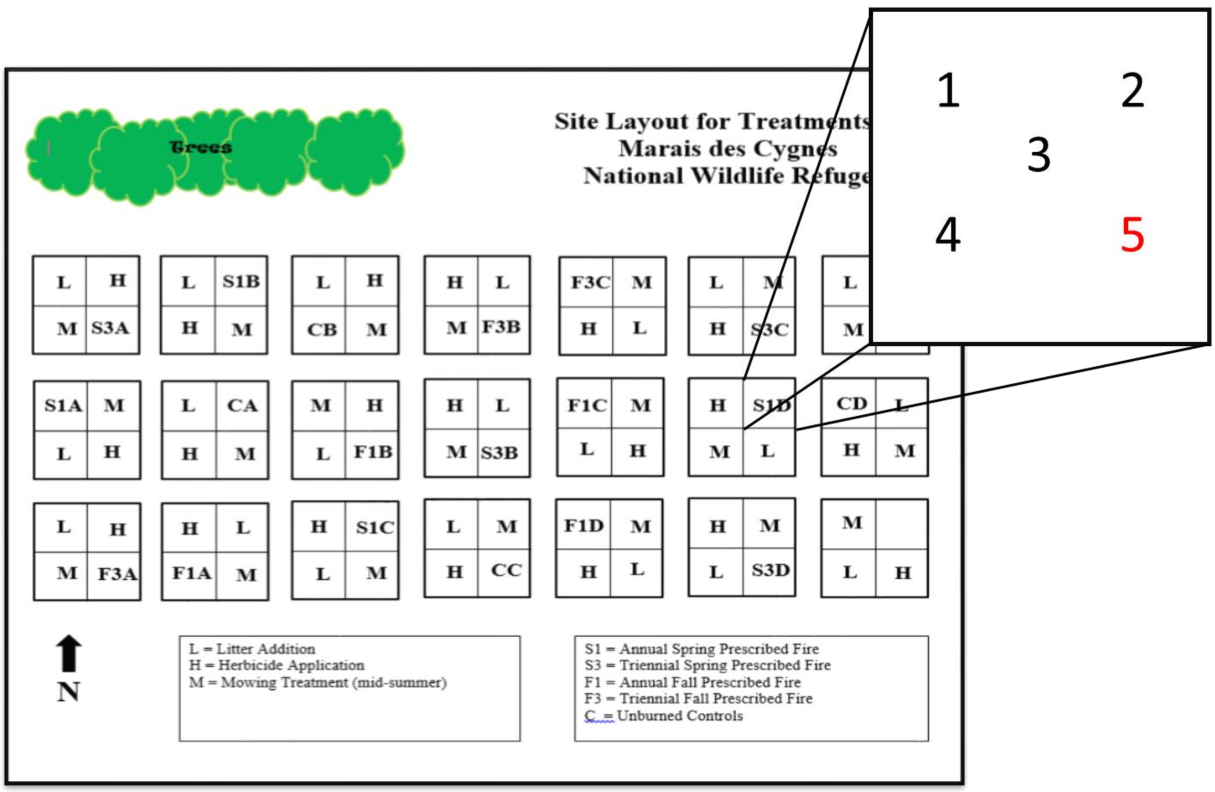

Trees
Site Layout for Treatments
Marais des Cygnes
National Wildlife Refuge
L H M S3A
L S1B H M
L H CB M
H L M F3B
F3C M H L
L M H S3C
L M
S1A M L H
L CA H M
M H L F1B
H L M S3B
F1C M L H
H S1D M L
CD L H M
L H M F3A
H L F1A M
H S1C L M
L M H CC
F1D M H L
H M L S3D
M L H
1
2
3
4
5
N
L = Litter Addition
H = Herbicide Application
M = Mowing Treatment (mid-summer)
S1 = Annual Spring Prescribed Fire
S3 = Triennial Spring Prescribed Fire
F1 = Annual Fall Prescribed Fire
F3 = Triennial Fall Prescribed Fire
C = Unburned Controls

Figure 3. Timeline of treatment application and plant collection at Marias des Cygnes National Wildlife Refuge, Pleasanton, KS in 2014-2015

Pre-burn (2014)

March 2014- Baseline burn across entire site.

April 2014- Fuel load addition treatment applied 1 week before spring burn.

April 2014- Spring burn treatment applied.

July 2014- Herbicide treatment applied.

July 2014- Mowing treatment applied.

Sept. 2014- Stem counts and heights measured and recorded.

Oct. 2014- Plants clipped in plots receiving fuel load addition the week prior to treatment.

Oct. 2014- Fuel load addition applied one week prior to Fall burn treatment.

Oct. 2014- Plants clipped in plots receiving herbicide treatment, mowing treatment, and burn only treatment.

Oct. 2014- Fall burn treatment applied

Post-burn (2015)

March 2015- Spring burn.

July 2015- Mowing treatment applied.

Sept. 2015- Stem counts and heights measured and recorded.

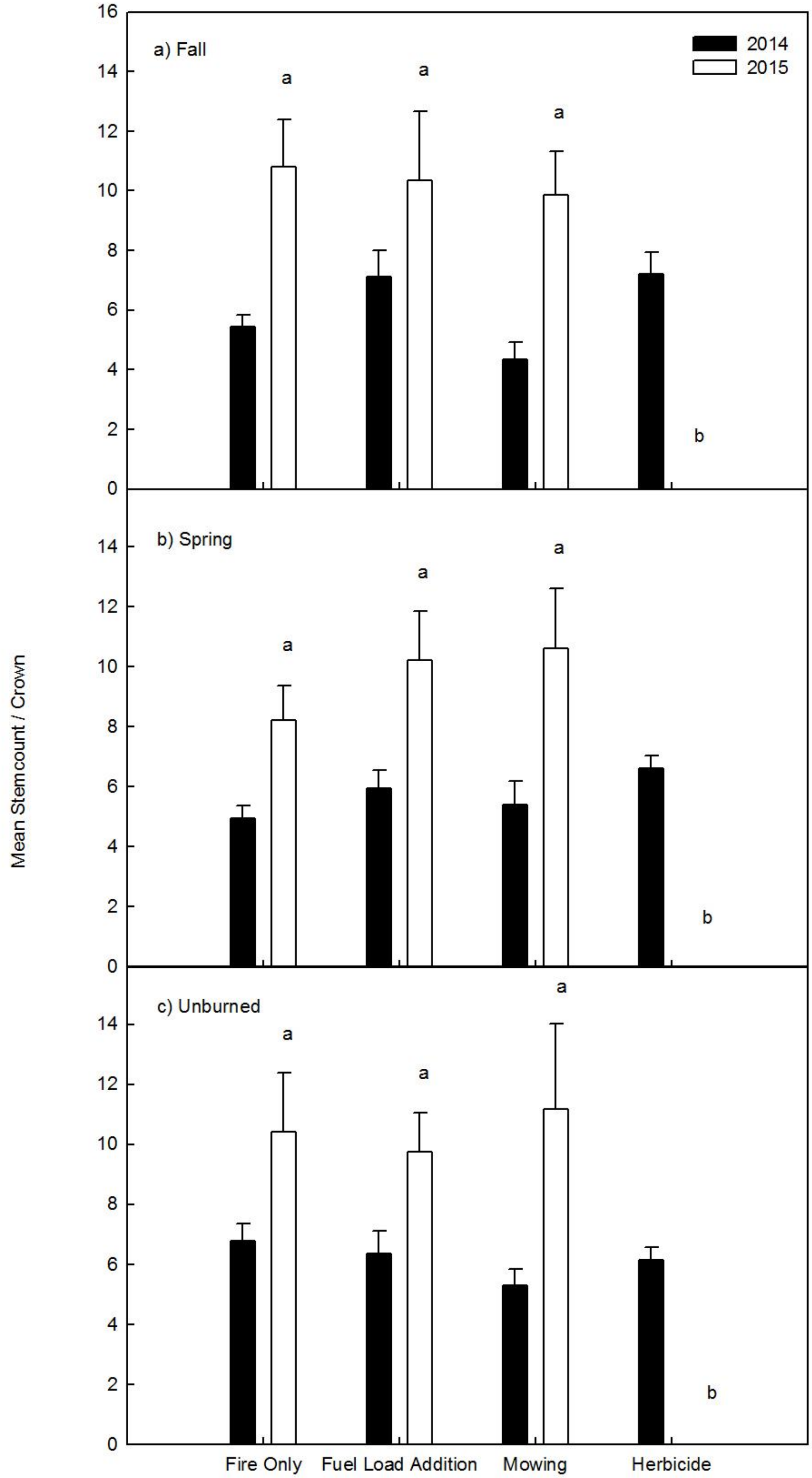
Oct. 2015- Plants clipped in plots receiving fuel load addition the week prior to treatment.

Oct. 2015- Fuel load addition applied one week prior to Fall burn treatment.

Oct. 2015- Plants clipped in plots receiving herbicide treatment, mowing treatment, and burn only treatment.

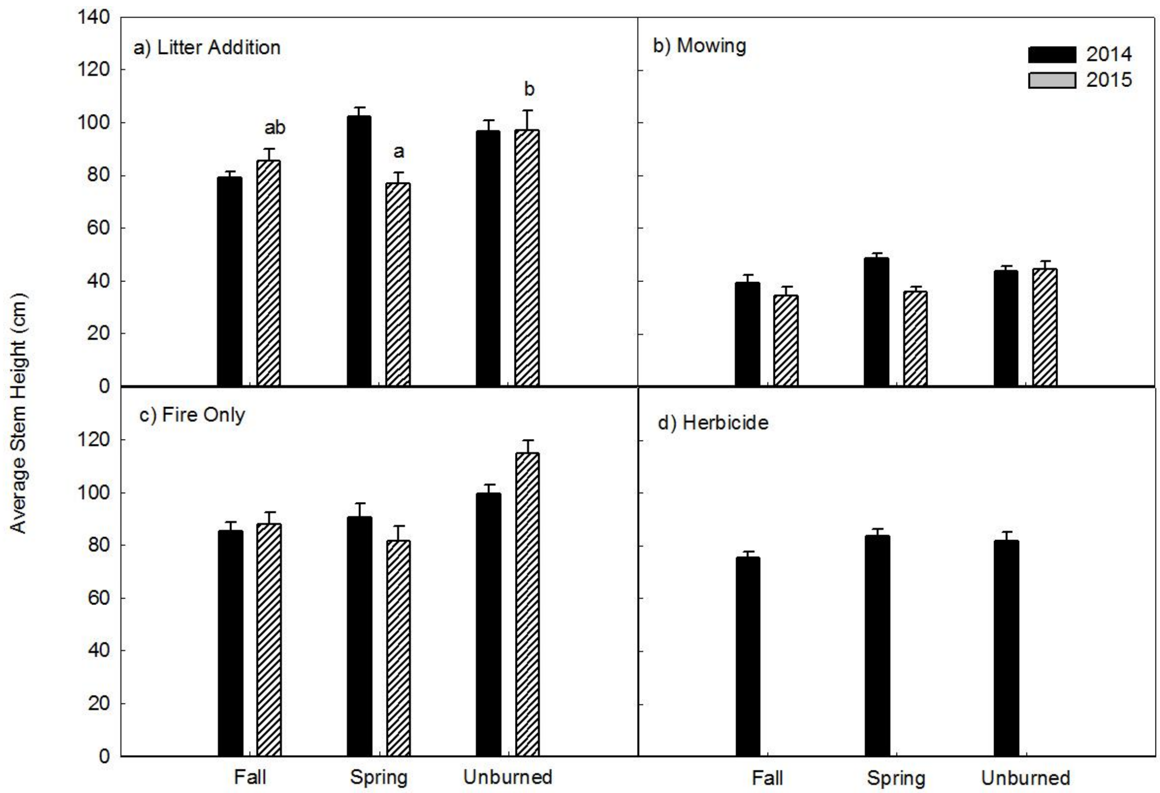
Oct. 2015- Fall burn treatment applied

Figure 4. Mean stem count per *Lespedeza cuneata* crown collected from Marias des Cygnes National Wildlife Refuge, Pleasanton, KS in 2014-2015. Bars are mean ± SE. Solid bars represent 2014, white bars represent 2015. Significant differences between treatments are indicated by a, b, c, d (p<0.05).



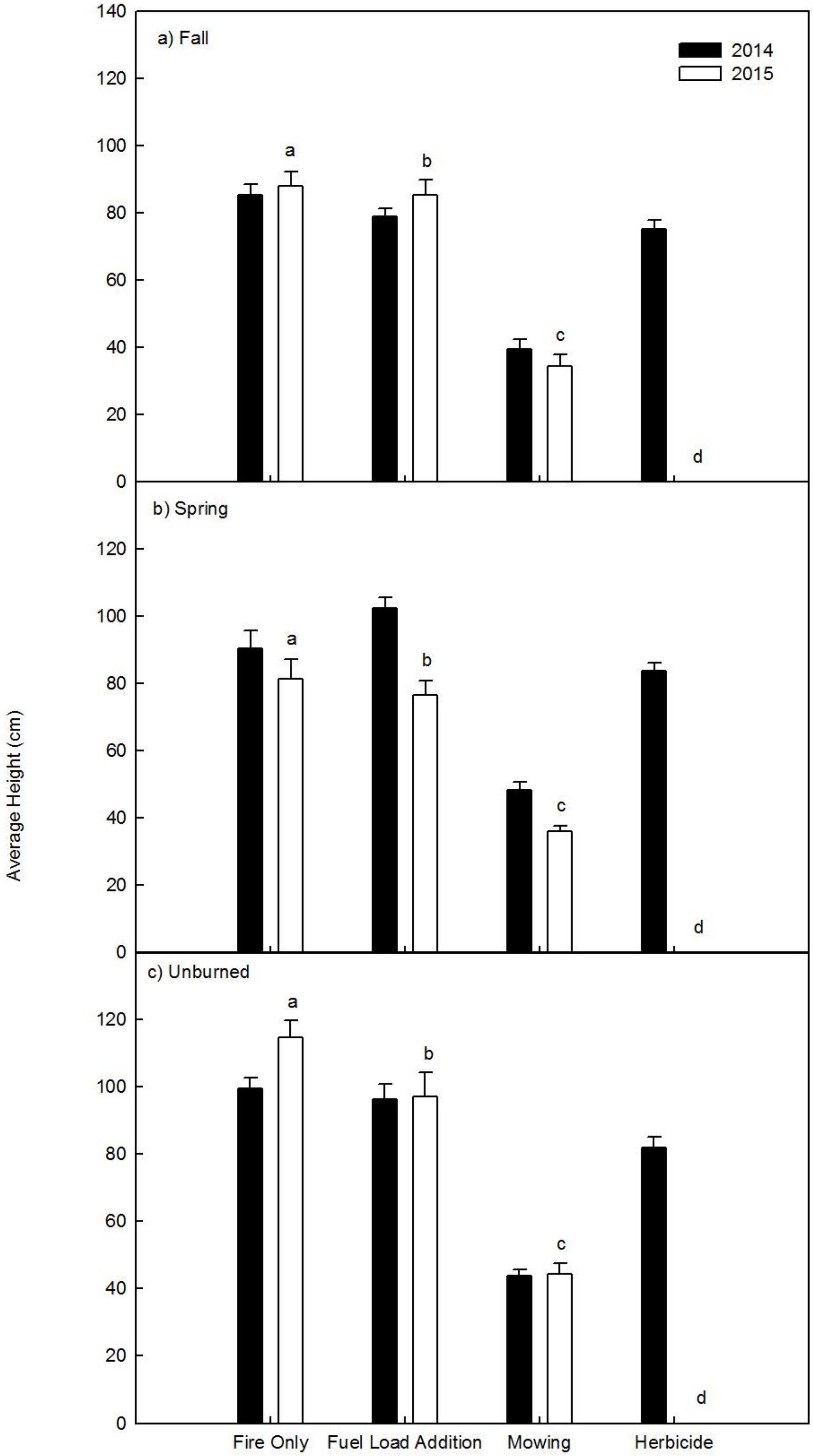
Mean Stemcount / Crown
a) Fall
b) Spring
c) Unburned
2014
2015
a
b
0
2
4
6
8
10
12
14
16
Fire Only
Fuel Load Addition
Mowing
Herbicide

Figure 5. Mean stem height per *Lespedeza cuneata* crown collected from Marias des Cygnes National Wildlife Refuge, Pleasanton, KS in 2014-2015. Bars are mean ± SE. Solid bars represent 2014, hatched bars represent 2015. Significant differences between fire season are indicated by a, b, c, d (p<0.05).



a) Litter Addition
b) Mowing
c) Fire Only
d) Herbicide
2014
2015
ab
a
b
Average Stem Height (cm)
140
120
100
80
60
40
20
0
Fall
Spring
Unburned

Figure 6. Mean stem height per *Lespedeza cuneata* crown collected from Marias des Cygnes National Wildlife Refuge, Pleasanton, KS in 2014-2015. Bars are mean ± SE. Solid bars represent 2014, white bars represent 2015. Significant differences between treatments are indicated by a, b, c, d (p<0.05).



a) Fall
2014
2015
b) Spring
c) Unburned
Average Height (cm)
0
20
40
60
80
100
120
140
a
b
c
d
Fire Only
Fuel Load Addition
Mowing
Herbicide

Figure 7. Mean aboveground standing biomass per *Lespedeza cuneata* crown collected from Marias des Cygnes National Wildlife Refuge, Pleasanton, KS in 2014-2015. Bars are mean ± SE. Solid bars represent 2014, white bars represent 2015. Significant differences between treatments are indicated by a, b, c, d (p<0.05).

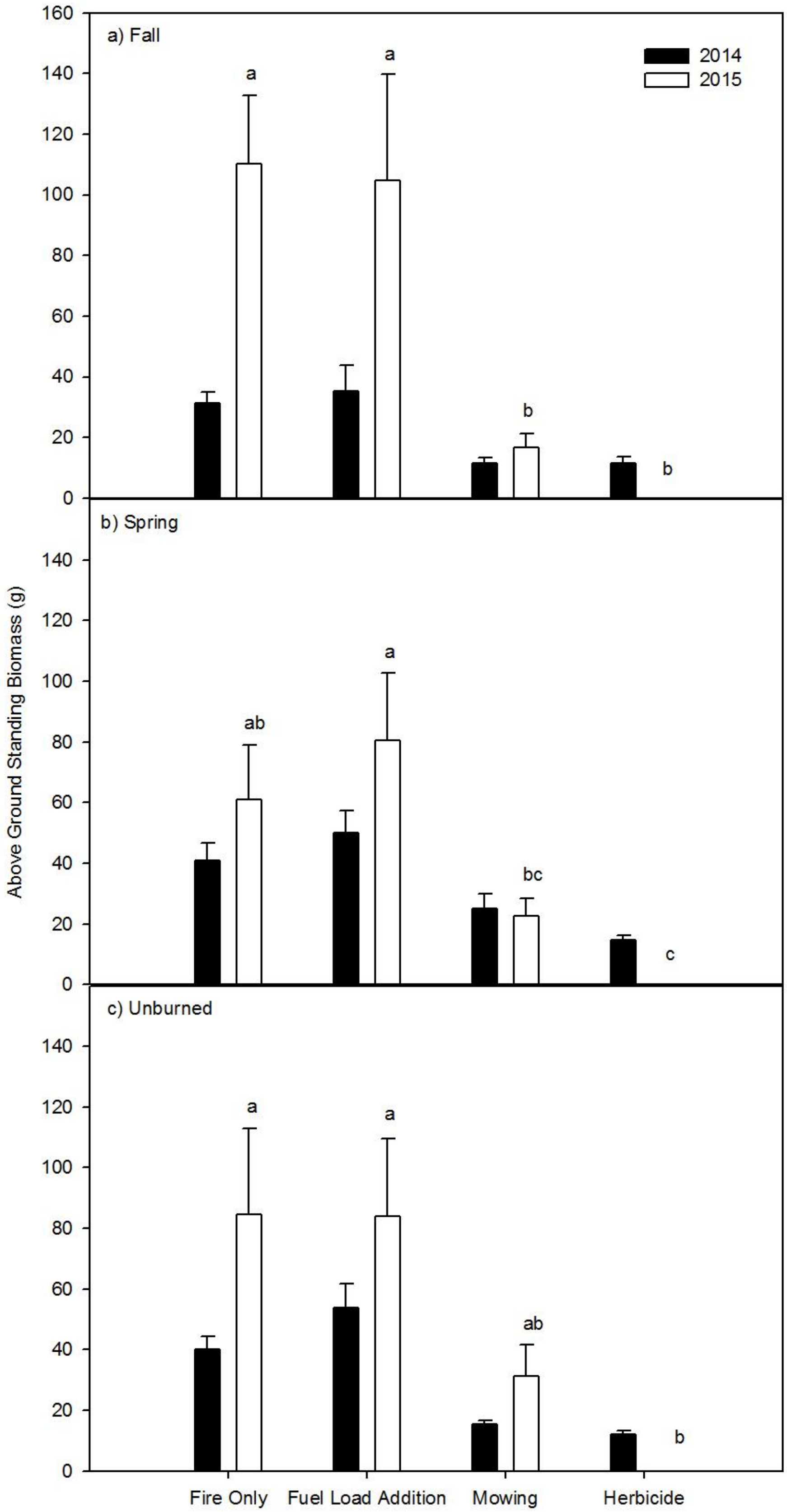

a) Fall
b) Spring
c) Unburned
2014
2015
Above Ground Standing Biomass (g)
Fire Only
Fuel Load Addition
Mowing
Herbicide
a
a
b
b
ab
a
bc
c
a
a
ab
b
0
20
40
60
80
100
120
140
160

Figure 8. Mean seed mass per *Lespedeza cuneata* crown collected from Marias des Cygnes National Wildlife Refuge, Pleasanton, KS in 2014-2015. Bars are mean ± SE. Solid bars represent 2014, white bars represent 2015. Significant differences between treatments are indicated by a, b, c, d (p<0.05).

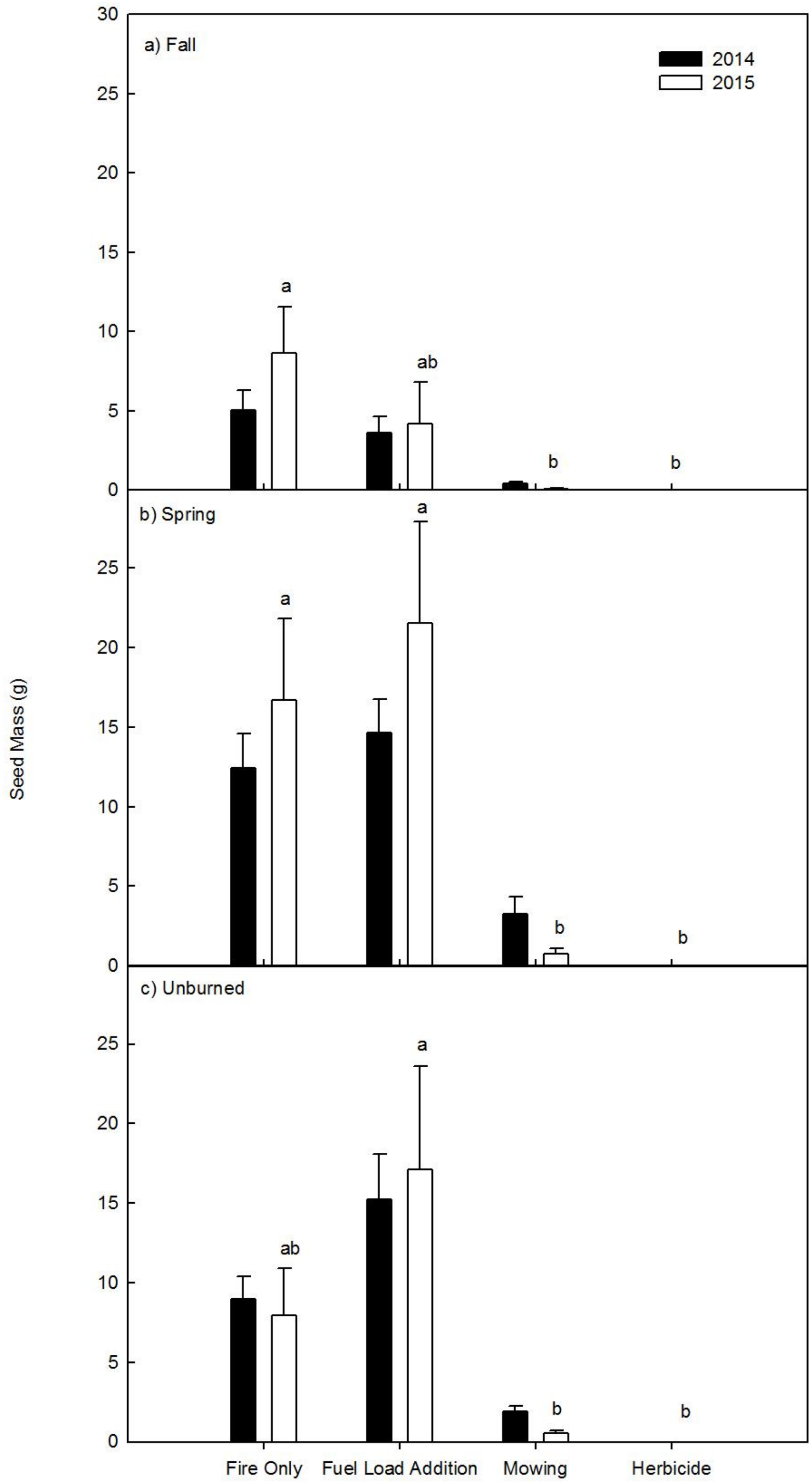
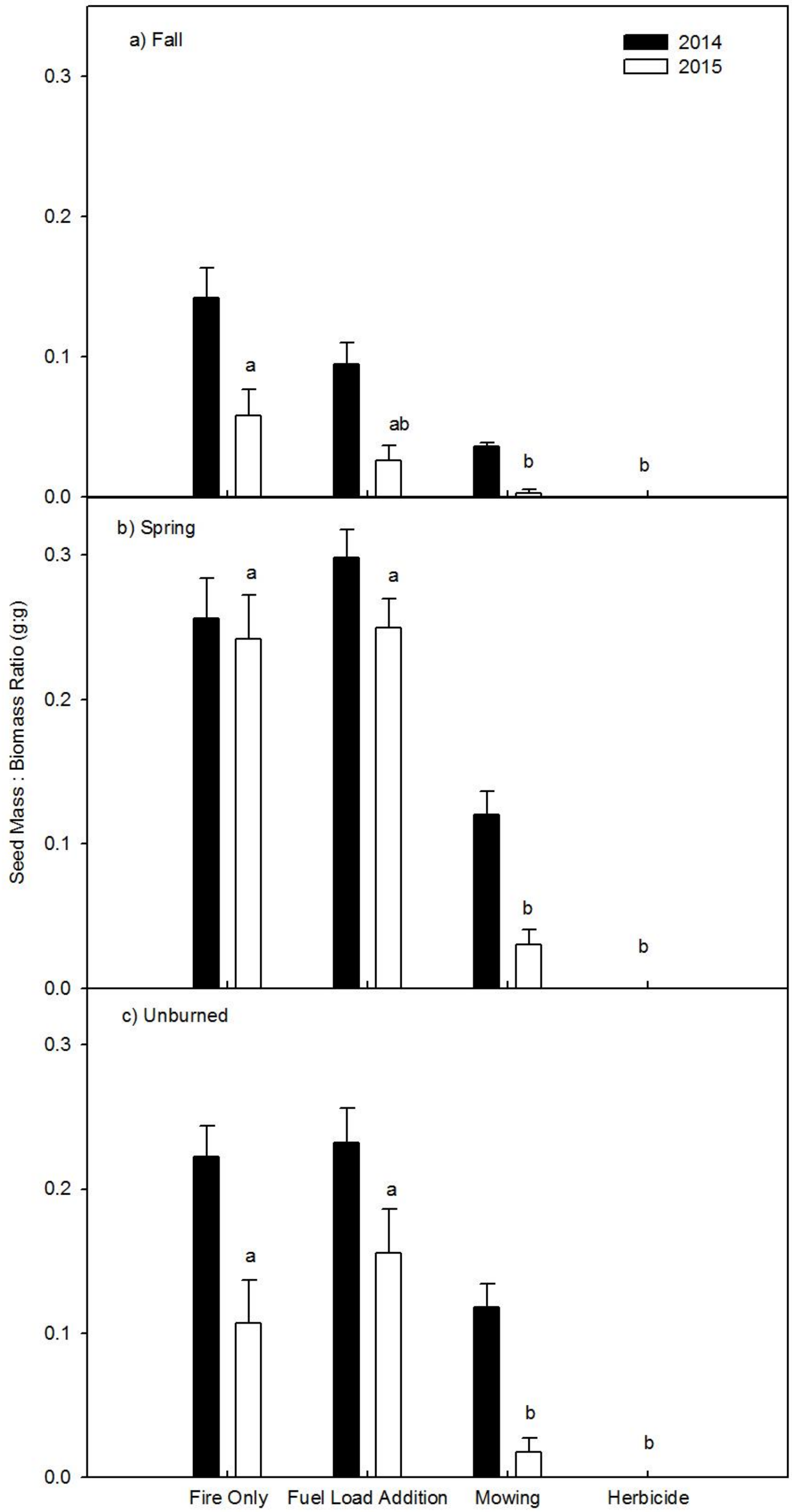

a) Fall
2014
2015
a
ab
b
b
b) Spring
a
a
b
b
c) Unburned
a
ab
b
b
Seed Mass (g)
30
25
20
15
10
5
0
Fire Only
Fuel Load Addition
Mowing
Herbicide

Figure 9. Ratio of seed mass to biomass for *Lespedeza cuneata* collected from Marias des Cygnes National Wildlife Refuge, Pleasanton, KS in 2014-2015. Bars are mean ± SE. Solid bars represent 2014, hatched bars represent 2015. Significant differences between fire season are indicated by a, b, c, d (p<0.05).


a) Fall
2014
2015
0.3
0.2
0.1
0.0
a
ab
b
b
b) Spring
a
a
b
b
c) Unburned
a
a
b
b
Seed Mass : Biomass Ratio (g:g)
Fire Only
Fuel Load Addition
Mowing
Herbicide