Effects of Prescribed Fire Timing on Vigor of Sericea Lespedeza in the Kansas Flint Hills

by

Jonathan Andrew Alexander

B.S., Kansas State University, 2015

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Animal Sciences and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2018

Approved by:

Major Professor
Dr. KC Olson

Copyright

Abstract

We evaluated effects of annual, prescribed burning on vigor of the noxious weed, sericea lespedeza (*Lespedeza cuneata*; **SL**) in native tallgrass prairie over a 4-yr period. We hypothesized that annual prescribed burning conducted during the growing season would selectively pressure SL, whereas locally-conventional, dormant-season prescribed burning would have no effect on SL. A 50-ha native tallgrass pasture infested with SL (initial basal frequency = 2 ± 1.3%, initial aerial frequency = 36 ± 3.4%) was used for our study. It was divided along watershed boundaries into 9 fire-management units (5 ± 2.6 ha) for this experiment. Burn units were assigned randomly to 1 of 3 prescribed-burning times (n = 3 / treatment): early spring (1 April; **EARLY**), mid-summer (1 August; **MID**), or late summer (1 September; **LATE**). Forage biomass, SL aerial frequency, SL stem length, SL seed production, soil cover, and plant species composition were measured along single, permanent 100-m transects in each burn unit. Treatment and measurement date influenced forage biomass and SL stem length (treatment × time). Forage biomass was not different ($P \geq 0.43$) between treatments on 17 July; however, forage biomass was greater ($P < 0.01$) in EARLY than MID and greater in MID than LATE on 10 October. Maximum stem length of SL was less ($P \leq 0.02$) in MID and LATE than in EARLY on 17 July and on 10 October. Aerial frequency of SL was least (main effect – $P < 0.01$) in LATE, intermediate in MID, and greatest in EARLY, whereas basal frequency of SL was less ($P < 0.01$) in MID and LATE compared with EARLY. Whole-plant dry weight and seed production of SL at dormancy were greatly diminished ($P \leq 0.02$) in MID and LATE compared with EARLY. Occurrence of bare soil, litter cover, and total basal plant cover were not different ($P \geq 0.21$) between treatments. Similarly, basal cover of grasses, forbs, and shrubs were not different ($P \geq 0.24$) between treatments. We interpreted these data to indicate that annual prescribed burning during the growing season had strong suppressive effects on SL compared to locally-conventional, early-season prescribed burning and produced no apparent detrimental effects on soil cover or non-target plant species. Post-fire regrowth was sufficient to prevent erosion and soil-moisture loss during the subsequent dormant season and would have allowed light to moderate grazing during the ensuing winter.

Key words: *Lespedeza cuneata*, prescribed fire, range improvement

Table of Contents

List of Figures

List of Tables

Acknowledgements

I would like to start out by thanking all the employees of the cow-calf unit over the past four and a half years. I truly appreciate the long hours spent collecting data, mowing fire breaks and helping burn between everything else going on. This project would not have been possible without the endless help I received throughout the entire project. I would also like to thank my committee, Drs. Walt Fick, John Jaeger, and Justin Waggoner, for your guidance and patience throughout my master's degree.

I would like to thank my wife, Dayna Alexander, for your patience with me as I spent long hours burning and late nights in the lab. Thank you for your help and support throughout the four years of this project. I have been blessed with the love and encouragement you have showed me. I would also like to thank my family for your support. I am honored to have received the love and encouragement I did throughout my time here at Kansas State University. I would also like to thank my fellow graduate students, Jack Lemmon, Garth Gatson, and Brandt Skinner for your help throughout the project. Your sense of humor and interest for range management made this project fun and enjoyable.

Finally, I would like to thank my advisor and mentor, Dr. K.C. Olson. If it weren't for you I would not have had the opportunity to pursue a master's degree. I have been truly blessed for what you have taught me and sticking with me when I didn't know the first thing about being a graduate student. I thank you for your guidance and the interest in range management you have instilled in me. I am honored to have worked for you throughout my time at Kansas State.

Chapter 1 - Review of Literature

Sericea Lespedeza (*Lespedeza cuneata*)

Introduction

Sericea lespedeza (**SL**; *Lespedeza cuneata*), a perennial forb, was introduced into the United States in the late 19th century from East Asia for its soil conservation properties on farmland and mine spoils, and for its perceived value for wildlife habitat. Sericea lespedeza was first planted in the United States in 1896 by the North Carolina Agriculture Experiment Station. The plant was introduced into Kansas in the 1930's on strip-mined land in the southeast portion of the state. In the succeeding decades, SL propagated, adapted environmentally, and moved spatially into the tallgrass prairie (Hobbs and Humphries, 1995). In the lag between introduction of SL and public awareness of its invasive tendencies, SL seed was harvested from infested rangelands and planted on land enrolled in the Conservation Reserve Program (Eddy et al., 2003). The subsequent propagation and spread of SL in the tallgrass prairie region is of great concern because it threatens to fundamentally alter the ecosystem of one of the most endangered biomes on earth.

Sericea lespedeza tends to be a highly-competitive invader in the tallgrass prairie biome for a variety of reasons. First, dietary selection of SL growing on native tallgrass pasturelands by beef cattle is limited due to elevated condensed tannin content (Aerts et al., 1999; Preedy et al., 2013b); therefore, control of propagation via grazing is unlikely because tallgrass pastoral production systems are overwhelmingly dominated by beef cattle. When condensed tannin levels in SL reach 5 to 12% of plant DM, depressed DMI, diet digestibility, and animal productivity have been documented (Aerts et al., 1999). New growth can be more palatable and contain less condensed tannins than mature plants; however, cattle may struggle to access new growth because of the proximity of robust, dead stems remaining from previous growing seasons.

Second, SL is reproductively prolific, producing copious amounts of seed annually; moreover, SL seeds have exhibited remarkable durability in the soil (Cummings et al., 2006). Sericea lespedeza spreads geographically via seed. The seed of SL is smooth and dense; therefore, it is generally not spread via wind like many perennial forb seeds. Sericea lespedeza depends heavily on human activity, animals, and flowing water to disperse its seed. Logan et al. (1969) found that only 40% of newly-formed seeds with an intact seed coat germinated, whereas 85% germinated when the seed coat was scarified (i.e., broken or cracked). Because of the properties of the seed coat, SL seed that has not been scarified can remain viable in the soil for many years leading to prolonged germination (Cummings et al., 2006).

Third, the root system of SL has allelopathic properties that reduce growth and productivity of both cultivated grasses (Kalburtji and Mosjidis, 1992) and native grasses (Dudley and Fick, 2003). Fourth, SL tends to produce a robust canopy that prevents sunlight from reaching understory plants, decreasing photosynthetic potential and carbohydrate synthesis (Ohlenbusch et al., 2007; Vermeire et al., 2007).

Finally, SL can thrive in shallow and acidic soils (Mosjidis, 1997) that will not support vigorous populations of native plants. Eddy et al. (2003) indicated that the combined effects of all competitive advantages of SL were capable of reducing native plant production by up to 92%. The Kansas state legislature declared SL a county-option noxious weed in 1988 (Eddy and Moore, 1998). Because of continued spread after that time, SL was declared a noxious weed statewide in Kansas in 2000 (Ohlenbusch et al., 2007).

Biological Control

Multiple control methods have been explored for SL, most of which have failed to achieve satisfactory control or have proven to be too costly to implement. Eddy et al. (2003) introduced lespedeza webworms to control the spread of SL. Lespedeza webworms suppressed the photosynthetic capabilities of the plant, which in turn reduced seed production. Environmental challenges resulted in inadequate webworm survival over time; moreover, use of SL as a forage crop in the southeastern United States forced researchers to find alternative methods of control to avoid harming forage varieties of SL.

Preedy et al. (2013a and 2013b) evaluated corn steep liquor (**CSL**) supplementation and its effect on herbivory habits of cattle on actively-growing SL in the Kanas Flint Hills. Corn steep liquor is a byproduct of wet corn milling and improved forage DMI and total-tract protein digestion when cattle were fed SL-contaminated hay (Eckerle et al., 2011). Preedy et al. (2013b) reported increased herbivory of SL by cow-calf pairs supplemented with CSL, without negative effects on cow body condition score or calf growth (Preedy et al., 2013a). Although herbivory of SL was recorded during this study, large-scale pasture influences on SL were not detected. Grazing may have had a small effect on seed producing capabilities of individual plants but no reductions in seed production or SL frequency were reported.

Another biological approach to control of SL involves the simultaneous or subsequent grazing of small ruminants (i.e., sheep or goats) in conjunction with beef cattle. Pacheco et al. (2012) assessed the effects of co-grazing cow-calf pairs and goats on herbivory patterns on native tallgrass rangeland infested with SL. Grazing cattle and goats together increased grazing pressure on SL without negatively affecting cow-calf performance or residual forage biomass. In pastures that were stocked with both cattle and goats, SL was grazed more frequently than in pastures where only cattle grazed.

Lemmon et al. (2017) evaluated sheep grazing as a potential biological control for SL. In that experiment, late-season, intensive sheep grazing following early-season steer grazing of SL-infested pastures was evaluated. Results indicated that sheep preferentially selected SL whereas steers avoided it; 92.1% of SL plants were grazed in pastures grazed by yearling steers followed by mature ewes compared with just 1.4% in pastures grazed by steers only. This increased grazing pressure on SL led to a reduction in seed production from 864 seeds/plant in the pastures grazed by steers only to just 114 seeds/plants in pastures grazed by steers and sheep. Although some logistical and cultural barriers may remain for small ruminant production in the Kansas Flint Hills, grazing by both sheep and goats may be beneficial to slowing the spread of SL.

Chemical Control

The control of SL through herbicide can generate enticing short-term results; however, collateral damage to non-target forbs is likely to result. Koger et al. (2002) evaluated the effects of applying triclopyr, fluroxypyr, and metsulfuron to SL throughout the growing season in a pasture-based system. Biomass of SL was reduced in all herbicide treatments when compared to the untreated controls. Grass biomass was also greater in all herbicide-treated plots. More SL stems survived after treatment with metsulfuron compared with triclopyr and fluroxypyr. Although all three chemicals provided some level of control, they did not affect existing seeds.

Farris and Murray (2009) evaluated herbicide control of SL at different maturities during the growing season. Two post-emergence chemicals were approved for SL application at the time of this study (triclopyr and metsulfuron-methyl). When triclopyr was applied at the recommended rate (6.7 kg ai/ha), 100% control was achieved at all levels of plant maturity.

Mesulfuron-methyl, when applied at the recommended rate of 0.017 kg ai/ha, only attained 100% control after plants had reached 50 cm in height. Although complete control was achieved with triclopyr at all times during the growing season, further research is needed to evaluate regrowth in subsequent years. The work of Farris and Murray (2009) took place in a monoculture environment. It should be noted that when herbicides are applied in a pasture environment, other constraints such as terrain, equipment, and the reduction of desirable forbs and grasses may be of concern.

Conclusion

Over 2,000 km^2 of tallgrass prairie are infested with SL in the state of Kansas (KDA, 2016). Multiple biological and chemical forms of control have been explored, many of which have failed to yield satisfactory results. Due to its aggressive nature, SL can reduce grass species basal cover by up to 66% and native forb basal cover by up to 70%; this results in a fundamental degradation of the ecological health of native grasslands (Eddy et al., 2003). Biological control has offered land managers some alternatives to herbicide-based approaches to control of SL. Preedy et al. (2013b) increased herbivory of SL by supplementing cow-calf pairs with CSL, without negatively affecting animal performance (Preedy et al., 2013a) Small ruminants appear to be less sensitive to condensed tannins than beef cattle and can be either co-grazed with beef cattle or grazed subsequent to beef cattle to reduce seed production and diminish basal cover of SL (Pacheco et al., 2012; Lemmon et al., 2017). In contrast, control of SL using the lespedeza webworm met with limited success (Eddy et al., 2003).

When treated with triclopyr or metsulfuron, adult SL plants were effectively controlled within a cropping system after a single application (Farris and Murray, 2009); however, extended seed dormancy necessitated treatment in subsequent years. Koger et al. (2002) evaluated herbicide treatment in a pasture system over multiple years. Sericea lespedeza biomass and seed production were reduced by all herbicide treatments. Although herbicides can be useful to slow the spread of SL, treatment can be expensive and can negatively affect native forbs.

Prescribed Burning

Introduction

Throughout the natural history of the Kansas Flint Hills, prescribed burning and wild fire have played key roles in sustaining the tallgrass prairie as a grassland ecosystem, where fire occurred intermittently during every season of the year (Jackson, 1965). In the absence of fire, trees and brush quickly invade and dominate the tallgrass prairie (Kucera 1960; Blan 1970).

Aboriginal peoples used prescribed burning to alter the movements of bison and to improve forage quality for all herbivores (Gleason, 1913). In the era following the American Civil War, cattlemen in the tallgrass prairie region noticed that transient domestic livestock gained more body weight when grazing pastures that had been recently burned than when grazing pastures that had not been burned (Kollmorgen and Simonett, 1965). Svejcar (1989) reported increased forage digestibility in pastures that had been burned relative to those that had not been burned.

Effects of Prescribed Burning on Sericea Lespedeza

Grazed native tallgrass pastures that were burned annually during the spring had an increase in SL of almost 2% of basal cover annually when compared with grazed, non-burned pastures (Cummings et al., 2007). Wong et al. (2012) reported that fire increased germination of SL seed roughly 2 fold in field experiments. This effect may be a result of scarification of the seeds by fire (Herranz et al., 1998).

In contrast, Cummings et al. (2007) reported that native tallgrass pastures that were patch-burned (i.e., individual pastures were divided into 3 watersheds and fire was applied to only 1 watershed annually in rotational fashion) during the spring and summer had decreased SL invasion rates (0.65% and 0.36% annual increase, respectively) compared with pastures annually burned during spring. Neither patch-burn treatment produced a negative invasion rate indicating that, although patch-burning may slow the spread of SL, it is not a satisfactory form of control. Interestingly, the summer patch-burn treatment allowed approximately half of the annual increase in invasion of SL that the spring patch-burn treatment allowed. This leads to speculation that annually-applied prescribed fire during the summer may reverse SL invasion. Assuming that prescribed burning during summer is as capable of scarifying SL seed as prescribed burning during the spring, annually-applied prescribed fire during summer may cause SL seeds to germinate, producing seedlings without the capability to survive through the ensuing winter.

Brush Control

Anderson (1970) reported that burning was an essential force for maintaining the tallgrass prairie ecosystem. In the absence of fire, the tallgrass prairie was invaded and dominated by woody-stemmed plant species in a relatively short period of time (Kucera, 1960; Blan, 1970). Bragg and Hulbert (1976) evaluated changes in the tallgrass prairie when fire was excluded over a 30-year period. Between 1937 and 1969, woody-stemmed plants increased 34% in pastures that were not burned in comparison with only a 1% increase in pastures that were burned annually. They concluded that controlled burning was a vital management practice for preventing woody-stemmed plant invasion in the tallgrass prairie.

Towne and Owensby (1984) retrospectively evaluated the effects of burning at different times of the year over a 60-yr period. They reported that total herbage production was greatest in plots that were burned in late spring annually and least in plots burned during the winter; pastures burned annually in early spring were intermediate. In plots that were annually burned during late-spring, a greater amount of indiangrass and big bluestem biomass was present when compared with plots that were annually burned in winter or early spring. Furthermore, annual burning during late spring significantly reduced perennial forbs compared with annual burning during winter or early spring. Non-burned plots and plots burned annually during the winter contained greater basal cover of woody plant species, such as buckbrush (*Symphoricarpos orbiculatus*), eastern red cedar (*Juniperus virginiana*), and roughleaf dogwood (*Cornus drummondii*), compared with plots burned annually during spring. In addition, total basal plant cover was greater in plots annually burned in early spring or late spring than plots that were not burned. Prescribed fire timings investigated by these researchers demonstrated major influences on plant species composition and total basal plant cover. In contrast, effects of annual prescribed burning applied during the growing season on plant species composition and basal cover remain to be fully explored.

Weir and Scasta (2017) measured vegetation responses to prescribed fire in western Oklahoma from 2004 to 2015. These authors reported that the timing of prescribed burning had profound effects on plant species composition and basal cover. Prescribed burning in the months of September and October resulted in no change in populations of woody-stemmed plant species, whereas prescribed burning in March and April resulted in a 37% increase in the population of woody-stemmed plants. In addition, prescribed burning in March and April had no effect on native tallgrass species basal cover (e.g. *Andropogon gerardii, Schizachyrium scoparium, Sorghastrum nutans, Bouteloua curtipendula),* while basal cover of those species increased 6% when prescribed fires were conducted in September or October. Weir and Scasta (2017) concluded that prescribed burning of native prairie during the late summer or early fall may have management advantages over prescribed burning during the conventional spring window of time. In addition, current concerns about smoke mitigation during March and April in the Kansas Flint Hills may be partially alleviated by a shift away from the traditional spring-burn paradigm and may lead to greater societal acceptance of prescribed fire as a management option.

Animal Performance

Svejcar (1989) evaluated the effects of prescribed burning of native tallgrass prairie on animal performance over a 3-yr period. Over a 5-mo annual grazing season, cattle grazing pastures that were burned mid-April gained an average of 15.2 kg per animal more than cattle grazing non-burned pastures. Biomass at the end of the growing season in grazing enclosures was greater in burned pastures than non-burned pastures (4,304 kg/ha and 2,539 kg/ha respectively). Prescribed burning applied before conventional spring and summer grazing takes place had benefits for both pasture management and cattle performance; however, effects of annual burning following livestock grazing (i.e., during late summer) remain unevaluated.

Conclusion

Fire was a regular occurrence in the great plains of North America prior to settlement by European peoples (Anderson, 2006). Anderson (1970) and Bragg and Hulbert (1976) reported rapid and extensive invasion of native tallgrass prairie by woody-stemmed plants (i.e., normally forest species) in the absence of fire, whereas prescribed burning during the late spring increased herbage production, basal plant cover, and biomass of key warm-season grass species (Towne and Owensby, 1984).

Weir and Scasta (2017) reported that prescribed burning during the months of March and April allowed a 36% increase in woody-stemmed plant basal cover, while prescribed burning during September and October resulted in no increase in woody-stemmed plant basal cover and a 6% increase in basal cover of warm-season grasses. Cummings et al. (2007) found that SL increased almost 4-fold in pastures that were burned in the spring compared with pastures that were burned in the summer. Regardless of when prescribed burns occurred, Wong et al. (2012) showed that fire had a direct effect on SL germination. Every burn unit in their study had approximately 2-fold greater SL germination compared with unburned plots. It is unknown what impact annual, late-summer prescribed burning may have on SL. Therefore, the objective of our study was to evaluate the effects of growing-season prescribed burning of native tallgrass range on vigor of SL, biomass production, soil cover, and plant species composition.

Literature Cited

Aerts, R. J., T. N. Barry, and W. C. McNabb. 1999. Polyphenols and agriculture: beneficial effects of proanthocyanindins in forages. Agric. Eco. Environ. 75:1-12.

Anderson, R. C. 1970. Prairies in the prairie state. Trans. Illinois State Acad. Sci. 63(2):214-221.

Anderson, R. C. 2006. Evolution and origin of the central grassland of North America: climate, fire, and mammalian grazers. J. Torrey Botan. Soc. 133(4):626-647.

Blan, K. R. 1970. Evaluation of eastern red cedar (*Juniperus virginiana*) infestations in the northern Kansas Flint Hills. MS Thesis. Kansas State Univ., Manhattan.

Bragg, T. B., and L. C. Hulbert. 1976. Woody plant invasion of unburned Kansas bluestem prairie. J. Range Manage. 29:19-24.

Cummings, C. D., S. D. Fuhlendorf, and D. M. Engle. 2007. Is altering grazing selectivity of invasive forage species with patch burning more effective than herbicide treatments? Range Ecol. Manage. 60:253-260.

Cummings, D. C., T. G. Bidwell, C. R. Medlin, S. D. Fuhlendorf, R. D. Elmore, and J. R. Weir. 2006. Ecology and management of sericea lespedeza. Oklahoma Agric. Exp. Sta., NREM-2874.

Dudley, D. M., and W. H. Fick. 2003. Effects of sericea lespedeza residues on selected tallgrass prairie grasses. Trans. Kansas Acad. Sci. 106:166–170.

Eckerle, G. J., K. C. Olson, J. R. Jaeger, J. W. Waggoner, J. L. Davidson, and L. A. Pacheco. 2011. High-tannin forage utilization by beef cows II. Effects of corn steep liquor (CSL) supplementation on intake and digestion of Tallgrass prairie hay contaminated with sericea lespedeza (Lespedeza cuneata). Proc. West. Sec. Amer. Soc. Anim. Sci. 62:203-206.

Eddy, T. A., and C. M. Moore. 1998. Effects of sericea lespedeza (*Lespedeza cuneata* (Dumont) G. Don) invasion on oak savannas in Kansas. Trans. Wisconsin Acad. Sci. Arts Letters 86:57–62.

Eddy, T., J. Davidson, and B. Obermeyer. 2003. Invasion dynamics and biological control prospects for sericea lespedeza in Kansas. Great Plains Res. 13:217–230.

Farris, R. L., and D. S. Murray. 2009. Control of seedling sericea lespedeza (*Lespedeza cuneata*) with herbicides. Invasive Plant Sci. Manage. 2:337-344.

Gleason, H. A. 1913. The relation of forest distribution and prairie fires in the Middle West. Torreya 13(8):173-181.

Herranz, J. M., P. Ferrandis, and J. J. Martinez-Sanchez. 1998. Influence of heat on seed germination of seven Mediterranean leguminosae species. Plant Ecol. 136:95–103.

Hobbs, R. J., and S. E. Humphries. 1995. An integrated approach to the ecology and management of plant invasion. Conserv. Biol. 9(4):761-770.

Jackson, A. S. 1965. Wildfires in the great plains grasslands. Tall Timbers Fire Ecol. Conf. Proc. 4:241-259.

Kalburtji, K. L., and J. A. Mosjidis. 1992. Effects of sericea lespedeza residues on warm-season grasses. J. Range Manage. 45:441–444.

KDA. 2016. 2016 Survey Data. https://agriculture.ks.gov/divisions-programs/plant-protect-weed-control/noxious-weed-control-program (Accessed 10 September 2017.

Koger, C. H., J. F. Stritzke, and C. D. Cummings. 2002. Control of sericea lespedeza (*Lespedeza cuneata*) with Triclopyr, Fluroxypyr, and Metsulfuron. Weed Sci. Soc. Amer. 16:893-900.

Kollmorgen, W. M., and D. S. Simonett. 1965. Grazing operations in the Flint Hills-bluestem pastures of Chase County, Kansas. Ann. Assoc. Amer. Geo. 55:260-290.

Kucera, C. L. 1960. Forest encroachment in native prairie. Iowa State J. Sci. 34(4):635-639.

Lemmon, J., W. H. Fick, J. A. Alexander, G. A. Gatson, and K. C. Olson. 2017. Intensive late-season sheep grazing following early-season steer grazing is an effective biological control mechanism for sericea lespedeza (*Lespedeza cuneata*) in the Kansas Flint Hills. Proc. West. Sec. Amer. Soc. Anim. Sci. 68:124-129.

Logan, R. H., C. S. Hoveland, and E. D. Donnelly. 1969. A germination inhibitor in the seedcoat of sericea [*Lespedeza cuneata* (Dumont) G. Don]. Agron. J. 61:265–266.

Mosjidis, J.A. 1997. Lespedeza cuneata [(Dumont de Courset) G. Don], in: I. F. Hanum and L. J. G.V.D. Maesen (Eds.), Plant Resources of South-East Asia No. 11, Auxiliary Plants. Backhuys Publishers, Leiden, Netherlands. pp. 170-173

Ohlenbusch, P. D., T. Bidwell, W. H. Fick, G. Kilgore, W. Scott, J. Davidson, S. Clubine, J. Mayo, and M. Coffin. 2007. Sericea lespedeza: history, characteristics, and identification. Kans. State Univ. Agric. Exp. Sta. MF-2408.

Pacheco, L. A., W. H. Fick, E. A. Bailey, D. L. Davis, G. W. Preedy, and K. C. Olson. 2012. Effects of co-grazing on herbivory patterns and performance by cattle and goats grazing native tallgrass rangeland infested by sericea lespedeza (*Lespedeza cuneata*). Proc. West. Sec. Amer. Soc. Anim. Sci. 63:169-172.

Preedy, G. W., L. W. Murray, W. H. Fick, L. A. Pacheco, E. A. Bailey, D. L. Davis, A. V. Siverson, and K. C. Olson. 2013b. High-tannin forage utilization by beef cows V. effects of corn steep liquor supplementation on dietary botanical composition of beef cows grazing native range infested by sericea lespedeza (*Lespedeza cuneata*). Proc. West. Sec. Amer. Soc. Anim. Sci. 64:310–316.

Preedy, G. W., W. H. Fick, L. W. Murray, L. A. Pacheco, E. A. Bailey, D. L. Davis, A. V. Siverson, and K. C. Olson. 2013a. High-tannin forage utilization by beef cows IV. Effects of corn steep liquor supplementation on performance and herbivory patterns of beef cows grazing native range infested by sericea lespedeza. Proc. West. Sec. Amer. Soc. Anim. Sci. 64:305-309.

Svejcar, T. J. 1989. Animal performance and diet quality as influenced by burning on tallgrass prairie. J. Range Manage. 42:11-15.

Towne, G., and C. Owensby. 1984. Long-term effects of annual burning at different dates in ungrazed Kansas tallgrass prairie. J. Range Manage. 37:392-397.

Vermeire, L. T., T. G. Bidwell, and J. Stritzke. 2007. Ecology and management of sericea lespedeza. Oklahoma Agric. Exp. Sta, PSS-2874.

Weir, J. R., and J. D. Scasta. 2017. Vegetation responses to season of fire in tallgrass prairie: a 13-year case study. Fire Ecol. 13::137–142.

Wong, B. M., G. R. Houseman, S. E. Hinman, and B. L. Foster. 2012. Targeting life-stages of sericea lespedeza (*Lespedeza cuneata*) with prescribed burns. Invasive Plant Sci. Manage. 5:487-493

Chapter 2 - Effects of prescribed burn timing on vigor of the noxious weed sericea lespedeza (*Lespedeza cuneata*) in the tallgrass prairie

Abstract

The presence of sericea lespedeza (**SL;** *Lespedeza cuneata*) in the native tallgrass prairie has negative effects on surrounding plants and the ecosystem at large. While there is an extensive body of research describing negative effects of SL, control options for this noxious weed remain limited. The effects of annual prescribed burning on the vigor of SL in native tallgrass prairie were investigated over a 4-yr period. We hypothesized that prescribed burning conducted during the growing season, at a time when SL was flowering or producing seed, would selectively pressure the plant, whereas locally-conventional, dormant-season prescribed burning would not affect SL vigor. A 50-ha native tallgrass pasture that was infested with SL (initial basal frequency = 2 ± 1.3%, initial aerial frequency = 36 ± 3.4%) was used for this experiment. Treatment units were divided along watershed boundaries into 9 fire-management units (5 ± 2.6 ha). Burn units were assigned randomly to 1 of 3 prescribed-burning times (n = 3 / treatment): early spring (1 April ± 10.7 d; **EARLY**); mid-summer (1 August ± 1.9 d; **MID**); or late summer (1 September ± 2.7 d; **LATE**). Sericea lespedeza biomass, aerial frequency, stem length, dry plant weight at dormancy, and seed production were measured along single, permanent 100-m transects in each burn unit. Sericea lespedeza biomass measured during the 2017 growing season was greater ($P < 0.01$) in EARLY than in MID and LATE. Treatment and measurement date influenced (treatment × time – $P < 0.01$) SL stem length. Mean stem length in EARLY did not change ($P = 0.21$) between 17 July and 10 October and was greater ($P \leq 0.02$) than mean SL stem length in MID and LATE on 17 July and 10 October. Within measurement date, mean SL stem length was not different ($P \geq 0.27$) between MID and LATE. Aerial frequency of SL (i.e., the percentage of 30-cm^2 plots in which SL was identified) was not influenced by time of measurement (treatment × time - $P = 0.28$); aerial frequency of SL was least (main effect – $P < 0.01$) in LATE, intermediate in MID, and greatest in EARLY. Whole-plant DM weight of SL at dormancy and seed production by SL were markedly less ($P < 0.01$) in MID and LATE compared with EARLY. Compared to locally-conventional spring burning, burning during the summer months over 4 consecutive yr resulted in large decreases in aerial frequency, stem length, seed production, and biomass of SL. Growing-season prescribed burning may be an inexpensive and comprehensive means to control SL propagation and invasion. Additional research is warranted to determine effects of prescribed burn timing on non-target plant species.

Key words: *Lespedeza cuneata*, prescribed fire, range restoration

Introduction

Sericea lespedeza (**SL**) was introduced into the United States from eastern Asia in the late 19th century for its soil-conservation purposes. Sericea lespedeza is a deeply-rooted perennial forb that is tolerant of poor soils. It was a widely-used conservation plant in the U.S. for nearly a century. Sericea lespedeza is extremely invasive in the tallgrass prairie ecosystem. Elevated concentrations of condensed tannins cause beef cattle to avoid grazing SL (Eckerle et al., 2011). A combination of canopy dominance, allelopathy, and prolific reproduction allows SL to rapidly propagate in native grasslands when seed is introduced. Seed can be transported great distances via the alimentary canal of wild and domestic herbivores and via farm equipment. In Kansas, SL has heavily degraded ~2,530 km^2 of pasture, primarily in the Flint Hills region (KDA, 2016).

The resulting damage to native habitats for wildlife and pasture quality for domestic herbivores has been devastating.

The predominant grazing management practice in the Kansas Flint Hills is known as intensive-early stocking. It involves annual spring burning in March or April followed by grazing with yearling beef cattle at a high stocking density for a relatively short period from April to August (Owensby et al. 2008). Intensive-early stocking involves removal of 40 to 60% of annual graminoid production; grazing lands then remain idle for the remainder of the year. Under this popular management practice, invasion by SL into the tallgrass prairie biome has steadily increased (Eddy et al. 2003).

Vermeire et al. (2007) and Wong et al. (2012) indicated that dormant-season spring fires likely stimulate SL germination, thereby allowing SL seedlings a full growing season to store root carbohydrate reserves and to improve survival odds. Heat is known to stimulate germination of leguminous species like SL (Herranz et al., 1998). Heat caused by prescribed fire likely has the effect of scarifying SL seeds lying near the surface of the soil. We speculated that prescribed fire during any season of the yr would promote SL germination; however, prescribed burning late during the growing season would limit photosynthetic opportunities for seedlings and potentially diminish survival odds. Adams et al. (1982) reported plants that bloom and produce seed late in the growing season, such as SL, may respond negatively to prescribed burns conducted at those points. Furthermore, Cummings et al. (2007) reported that application of growing-season prescribed fire at 3-yr intervals decreased the rate of SL invasion in Oklahoma tallgrass prairie. Therefore, the objective of our experiment was to evaluate the effects of annual, growing-season prescribed burning of native tallgrass prairie on vigor of SL.

Materials and Methods

Location

Our experiment was conducted between March 2014 and November 2017. We used a 50-ha native tallgrass pasture located in Geary Co., KS (39°2’N, 96°42’W). Soils were of the Benfield-Florence complex with 5 to 30% slope (90% of total area), Kahola silt loam (channeled; 9% of total area), or Tully silty clay loam (3 to 7% slope; 1% of total area). The site was historically grazed during winter and spring by beef cattle; moreover, the infestation of sericea lespedeza on the site was problematic for the 20-yr period preceding our experiment (Tom Goudey, 2014, Geary Co. Noxious Weed Dept., Junction City, KS, personal communication). Escort XP® (metsulfuron methyl; Bayer Crop Science LP, Research Triangle Park, NC) was applied aerially onto the site in the fall of 2013 at a rate of 70 g/ha. Despite herbicide treatment, basal frequency of SL was 2 ± 1.3% and aerial frequency was 36 ± 3.4% the following spring.

Treatments

The research site was divided along natural watershed boundaries into 9 fire-management units (5 ± 2.6 ha). Burn unit boundaries were delineated by mowing firebreaks (≈ 6 m wide) around each perimeter. Firebreaks were mowed before applying each treatment. Units were assigned randomly to 1 of 3 prescribed-burning times (n = 3 / treatment): early spring (1 April ± 10.7 d; **EARLY**) which served as a positive control; mid-summer (1 August ± 1.9 d; **MID**); or late summer (1 September ± 2.7 d; **LATE**). Treatments were applied at or near target dates for 4 consecutive yr.

Weather

Prescribed burns were carried out only when appropriate environmental conditions prevailed: surface wind speed = 8 to 20 km/h; surface wind direction = steady and away from urban areas; mixing height ≥ 550 m; transport wind speed = 13 to 33 km / h; relative humidity = 40 to 70%; ambient temperature = 13 to 30 °C; and Haines index ≤ 4. All prescribed-burning activities were carried out with the permission of Geary Co. Emergency Services, Junction City, KS (permit no. 348). The long-term average annual precipitation for this site was 83.8 cm. In yrs 1 and 4 of the study, yearly precipitation was below average (63.5 and 76.2 cm, respectively). Years 2 (91.4 cm) and 3 (111.7 cm) exceeded the average annual precipitation.

SL Frequency and Stem Length

Sericea lespedeza aerial frequency and SL maximum stem length were measured twice annually along single, permanent 100-m transects in each fire-management unit (100 × 30-cm^2 plots / transect). Transects were laid out on a southwest-to-northeast gradient exclusively on Benfield-Florence complex soils with less than 2% slope; transect ends were marked using steel fence posts. Transects were read at 1-m intervals on 17 July ± 7.5 d and 10 October ± 3.7 d. A 100-m measuring tape was stretched from the southwestern end to the northeastern end of each transect. A 30 × 30 cm plot was projected parallel to the eastern side of transects at each point of measurement. Within the plot, presence of SL was noted (e.g., yes or no). If SL was present, stem height of the SL plant closest to the 1-m interval on the measuring tape was recorded. Stems were measured in cm from the surface of the soil to maximum length by manually holding the SL stem erect.

Whole-Plant Dry Weight, Seed Production, and Biomass of SL

A total of 100 SL stems were collected at randomly-selected intervals along permanent transects in each burn-management unit immediately after the first killing frost (average date = 1 November ± 3.2 d). Stems were clipped at ground level, placed into a labeled paper bag, dried in a forced-air oven (50ºC; 96 h), and weighed to the nearest mg. Individual stems in each sample (n = 100) were then defoliated manually; seeds, leaves, chaff, and stems were placed collectively into a South Dakota Seed Blower (E.L. Erickson Products, Model B; 10-cm tube) to separate seeds. Cleaned seed was weighed to the nearest mg. Seed weight was converted to seed count assuming a density of 770 seeds / g (Vermeire et al., 2007; Vandevender, 2014). Average seed production per stem was calculated by dividing the number of seeds by the number of SL stems in each sample.

In the final year of the experiment, 10 randomly-placed 0.25-m^2 plots located adjacent to each transect were clipped at a height of 1 cm to estimate SL biomass within each burn-management unit (11 July 2017). Clipped material was hand sorted into SL biomass and non-SL biomass, dried in a forced-air oven (50ºC; 96 h), and weighed to the nearest mg.

Statistical Analysis

Treatment × yr effects on aerial frequency and stem length of SL were analyzed as a completely random design using a general linear model (PROC GLM, SAS Inst. Inc., Cary, NC). Class variables included yr, transect, and treatment. The model included terms for treatment, yr, and treatment × yr. Treatment × yr effects were not detected ($P = 0.37$); therefore, aerial frequency and stem length of SL were analyzed as a completely random design using a mixed model (SAS Inst. Inc., Cary, NC). Class variables included transect, treatment, and time of measurement (i.e., July or October). Year was used as a covariate. When protected by a significant *F*-test ($P \leq 0.05$), least-squares means for the highest-order significant interaction were separated using the method of Least Significant Difference.

Treatment × yr effects on dry weight of SL stems and SL seed production were evaluated using a general linear model (PROC GLM, SAS Inst. Inc., Cary, NC). Class variables included yr, transect, and treatment. Effects of treatment × yr on SL stem dry weight and seed production were detected ($P < 0.01$); however, these interactions were interpreted to have occurred because of the magnitude of differences between treatments. Subsequently, dry weight of SL stems and SL seed production were analyzed as a completely random design with transect, treatment, and year as class variables. The models included an effect for treatment only and yr was used as a covariate. Least-squares means for treatment were reported. When protected by a significant *F*-test ($P \leq 0.05$), least-squares main effect means were separated using the method of Least Significant Difference.

Clipped SL biomass was analyzed as a completely random design (PROC MIXED, SAS Inst. Inc., Cary, NC). Class statements included transect, treatment, and observation. Observation within transect was considered a repeated measure. Least-squares means for treatment main effects were reported. Means were separated using the method of Least Significant Difference when protected by a significant *F*-test ($P \leq 0.05$).

Results and Discussion

Total forage biomass and SL biomass were estimated using a clipping technique during the final yr of our experiment. The intent was to gauge the cumulative effects of 4 consecutive yr of annual burning in either April, August, or September on SL biomass as a proportion of total forage biomass. Biomass estimates were conducted 91 d after the April burn but 22 and 50 d prior to the August and September burns in 2017, respectively. Total forage biomass was greater

($P \leq 0.03$) on 11 July 2017 in EARLY and MID compared with LATE (Figure 2.1); however, SL biomass at that time was greater ($P \leq 0.03$) in EARLY than in MID and LATE. Biomass of SL in EARLY was estimated at 901 kg DM / ha, or 19% of total biomass, whereas biomasses of SL in MID and LATE were estimated to be 394 kg DM / ha (8% of total biomass) and 86 kg DM / ha (2% of total biomass), respectively. Allred et al. (2010) reported that SL had 130% more above-ground biomass at the end of the growing season than big bluestem (*Andropogon gerardii*), clearly underscoring the competitive capabilities of SL in relation to plant species characteristic of the tallgrass prairie. When above-ground plant biomass decreases, root production is universally depressed (Jameson, 1963). An increase in above-ground SL biomass was likely associated with an increase in SL root biomass coincident with decreased root biomass of native plants. Partial defoliation of SL achieved through grazing late in the growing season resulted in reduced SL biomass (Pacheco et al., 2012; Preedy et al., 2013; Lemmon et al., 2017). Nearly complete defoliation of SL, achieved through repeated prescribed burning late in the growing season, may have resulted in progressively depressed SL root carbohydrate reserves, mortality of some mature SL plants, and less robust surviving SL plants.

Treatment and measurement date (i.e., 19 July and 10 October) influenced (treatment × time – $P < 0.01$) SL stem length (Figure 2.2). Mean stem length in EARLY did not change ($P = 0.21$) between 17 July and 10 October and was greater ($P \leq 0.02$) than mean SL stem length in MID and LATE on 17 July and 10 October. Within measurement date, mean SL stem length was not different ($P \geq 0.27$) between MID and LATE.

At the outset of the study, aerial frequency of SL on all transects averaged 36 ± 3.4% and was not different ($P = 0.25$) between treatments (data not shown). Subsequently, aerial frequency of SL was not influenced by time of measurement; therefore, main effects of treatment were reported (Table 2.1). Aerial frequency of SL was least (*P* < 0.01) in LATE (18.0% of 30-cm^2 plots), intermediate in MID (30.8% of plots), and greatest in EARLY (53.0% of plots).

Once established, SL typically grows taller than competing native plants and tends to have a dense, branching aerial structure that can prevent sunlight from reaching understory plants (Ohlenbusch et al., 2007; Vermeire et al., 2007; Allred et al., 2010). Leaf area is critical for plant growth and carbon assimilation (Reich et al., 1997); SL had greater leaf area in proportion to total plant mass than competing native plants during the latter part of the growing season (Allred et al., 2010). In our experiment, MID and LATE prescribed-fire treatments limited the canopy-dominating qualities of SL, allowing native plants an opportunity to colonize soil and canopy space formerly occupied by SL.

Whole-plant DM weight of SL at dormancy and seed production per SL stem were greatly diminished (*P* < 0.01) in MID and LATE compared with EARLY (Table 2.1). Seed production in areas treated with prescribed fire in early August was approximately 4% of that in areas treated with dormant-season spring fire. In areas treated with prescribed fire in early September, seed production was approximately 0.05% that of areas treated with dormant-season spring fire.

We interpreted these data to indicate that prescribed burning during early August or early September effectively reduced the canopy dominance, vigor, and seed-based reproductive capabilities of SL compared to locally-conventional prescribed burning in early April. Shifting prescribed burning from the dormant season to the growing season was associated with diminished SL aerial frequency, stem length, and whole-plant dry weight at dormancy. It was also associated with lesser SL biomass during the final yr of our experiment. Based on this evidence, we concluded that prescribed burning conducted during the growing season likely inhibited the ability of mature SL plants to achieve canopy dominance, thereby improving photosynthetic potential of competing plants.

Possibly the most notable result of our experiment was the finding that prescribed burning during early August or early September sharply curtailed seed production by SL compared with locally-conventional prescribed burning in April. Sericea lespedeza is a prolific seed producer (Ohlenbusch et al., 2007); moreover, seed is the means by which SL spreads geographically. Therefore, control or elimination of seed production may significantly slow the invasion of SL in the tallgrass prairie biome.

Cummings et al. (2006) reported that SL seeds have remarkable durability in the soil. This begs the question of the fate of existing SL seeds in the soil bank. Vermeire et al. (2007) indicated that prescribed burning during spring stimulated germination of SL soil-bank seed by scarifying the seed coat. Under these circumstances, SL seedlings would be afforded a full growing season to store root carbohydrate reserves and to improve survival odds for subsequent years. The timing of fire, however, may not be critical for promoting SL seed germination (Wong et al., 2012). It is reasonable to assume that prescribed fire during any season would promote SL seed germination. It follows that SL seed germination that occurred late during the growing season would limit photosynthetic opportunities for seedlings and potentially diminish survival odds. Reduction in SL aerial frequency observed in our experiment, assuming it represents a reduction in reproducing individuals, may be partially explained by mortality of SL seedlings that initiated growth late in the growing season.

Implications

Compared to locally-conventional, spring prescribed burning, burning during early August or early September for 4 consecutive yr resulted in significant reduction of SL vigor and seed production. Growing-season prescribed burning may be an inexpensive and fairly comprehensive means to control SL propagation. At the time of this writing, prescribed burning in the Kansas Flint Hills had a cash cost of less than $2 USD / ha, whereas fall application of herbicide was estimated to cost between $32 and $75 USD / ha. Notably, prescribed burning during August or early September is temporally compatible with locally-favored yearling beef cattle grazing systems, such as intensive-early stocking.

Figures

Figure 2.1 Effects of the timing of annual prescribed burning of native tallgrass rangeland on total biomass and sericea lespedeza (**SL**) biomass during mid-summer of yr 4 of a 4-yr experiment. The research site was divided along natural watershed boundaries into 9 fire-management units (5 ± 2.6 ha). Burn units were assigned randomly to 1 of 3 prescribed-burning times (n = 3 / treatment): early spring (1 April ± 10.7 d; **EARLY**) which served as a positive control; mid-summer (1 August ± 1.9 d; **MID**); or late summer (1 September ± 2.7 d; **LATE**). Treatments were applied at or near target dates for 4 consecutive yr. Total biomass means not bearing a common superscript letter of a or b differ ($P < 0.01$; SEM = 387.3). Sericea lespedeza biomass means not bearing a common superscript letter of c or d differ ($P < 0.01$; SEM = 201.1).

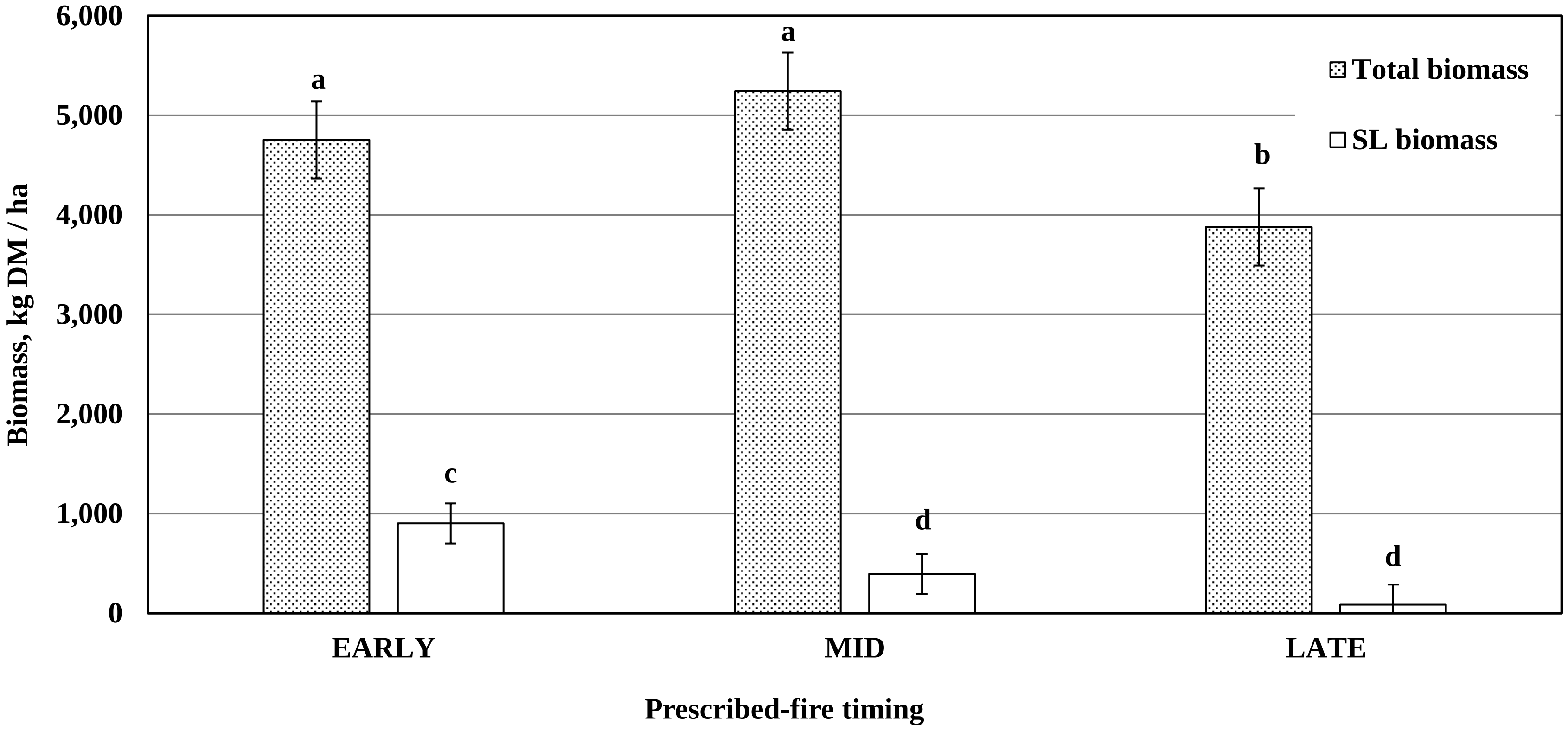
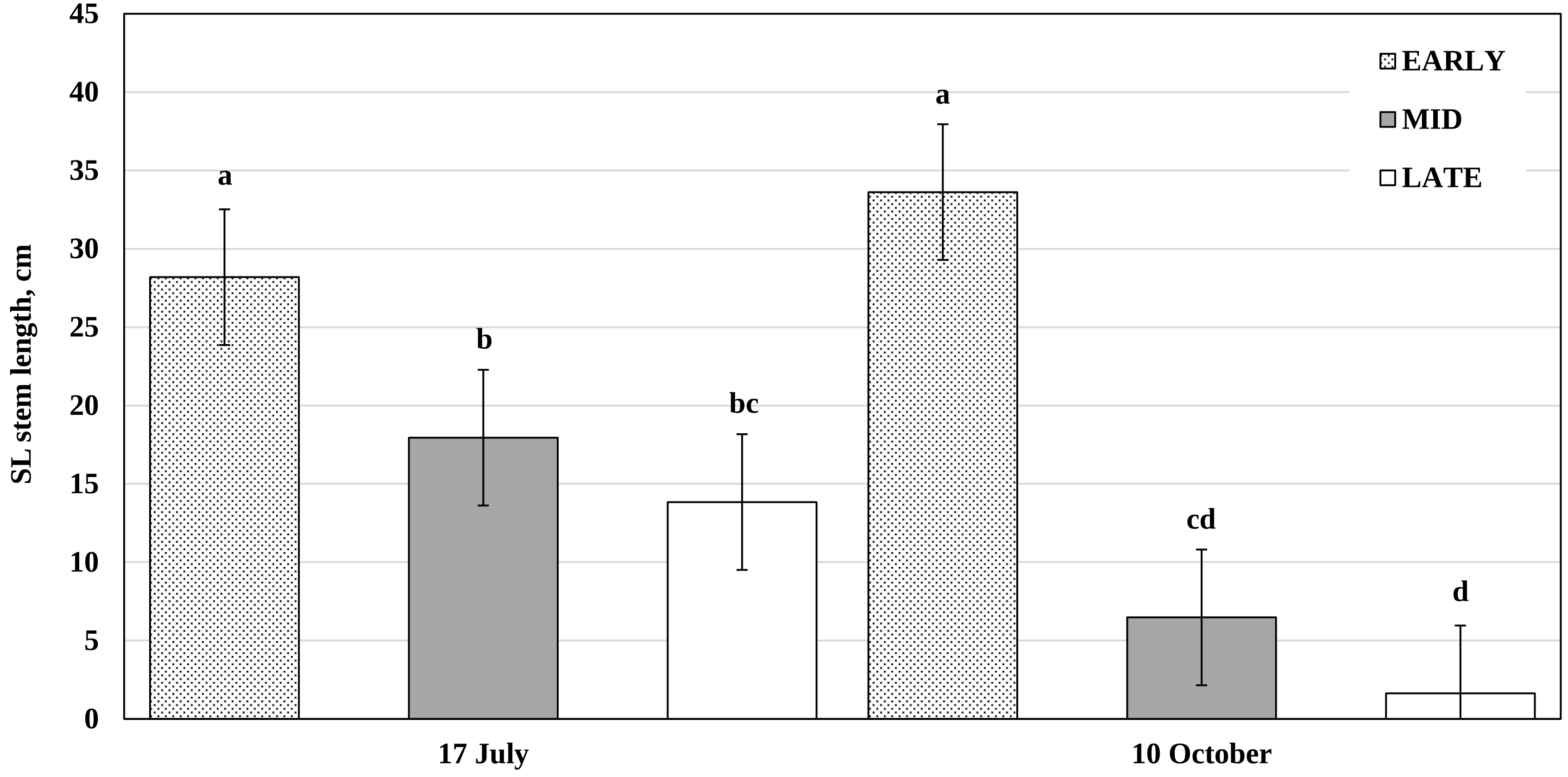


Figure 2.2 Effects of the timing of annual prescribed burning of native tallgrass rangeland on sericea lespedeza (**SL**) stem length measured on 17 July ± 7.5 d and 10 October ± 3.7 d (treatment × time – $P < 0.01$). The research site was divided along natural watershed boundaries into 9 fire-management units (5 ± 2.6 ha). Burn units were assigned randomly to 1 of 3 prescribed-burning times (n = 3 / treatment): early spring (1 April ± 10.7 d; **EARLY**) which served as a positive control; mid-summer (1 August ± 1.9 d; **MID**); or late summer (1 September ± 2.7 d; **LATE**). Treatments were applied at or near target dates for 4 consecutive yr. Means with unlike superscripts a, b, c, or d differ ($P \leq 0.04$; SEM = 4.33).



Tables

Table 2.1 Effects of the timing of prescribed burning of native tallgrass rangeland on sericea lespedeza (**SL**; *Lespedeza cuneata*) aerial frequency, whole-plant DM weight at dormancy, and seed production

Item	Early spring (1 April)	Mid-summer (1 August)	Late summer (1 September)	SEM[*]	*P*-value[†]
SL aerial frequency, % of all plots	53.0^a	30.8^b	18.0^c	5.43	< 0.01
SL whole-plant DM weight, mg / stem	$3{,}815^a$	446^b	130^b	452.7	< 0.01
SL seed production, no. / stem	590.3^a	25.3^b	0.3^b	139.42	< 0.01

[*] Mixed-model SEM associated with comparison of treatment main effect means.

[†] Treatment main effect.

[a, b] Means within a row with unlike superscripts differ ($P \leq 0.02$).

Literature Cited

Adams, D. E., R. C. Anderson, and S. L. Collins. 1982. Differential response of woody and herbaceous species to summer and winter burning in an Oklahoma grassland. Southwest. Nat. 27:55-61.

Allred, B. W., S. D. Fuhlendorf, T. A. Monaco, and R. E. Will. 2010. Morphological and physiological traits in the success of the invasive plant *Lespedeza cuneata*. Biol. Invasions 12:739-749.

Cummings, D. C., T. G. Bidwell, C. R. Medlin, S. D. Fuhlendorf, R. D. Elmore, and J. R. Weir. 2006. Ecology and management of sericea lespedeza. Oklahoma Agric. Exp. Sta., NREM-2874.

Cummings, C. D., S. D. Fuhlendorf, and D. M. Engle. 2007. Is altering grazing selectivity of invasive forage species with patch burning more effective than herbicide treatments? Range Ecol. Manage. 60:253-260.

Eckerle, G. J., K. C. Olson, J. R. Jaeger, J. W. Waggoner, J. L. Davidson, and L. A. Pacheco. 2011. High-tannin forage utilization by beef cows III. Effects of corn steep liquor supplementation on voluntary selection of tallgrass prairie hay contaminated with sericea lespedeza (*Lespedeza cuneata*) and uncontaminated tallgrass prairie hay. Proc. West. Sec. Amer. Soc. Anim. Sci. 62:207-210.

Eddy, T., J. Davidson, and B. Obermeyer. 2003. Invasion dynamics and biological control prospects for sericea lespedeza in Kansas. Great Plains Res. 13:217–230.

Herranz, J. M., P. Ferrandis, and J. J. Martinez-Sanchez. 1998. Influence of heat on seed germination of seven Mediterranean leguminosae species. Plant Ecol. 136:95–103.

Jameson, D. A. 1963. Responses of individual plants to harvesting. Bot. Rev. 29:632-694.

KDA. 2016. 2016 noxious weed survey data, Kansas Dept. Agric. [https://agriculture.ks.gov/divisions-programs/plant-protect-weed-control/noxious-weed-control-program.](https://agriculture.ks.gov/divisions-programs/plant-protect-weed-control/noxious-weed-control-program) Accessed 10 September 2017.

Lemmon, J., W. H. Fick, J. A. Alexander, G. A. Gatson, and K. C. Olson. 2017. Intensive late-season sheep grazing following early-season steer grazing is an effective biological control mechanism for sericea lespedeza (*Lespedeza cuneata*) in the Kansas Flint Hills. Proc. West. Sec. Amer. Soc. Anim. Sci. 68:124-129.

Ohlenbusch, P. D., T. Bidwell, W. H. Fick, G. Kilgore, W. Scott, J. Davidson, S. Clubine, J. Mayo, and M. Coffin. 2007. Sericea lespedeza: history, characteristics, and identification. Kansas Agric. Exp. Sta. MF-2408.

Owensby, C. E., L. M. Auen, H. F. Berns, and K. C. Dhuyvetter. 2008. Grazing systems for yearling cattle on tallgrass prairie. Range. Ecol. Manage. 61:204-210.

Pacheco, L. A., W. H. Fick, E. A. Bailey, D. L. Davis, G. W. Preedy, and K. C. Olson. 2012. Effects of co-grazing on herbivory patterns and performance by cattle and goats grazing native tallgrass rangeland infested by sericea lespedeza (*Lespedeza cuneata*). Proc. West. Sec. Amer. Soc. Anim. Sci. 63:169-172.

Preedy, G. W., L. W. Murray, W. H. Fick, L. A. Pacheco, E. A. Bailey, D. L. Davis, A. V. Siverson, and K. C. Olson. 2013. High-tannin forage utilization by beef cows V. Effects of corn steep liquor supplementation on dietary botanical composition of beef cows grazing native range infested by sericea lespedeza (*Lespedeza cuneata*). Proc. West. Sec. Amer. Soc. Anim. Sci. 64:310–316.

Reich, P. B., M. B. Walters, and D. S. Ellsworth. 1997. From tropics to tundra: global convergence in plant functioning. Proc. Natl. Acad. Sci. USA 94:13730–13734.

Vandevender, J. 2014. Planting guide: Sericea lespedeza. USDA-NRCS. http://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/mvpmcpg7034.pdf. Accessed 1 December 2017.

Vermeire, L. T., T. G. Bidwell, and J. Stritzke. 2007. Ecology and Management of Sericea Lespedeza. Oklahoma Agric. Exp. Sta., PSS-2874.

Wong, B. M., G. R. Houseman, S. E. Hinman, and B. L. Foster. 2012. Targeting life-stages of sericea lespedeza (*Lespedeza cuneata*) with prescribed burns. Invasive Plant Sci. Manage. 5:487-493.

Chapter 3 - Effects of prescribed-burn timing on native tallgrass plant composition and diversity in the Kansas Flint Hills

Abstract

The most common grazing management practice in the northern Kansas Flint Hills involves annual spring burning in April followed by intensive grazing with yearling beef cattle from April to August. Under this management practice – known locally as intensive-early stocking, there has been a steady increase in the presence of the invasive plant sericea lespedeza (**SL**; *Lespedeza cuneata*). Introduced in the late 19th century for its soil conservation properties, SL has recently been an aggressive invader in native Flint Hills plant communities. Up to this time, control of SL has been limited to repeated, costly applications of herbicide which have met with limited success and resulted in collateral damage to non-target plant species. The objective of this 4-yr experiment was to document the effects of prescribed burning during April, August, or September on basal frequency of SL, total forage biomass, and basal cover of grasses, forbs, and shrubs that are native to the tallgrass prairie region. We used a 50-ha native tallgrass pasture infested with SL (initial basal frequency = 2 ± 1.3%, initial aerial frequency = 36 ± 3.4%) that was divided along natural watershed boundaries into 9 fire-management units (5 ± 2.6 ha) for this experiment. Burn units were assigned randomly to 1 of 3 annual prescribed-burning times (n = 3 / treatment): early spring (1 April ± 10.7 d; **EARLY**); mid-summer (1 August ± 1.9 d; **MID**); or late summer (1 September ± 2.7 d; **LATE**). Total forage biomass, soil cover, and basal vegetation cover were measured along single, permanent 100-m transects in each burn unit. Treatment and measurement date (i.e., 17 July and 10 October) influenced (treatment × time – $P < 0.01$) total forage biomass; it was not different ($P \geq 0.43$) between treatments on 19 July; however, forage biomass was greater ($P < 0.01$) in EARLY than MID and LATE on 10 October.

Occurrence of bare soil, litter cover, and total basal plant cover were not different ($P \geq 0.29$) between treatments. Similarly, basal cover of all grasses, C4 grasses, C3 grasses, annual grasses, all forbs, and all shrubs were not different ($P \geq 0.11$) between treatments. Conversely, basal cover of SL, Baldwin's ironweed, and western ragweed were greater ($P \leq 0.01$) in EARLY compared with MID and LATE, whereas combined basal cover of major wildflowers was less ($P = 0.03$) in EARLY than in LATE. We interpreted these data to indicate that prescribed burning during the growing season produced no detrimental effects on total forage biomass, soil cover, or desirable non-target plant species, while having strong suppressive effects on basal cover of SL. Additional research is warranted to investigate how to incorporate growing-season prescribed burning into common grazing management practices in the Flint Hills of Kansas.

Key words: basal cover, biomass, *Lespedeza cuneata*, prescribed burning, tallgrass prairie

Introduction

Prescribed burning and wildfires have historically protected the tallgrass prairie from encroachment by invasive woody-stemmed plants (Jackson, 1965). In the absence of fire, trees and shrubs quickly invade and dominate the tallgrass prairie (Kucera, 1960; Blan, 1970). Prescribed burning has also been associated with greater subsequent weight gains by domestic livestock grazing in burned areas compared with non-burned areas (Kollmorgen and Simonett, 1965).

Early European settlers to the Flint Hills region generally practiced prescribed burning during the months of January and February to hasten the availability of high-quality forage for domesticated livestock (Towne and Owensby, 1984). Currently, the major grazing management practice in the Kansas Flint Hills - known as intensive-early stocking - involves annual spring burning in March or April followed by grazing with yearling beef cattle at a high stocking density for a relatively short period from April to August (Owensby et al. 2008). Intensive-early stocking involves removal of 40 to 60% of annual graminoid production; grazing lands then remain idle for the remainder of the year. Under this management practice, invasion by sericea lespedeza (**SL**; *Lespedeza* cuneata) into the tallgrass prairie biome has steadily increased (Eddy et al., 2003); moreover, significant concentrations of smoke resulting from a temporally-concentrated window of prescribed fire application have resulted in degradation of air quality for downwind municipalities (Towne and Craine, 2014; Weir and Scasta, 2017). Applying prescribed fire during the late growing season may inhibit SL invasion because SL typically flowers and produces seed during this period; however, effects on non-target plant species also merit exploration. It may also provide a powerful economic motive for land managers to reduce smoke intensity during spring. Therefore, the objective of this experiment was to document the effects of prescribed burning during April, August, or September on SL and the grasses, forbs, and shrubs that are native to the tallgrass prairie region.

Materials and Methods

Location

Our experiment was conducted between March 2014 and November 2017. We used a 50-ha native tallgrass pasture located in Geary Co., KS (39°2’N, 96°42’W). Soils were of the Benfield-Florence complex with 5 to 30% slope (90% of total area), Kahola silt loam (channeled; 9% of total area), or Tully silty clay loam (3 to 7% slope; 1% of total area). The site was historically grazed during winter and spring by beef cattle; moreover, the infestation of SL on the site was problematic for the 20-yr period preceding our study (Tom Goudey, 2014, Geary Co. Noxious Weed Dept., Junction City, KS, personal communication). Escort XP® (metsulfuron methyl; Bayer Crop Science LP, Research Triangle Park, NC) was applied aerially onto the site in the fall of 2013 at a rate of 70 g/ha. Despite herbicide treatment, basal frequency of SL was 2 ± 1.3% and aerial frequency was 36 ± 3.4% the following spring.

Treatments

The research site was divided along natural watershed boundaries into 9 fire-management units (5 ± 2.6 ha). Burn unit boundaries were delineated by mowing firebreaks (≈ 6 m wide) around each perimeter. Firebreaks were mowed before applying each treatment. Burn units were assigned randomly to 1 of 3 prescribed-burning times (n = 3 / treatment): early spring (1 April ± 10.7 d; **EARLY**) which served as a positive control; mid-summer (1 August ± 1.9 d; **MID**); or late summer (1 September ± 2.7 d; **LATE**). Treatments were applied at or near target dates for 4 consecutive yr.

Weather

Prescribed burns were carried out only when appropriate environmental conditions prevailed: surface wind speed = 8 to 20 km / h; surface wind direction = steady and away from urban areas; mixing height ≥ 550 m; transport wind speed = 13 to 33 km / h; relative humidity = 40 to 70%; ambient temperature = 13 to 30 °C; and Haines index ≤ 4. All prescribed-burning activities were carried out with the permission of Geary Co. Emergency Services, Junction City, KS (permit no. 348). The long-term average annual precipitation for this site was 83.8 cm. In yrs 1 and 4 of the study, yearly precipitation was below average (63.5 and 76.2 cm, respectively). Years 2 (91.4 cm) and 3 (111.7 cm) exceeded the average annual precipitation.

Vegetation Response

Forage biomass was measured annually along permanent 100-m transects in each fire-management unit (100 points / transect). Transects were laid out on a southwest-to-northeast gradient exclusively on Benfield-Florence complex soils with less than 2% slope; transect ends were marked using steel fence posts. Transects were read at 1-m intervals on 17 July ± 7.5 d and 10 October ± 3.7 d annually. A 100-m measuring tape was stretched from the southwestern end to the northeastern end of each transect. At 1-m intervals along each transect, biomass was estimated according to Robel et al. (1970).

Post-treatment forage quality was assessed on 10 October 2017 using 10 steel-framed clipping squares (0.25 m^2) placed randomly along each transect. Forage was clipped at a height of 1 cm and hand-sorted into SL and non-SL biomass; SL biomass was discarded and non-SL biomass was placed into paper bags and dried at 50° C for 96 h. Samples were ground (#4 Wiley Mill, Thomas Scientific, Swedesboro, NJ) to pass a 1-mm screen, composited by weight within transect, and then submitted to the Kansas State University Analytical Laboratory, Manhattan, KS for analysis of DM (Goering and van Soest, 1970); OM (Goering and van Soest, 1970); N (AOAC International, 2000) using combustion analysis (Leco TruMac N, St, Joseph, MI); NDF (Van Soest et al., 1991; modified for the Ankom 200 fiber analyzer, Ankom Technology Corp.); ADF (AOAC International, 2005 modified for the Ankom 200 fiber analyzer, Ankom Technology Corp.); Ca (Mills and Jones, 1996); and P (Mills and Jones, 1996). Chemical composition of forage samples is expressed in Table 3.1.

Plant species composition and soil cover were evaluated annually along each permanent transect in mid-October (yr 1 and 4) or mid-July (yr 1, 2, 3, and 4) using a modified step-point technique (Owensby, 1973; Farney et al., 2017). Transect points (n = 100 / transect) were evaluated for bare soil, litter cover, or basal plant area (% of total area). Plants were identified by species; basal cover of individual species was expressed as a percentage of total basal plant area. Comprehensive lists of graminioids, forbs, and shrubs encountered during plant-composition analyses are depicted in Tables 3.2, 3.3, and 3.4, respectively.

Plant species were classified into growth-form categories in order to evaluate changes in plant growth form composition (Hickman et al., 2004). Categories included C4 tall grasses, C4 mid grasses, C4 short grasses, C3 grasses and sedges, annual grasses, perennial forbs, annual forbs, major wildflowers (i.e., catclaw sensitivebriar [*Mimosa nuttallii*], dotted gayfeather [*Liatris punctata*], heath aster [*Symphyotrichum ericoides*], prairie coneflower [*Ratibida columnifera*], purple poppymallow [*Callirhoe involucrata*], purple prairieclover [*Dalea purpurea*], roundhead prairieclover [*Dalea multiflora*], and white prairie clover [*Dalea candida*]), shrubs, and ‘increaser’ shrubs (i.e., roughleaf dogwood [*Cornus drummondii*], smooth sumac [*Rhus glabra*], and buckbrush [*Symphoricarpos orbiculatus*]).

Plant species richness (S = number of species sampled per transect), Shannon diversity ($H' = -\sum p_i - \ln p_i$, where p_i = proportional contribution of plants of species i to the plant community), and evenness ($H'/\ln S$) were calculated for each transect using all plant species, native plant species only, grasses only, and forbs only (Magurran, 2004). In addition, Simpson dominance ($D = \sum p_i^2$, where p_i represents the proportion of the total plant community comprised of species i) was calculated to estimate the probability of two plants randomly and independently selected from the community belonging to the same species (Simpson, 1949; Pielou, 1975). To generate an index that is positively related to diversity, the Simpson diversity index ($-\log D$) was also calculated (Pielou, 1975; Magurran, 2004).

Statistical Analysis

Treatment × yr effects on total forage biomass were analyzed as a completely random design using a general linear model (PROC GLM, SAS Inst. Inc., Cary, NC). Class variables included yr, transect, and treatment. The model included terms for treatment, yr, and treatment × yr. Treatment × yr effects on total forage biomass were not significant ($P = 0.99$); therefore, total forage biomass was analyzed as a completely random design using a mixed model (PROC MIXED, SAS Inst. Inc., Cary, NC). Class variables were transect, treatment, and time of measurement (i.e., July or October). The model included terms for treatment, time, and treatment × time. Year was used as a covariate. Least-squares means for treatment × time were separated using the method of Least Significant Difference when protected by a significant *F*-test ($P \leq 0.05$).

Treatment × yr effects on the percentages of bare soil, litter cover, total basal vegetation cover, grass basal cover, forb basal cover, shrub basal cover, basal cover of individual plant species, and diversity measures were analyzed as a completely random design using a general linear model (PROC GLM, SAS Inst. Inc., Cary, NC). Class variables included yr, transect, and treatment. The model included terms for treatment, yr, and treatment × yr. Treatment × yr effects on percentages of bare soil, litter cover, total basal vegetation cover, grass basal cover, forb basal cover, shrub basal cover, basal cover of individual plant species, and diversity indices were not detected ($P \geq 0.11$) for any measurement. Subsequently, the percentages of bare soil, litter cover, total basal vegetation cover, grass basal cover, forb basal cover, shrub basal cover, basal cover of individual plant species, and diversity measures were analyzed as a completely random design using a mixed model (SAS Inst. Inc., Cary, NC). Class variables were year, treatment, and transect. The model contained a term for treatment only and year was used as a covariate. When protected by a significant *F*-test ($P \leq 0.05$), least-squares treatment means were separated using the method of Least Significant Difference.

Results and Discussion

Forage Biomass

Total forage biomass was influenced by treatment and measurement date (treatment × time, $P < 0.01$; Table 3.5). Forage biomass was not different ($P \geq 0.43$) between treatments on 17 July. We concluded that repeated burning during the growing season did not impair forage production compared to conventional spring burning. On 10 October, forage biomass was greater ($P < 0.01$) in EARLY than in MID and LATE.

Prescribed fire treatments on 1 August and 1 September resulted in nearly complete removal of above-ground plant material; however, forage regrowth following fires resulted in significant accumulations of biomass prior to seasonal plant dormancy. Total forage biomass on EARLY burn units decreased by an average of 752 kg DM/ha between 17 July and 10 October, a reduction of 18.7%. By comparison, total forage biomass on MID and LATE burn units recovered to 37% and 21%, respectively, of pre-fire total forage biomass levels during the periods between treatment application and measurement. Auen and Owensby (1988) evaluated the effects of dormant-season herbage removal on subsequent biomass accumulation, soil moisture, and total non-structural carbohydrate accumulation in big bluestem. They reported that mowing herbage to a 5-cm height in fall or winter resulted in no changes to subsequent total biomass accumulation, soil moisture, or root carbohydrate reserves in big bluestem compared with non-mowed areas. Towne and Craine (2014) reported also that above-ground net primary production of grasses was not different when native tallgrass watersheds were burned frequently over a 20-yr period in either November, February, or April; those authors opined that soil moisture losses were similar across fire regimes because plant productivity was unchanged. Therefore, we concluded that post-fire regrowth was likely sufficient to prevent erosion and that soil-moisture losses were similar between burn treatments during the subsequent dormant season. In addition, forage regrowth on watersheds treated with prescribed fire during August or September in our experiment would have allowed light to moderate grazing during the ensuing fall and winter.

A potential benefit to prescribed burning during growing season is that quality of forage regrowth in our experiment appeared to be better in MID and LATE compared with EARLY (Table 3.1). Forage CP was 2.3 to 2.9% greater, NDF was 3.2 to 5.6% less, and ADF was 5.8 to 8.1% less in MID and LATE compared with EARLY. These improvements in fall forage quality for grazing livestock may ameliorate some of the liabilities associated with reductions in biomass.

Soil Cover

Frequencies of bare soil, litter cover, and total basal plant cover were not different ($P \geq 0.29$) between EARLY, MID, and LATE (Table 3.6). Values reported in our experiment were generally indicative of healthy tallgrass prairie ecosystems (Fuhlendorf and Engle, 2004). Basal cover values for all grasses, C4 grasses, C3 grasses and sedges, and annual grasses were also not different ($P \geq 0.11$) between prescribed-burn treatments (Table 3.7). In contrast, we observed shifts in basal cover among growth forms within the C4 grasses. Cumulative basal cover of C4 tall grasses (i.e., big bluestem, Eastern gamagrass, indiangrass, purpletop, sand paspalum, and switchgrass) was greater ($P < 0.01$) in EARLY and MID than in LATE. This change was accompanied by an increase ($P < 0.01$) in C4 mid grasses in LATE compared with EARLY and MID.

In order to evaluate the nature of the shift in basal cover between C4 tall and mid growth forms, we examined basal cover values of individual species: big bluestem, indiangrass, and switchgrass (i.e., predominant tall growth-form grasses) and little bluestem and sideoats grama (i.e., predominant mid growth-form grasses). These species were chosen because they represented cumulative cover contributions of greater than 80% of the basal cover attributed to their respective growth-form classifications across the prescribed fire regimes under study. Big bluestem cover was less ($P = 0.02$) in LATE than in EARLY and MID (Table 3.8). Indiangrass basal cover was greatest ($P = 0.04$) in MID and least in LATE; it was intermediate to and not different (pairwise comparisons - $P \geq 0.17$) from MID and LATE in EARLY. Basal covers of sideoats grama and switchgrass were not different ($P \geq 0.07$) between treatments; however, basal cover of little bluestem was greater ($P = 0.01$) in LATE than in EARLY and MID. We concluded that the shift in basal cover between C4 tall grasses and C4 mid grasses in our study was primarily caused by a shift from big bluestem to little bluestem in the LATE prescribed fire treatment. We further noted that C4 tall and mid-grass compositions in EARLY and MID were similar to one another. Towne and Kemp (2008) noted that composition of C4 tall grasses was not changed when pastures were burned frequently in either April or late July to mid-August.

Total basal cover attributable to forbs was not different ($P = 0.16$) between the prescribed-fire regimes evaluated in our experiment; however, there were notable shifts within forb growth forms between treatments (Table 3.9). Basal cover values for annual forbs were greater ($P = 0.02$) in MID and LATE than in EARLY; however, differences between treatments were numerically small and < 1.5% of total basal cover. In contrast, cumulative basal cover values of perennial forbs were less ($P = 0.02$) in MID and LATE compared with EARLY. In order to determine the nature of the change in perennial forb cover between treatments, we examined basal cover values of SL, Baldwin’s ironweed, and Western ragweed; these were chosen because they collectively represented 77, 50, and 43% of cumulative basal cover attributable to perennial forbs in EARLY, MID, and LATE, respectively. Additionally, we evaluated cumulative basal cover of major wildflower species (i.e., catclaw sensitivebriar, dotted gayfeather, heath aster, prairie coneflower, purple poppymallow, purple prairieclover, roundhead prairieclover, and white prairie clover) because of the critical roles these species play in food and habitat provision for native invertebrate and vertebrate species.

Basal covers of SL, Baldwin's ironweed, and Western ragweed in EARLY were greater ($P \leq 0.01$) than in those in MID and LATE. Towne and Kemp (2008) indicated prescribed burning during summer resulted in greater variation in Western ragweed cover than prescribed burning during spring, whereas frequency of Baldwin's ironweed was not different between watersheds burned in spring or summer. Sericea lespedeza is classified as an exotic, invasive species in Kansas (Ohlenbusch et al., 2007) and Oklahoma (Vermeire et al., 2007). In addition, Baldwin's ironweed and Western ragweed are generally regarded as 'increaser' forbs with limited value for beef-cattle grazing (Stubbendieck et al., 1992; Haddock, 2005). We interpreted these data to indicate that prescribed burning of native tallgrass range in August or September controlled vegetative propagation of these forbs compared with prescribed burning in April. In the specific case of SL, prescribed burning in August resulted in a 54% decline in SL basal cover compared with prescribed burning in April, whereas prescribed burning in September resulted in a 76% decline in SL basal cover compared with prescribed burning in April.

Koger et al. (2002) reported similar control of mature SL plants with a foliar application of metsulfuron, a commonly used pasture herbicide in Kansas. These authors noted that viable juvenile SL plants remained following herbicide treatments and attributed survival to the nature of aerial herbicide application above an inherently-dense plant canopy. Some herbicide was likely intercepted by overstory plants and did not reach the understory occupied by SL seedlings.

In contrast, growing-season prescribed fires in our experiment likely affected both adult and juvenile SL plants because they are generally carried by fine fuels at or near the surface of the soil.

Reductions in basal covers of SL, Baldwin's ironweed, and Western ragweed were accompanied by an increase ($P = 0.03$) in combined basal cover of major wildflowers in LATE compared with EARLY. Control of SL with herbicides may result in damage to sensitive non-target forbs, such as wildflowers (Blocksome, 2006). Prescribed burning during September was not associated with damage to this growth-form classification. Native wildflowers are an essential food source for native invertebrates, which are in turn food sources for grassland-nesting birds (Beran et al., 1999). Increases in cumulative basal cover of wildflowers may be related to reports by Ogden (2016) that areas of our experimental site treated with prescribed fire in early September had greater usage by certain grassland-nesting bird species than areas treated with prescribed fire in April.

Total basal cover attributed to woody-stemmed plants (i.e., shrubs) was not different ($P = 0.50$) between EARLY, MID, and LATE prescribed-burning treatments, and was generally below accepted norms for locally-conventional beef-cattle grazing systems (Table 3.10). Conversely, combined basal cover of 'increaser' shrubs (i.e., roughleaf dogwood, smooth sumac, and buckbrush) was less ($P = 0.04$) in MID than in EARLY and LATE. Basal cover of leadplant, a documented component of beef cattle diets (Sproul et al., 2010; Aubel et al., 2011), was not affected ($P = 0.31$) by the prescribed fire regimes under study, whereas New Jersey tea basal cover was greater ($P < 0.01$) in MID than in EARLY or LATE. New Jersey tea has significant value as a forage resource for herbivores and as a nectar source for grassland insects (USDA, 2010).

Plant Species Diversity

Evenness, Shannon diversity, Simpson dominance, and Simpson diversity of all plant species and native plant species only were not influenced (*P* ≥ 0.09) by the timing of prescribed burning in our experiment (Table 3.11). In general, species evenness and Shannon diversity values were similar to those reported by Hickman et al. (2004) for annually-burned tallgrass prairie managed under moderate grazing intensity. In contrast, Simpson diversity was generally greater than that reported by Randa and Yunger (2001) on restored tallgrass prairie that was either burned or mowed. Simpson diversity of undisturbed, native tallgrass prairie remnants was reportedly greater than that of restored tallgrass prairie sites (McLachlan and Knispel, 2005; Polley et al., 2005). In our experiment, overall plant-species richness and native plant-species richness were greater (*P* < 0.01) in MID and LATE than in EARLY. Towne and Kemp (2008) observed similar trends in plant species richness on tallgrass prairie that was frequently burned in the summer compared to that frequently burned in the spring.

Richness, evenness, Shannon diversity, Simpson diversity, and Simpson dominance were not different (*P* ≥ 0.46) among grass and grass-like species only on EARLY, MID, and LATE prescribed fire treatments (Table 3.12). Frequency and cover attributable to 10 native tallgrass prairie graminoid species was generally stable over a 14-yr period between spring and summer prescribe-fire regimes according to Towne and Kemp (2008). In contrast, forb richness, evenness, Shannon diversity, and Simpson diversity were greater (*P* ≤ 0.02) in MID and LATE than in EARLY. Additionally, Simpson dominance was less (*P* < 0.01) in MID and LATE than in EARLY (0.52, 0.45, and 0.65, respectively), indicating greater balance between forb community components.

Although the total basal cover of forbs was not different ($P = 0.16$) between EARLY, MID, and LATE treatments (Table 3.9), there were 50% more ($P < 0.01$) forb species present in MID and LATE compared with EARLY and forb evenness was greater ($P = 0.02$) in MID and LATE compared with EARLY (Table 3.12). Authors interpreted these data to be evidentiary to the allelopathic properties of SL. Basal cover of SL in EARLY was 7.27% of total basal vegetation cover, more than 2× that in MID and more than 4× that in LATE (Table 3.9). As SL was progressively weakened by growing-season prescribed fires, forbs in particular were able to re-establish themselves in the void left by SL.

Although forbs are a relatively small contributor to total biomass of native tallgrass prairie, they are a key component of many ecosystem processes (Grime, 1998). Forbs are a valuable diet component for domesticated livestock, wild ungulates, birds, and invertebrates and the relative importance of forbs in the diets of herbivores may change seasonally (Cook, 1983). Biondini et al. (1989) suggested that forbs were of greater diagnostic value for judging environmental conditions than other plant types; in general, greater forb heterogeneity was equated with greater overall health. Weir and Scasta (2017) reported that forb diversity and cover increased as prescribed burning was moved from spring to later times of the year. Similarly, Towne and Kemp (2008) reported linear increases in richness of forb species over time in areas frequently burned during summer. In contrast, forb richness did not change over time in areas frequently burned during spring. In our study, growing-season prescribed burning increased diversity among forb species compared with dormant-season prescribed burning without increasing basal cover of forbs. This reflects a pattern of multiple, desirable forb species filling the ecosystem void left by declining SL populations in the growing-season burn treatments. This trend may be the cause of the desirable shift in songbird and butterfly populations towards areas of decreased SL abundance noted on this site by Ogden (2016).

Implications

Our results were interpreted to indicate that growing-season prescribed burning resulted in several positive influences on overall ecological health of tallgrass prairie. Altering the timing of prescribed burning from the traditional spring season to either mid-summer or late summer did not result in measurable changes to total forage biomass, bare soil, litter, total basal vegetation cover, C4 grass cover, C3 grass cover, or forb cover. Growing-season prescribed burning provided adequate control of woody plants when compared to locally-conventional prescribed burning during spring. Importantly, prescribed burning during the growing season placed selective pressure on SL and certain other undesirable forbs and shrubs that prescribed fire during the dormant season was unable to achieve. We concluded that prescribed burning during August or early September provided an inexpensive and comprehensive means to control vegetative SL propagation while improving forb diversity, improving habitat for native pollinators, and enhancing overall ecosystem health without decreasing the value of grasslands for grazing by transient yearling cattle.

Tables

Table 3.1 Effects of prescribed fire timing on chemical composition (mean ± SD) of tallgrass prairie forage as measured in October 2017.

Item	Early spring (04/01)	Mid-summer (08/01)	Late summer (09/01)
DM, %	94.3 ± 0.47	94.9 ± 0.24	93.7 ± 0.26
	--------------------------------	% DM	--------------------------------
OM, %	88.7 ± 1.75	87.9 ± 0.81	85.8 ± 1.29
CP, %	4.4 ± 0.51	6.7 ± 0.93	7.3 ± 0.86
NDF, %	66.1 ± 3.53	60.5 ± 2.22	62.9 ± 1.90
ADF, %	39.9 ± 2.33	31.8 ± 2.90	34.1 ± 4.52
Ca, %	0.33 ± 0.053	0.29 ± 0.021	0.33 ± 0.039
P, %	0.06 ± 0.004	0.11 ± 0.027	0.12 ± 0.023

Table 3.2 Grass and grass-like species encountered on native tallgrass watersheds burned during April, August, or September in 2014, 2015, 2016, and 2017

Common name	Scientific name	Classification	Status	Metabolism	Growth form
Big bluestem	*Andropogon gerardii*	Perennial	Native	C4	Tall
Blue grama	*Bouteloua gracilis*	Perennial	Native	C4	Short
Buffalograss	*Buchloe dactyloides*	Perennial	Native	C4	Short
Canada wildrye	*Elymus canadensis*	Perennial	Native	C3	Tall
Eastern gamagrass	*Tripsacum dactyloides*	Perennial	Native	C4	Tall
Fall witchgrass	*Digitaria cognata*	Perennial	Native	C4	Mid
Hairy grama	*Bouteloua hirsuta*	Perennial	Native	C4	Short
Indiangrass	*Sorghastrum nutans*	Perennial	Native	C4	Tall
Japanese brome	*Bromuis japonicus*	Annual	Introduced	C3	Short
Kentucky bluegrass	*Poa pratensis*	Perennial	Introduced	C3	Short
Little bluestem	*Schizachyrium scoparium*	Perennial	Native	C4	Mid
Prairie junegrass	*Koeleria macrantha*	Perennial	Native	C3	Short
Prairie threeawn	*Aristida oligantha*	Annual	Native	C4	Short
Purple lovegrass	*Eragrostis spectabilis*	Perennial	Native	C4	Mid
Purpletop	*Tridens flavus*	Perennial	Native	C4	Tall
Sand paspalum	*Paspalum setaceum*	Perennial	Native	C4	Mid
Scribner panicum	*Dichanthelium oligosanthes*	Perennial	Native	C3	Short
Sedge	*Carex* spp.	Perennial	Native	C3	n.a.
Sideoats grama	*Bouteloua curtipendula*	Perennial	Native	C4	Mid
Switchgrass	*Panicum virgatum*	Perennial	Native	C4	Tall
Tall dropseed	*Sporobolus asper*	Perennial	Native	C4	Mid
Tumble windmillgrass	*Chloris verticillata*	Perennial	Native	C4	Short
Virginia wildrye	*Elymus virginicus*	Perennial	Native	C3	Tall

Table 3.3 Forb species encountered on native tallgrass watersheds burned during April, August, or September in 2014, 2015, 2016, and 2017

Common name	Scientific name	Growth	Status
Annual broomweed	*Amphiachyris dracunculoides*	Annual	Native
Ashy sunflower	*Helianthus mollis*	Perennial	Native
Baldwin's ironweed	*Vernonia baldwinii*	Perennial	Native
Blackeyedsusan	*Rudbeckia hirta*	Perennial	Native
Blue wildindigo	*Baptisia australis*	Perennial	Native
Brittlebract plantain	*Plantago spinulosa*	Annual	Native
Carolina horsenettle	*Solanum carolinense*	Perennial	Native
Catclaw sensitivebriar	*Mimosa nuttallii*	Perennial	Native
Clammy groundcherry	*Physalis heterophylla*	Perennial	Native
Common St. Johnswort	*Hypericum perforatum*	Perennial	Introduced
Common yellow oxalis	*Oxalis stricta*	Perennial	Native
Daisy fleabane	*Erigeron strigosus*	Annual	Native
Dotted gayfeather	*Liatris punctata*	Perennial	Native
False boneset	*Brickellia eupatorioides*	Perennial	Native
Field pussytoes	*Antennaria neglecta*	Perennial	Native
Fringeleaf ruellia	*Ruellia humilis*	Perennial	Native
Green antelopehorn	*Asclepias viridis*	Perennial	Native
Grooved flax	*Linum sulcatum*	Annual	Native
Heath aster	*Symphyotrichum ericoides*	Perennial	Native
Horsenettle	*Solanum carolinense*	Perennial	Native
Korean lespedeza	*Kummerowia stipulacea*	Annual	Introduced
Longbeard hawkweed	*Hieracium longipilum*	Annual	Native
Missouri goldenrod	*Solidago missouriensis*	Perennial	Native
Oneseed croton	*Croton monanthogynus*	Annual	Native
Pale poppymallow	*Callirhoe alcaeoides*	Perennial	Native
Pitcher sage	*Salvia azurea*	Perennial	Native
Prairie coneflower	*Ratibida columnifera*	Perennial	Native
Prairie groundsel	*Senecio plattensis*	Perennial	Native
Purple poppymallow	*Callirhoe involucrata*	Perennial	Native
Purple prairieclover	*Dalea purpurea*	Perennial	Native
Rough falsepennyroyal	*Hedeoma hispida*	Annual	Native
Roundhead lespedeza	*Lespedeza cuneata*	Perennial	Native
Roundhead prairieclover	*Dalea multiflora*	Perennial	Native
Sericea lespedeza	*Lespedeza cuneata*	Perennial	Introduced
Silver scurfpea	*Psoralea argophylla*	Perennial	Native
Smallflower gaura	*Gaura parviflora*	Annual	Native
Stiff goldenrod	*Oligoneuron rigidum*	Perennial	Native
Tall goldenrod	*Solidago altissima*	Perennial	Native
Venice mallow	*Hibiscus trionum*	Annual	Native
Violet lespedeza	*Lespedeza violacea*	Perennial	Native
Virginia copperleaf	*Acalypha virginica*	Annual	Native
Virginia pepperweed	*Lepidium virginicum*	Perennial	Native
Wavyleaf thistle	*Cirsium undulatum*	Perennial	Native
Western ragweed	*Ambrosia psilostachya*	Perennial	Native
Western yarrow	*Achillea millefolium*	Perennial	Native
White milkwort	*Polygala alba*	Perennial	Native
White prairieclover	*Dalea candida*	Perennial	Native
Whorled milkweed	*Asclepias verticillata*	Perennial	Native
Wild onion	*Allium* spp.	Perennial	Native
Woolly verbena	*Verbena stricta*	Perennial	Native

Table 3.4 Shrub species encountered on native tallgrass watersheds burned during April, August, or September in 2014, 2015, 2016, and 2017

Common name	Scientific name	Growth	Status
American plum	*Prunus americana*	Perennial	Native
Buckbrush	*Symphoricarpos orbiculatus*	Perennial	Native
Common honey locust	*Gleditsia triacanthos*	Perennial	Native
Elm	*Ulmus* spp.	Perennial	Native
Leadplant	*Amorpha canescens*	Perennial	Native
New Jersey tea	*Ceanothus americanus*	Perennial	Native
Osage orange	*Maclura pomifera*	Perennial	Native
Poison ivy	*Rhus radicans*	Perennial	Native
Roughleaf dogwood	*Cornus drummondii*	Perennial	Native
Smooth Sumac	*Rhus glabra*	Perennial	Native

Table 3.5 Effects of the timing of prescribed burning on total forage biomass in native tallgrass rangeland

Evaluation date	Prescribed-burn timing	Total forage biomass, kg DM/ha
17 July	Early spring (1 April)	4,770^{a}
	Mid-summer (1 August)	4,730^{a}
	Late summer (1 September)	4,437^{a}
10 October	Early spring (1 April)	4,018^{a}
	Mid-summer (1 August)	1,761^{b}
	Late summer (1 September)	935^{b}
	SEM[*]	420.50
	P – treatment × time	< 0.01

[*] Mixed-model SEM associated with comparison of treatment × time means.

[a, b] Means within a column with unlike superscripts are different ($P \leq 0.05$).

Table 3.6 Effects of the timing of prescribed burning on occurrence of bare soil, litter cover, and total basal vegetation cover on native tallgrass rangeland

Item	Early spring (1 April)	Mid-summer (1 August)	Late summer (1 September)	SEM[*]	*P*-value[†]
Bare soil, % total area	39.4	43.3	39.5	8.80	0.88
Litter cover, % total area	50.7	47.4	49.6	9.04	0.93
Basal vegetation cover, % total area	9.9	9.3	10.9	1.05	0.29

[*] Mixed-model SEM associated with comparison of treatment main effect means.

[†] Treatment main effect.

Table 3.7 Effects of the timing of prescribed burning on basal cover of grasses on native tallgrass rangeland

Item	Early spring (1 April)	Mid-summer (1 August)	Late summer (1 September)	SEM[*]	*P*-value[†]
Total grass cover, % total basal cover	82.8	85.9	86.5	2.17	0.20
C4 grasses, % total basal cover	67.7	65.9	64.8	3.40	0.70
C4 tall grasses[‡], % total basal cover	36.2^{a}	41.1^{a}	22.1^{b}	3.52	< 0.01
C4 mid grasses[§], % total basal cover	28.2^{a}	23.7^{a}	39.3^{b}	3.48	< 0.01
C4 short grasses[#], % total basal cover	3.3^{a}	1.1^{b}	3.4^{a}	1.00	0.04
C3 grasses and sedges[‖], % total basal cover	15.1	19.7	21.7	3.11	0.11
Annual grasses[**], % total basal cover	0.07	0.33	0	0.227	0.31

[*] Mixed-model SEM associated with comparison of treatment main effect means.

[†] Treatment main effect.

[‡] Combined basal cover of big bluestem (*Andropogon gerardii*), Eastern gamagrass (*Tripsacum dactyloides*), indiangrass (*Sorghastrum nutans*), purpletop (*Tridens flavus*), sand paspalum (*Paspalum setaceum*), and switchgrass (*Panicum virgatum*).

[§] Combined basal cover of fall witchgrass (*Digitaria cognata*), little bluestem (*Schizachyrium scoparium*), purple lovegrass (*Eragrostis spectabilis*), sideoats grama (*Bouteloua curtipendula*), and tall dropseed (*Sporobolus asper*).

[#] Combined basal cover of blue grama (*Bouteloua gracilis*), buffalograss (*Bouteloua dactyloides*), hairy grama (*Bouteloua hirsuta*), and tumble windmillgrass (*Chloris verticillata*).

[‖] Combined basal cover of Canada wildrye (*Elymus canadensis*), Japanese bromegrass (*Bromus japonicus*), Kentucky bluegrass (*Poa pratensis*), prairie junegrass (*Koeleria macrantha*), sedges (*Carex* spp.), Scribner panicum (*Dichanthelium oligosanthes*), and Virginia wildrye (*Elymus virginicus*).

[**] Combined basal cover of Japanese bromegrass (*Bromus japonicus*) and prairie threeawn (*Aristida oligantha*).

[a, b] Within row, means with unlike superscripts differ ($P \leq 0.05$).

Table 3.8 Effects of the timing of prescribed burning on basal cover of specific graminoids on native tallgrass rangeland

Item	Early spring (1 April)	Mid-summer (1 August)	Late summer (1 September)	SEM[*]	*P*-value[†]
Big bluestem, % total basal cover	18.4^{a}	18.1^{a}	11.9^{b}	2.61	0.02
Indiangrass, % total basal cover	12.1^{ab}	15.0^{a}	9.4^{b}	2.13	0.04
Switchgrass, % total basal cover	5.5	4.0	1.5	1.70	0.07
Little bluestem, % total basal cover	14.2^{a}	11.8^{a}	23.0^{b}	3.76	0.01
Sideoats grama, % total basal cover	9.9	7.4	11.0	3.27	0.53

[*] Mixed-model SEM associated with comparison of treatment main effect means.

[†] Treatment main effect.

[a, b] Within row, means with unlike superscripts differ ($P \leq 0.05$).

Table 3.9 Effects of the timing of prescribed burning on basal cover of forbs on native tallgrass rangeland

Item	Early spring (1 April)	Mid-summer (1 August)	Late summer (1 September)	SEM[*]	*P*-value[†]
Total forb cover, % total basal cover	15.4	12.1	11.2	2.28	0.16
Perennial forbs, % total basal cover	15.3^{a}	10.9^{b}	9.7^{b}	2.05	0.02
Annual forbs, % total basal cover	0.05^{a}	1.21^{b}	1.45^{b}	0.517	0.02
Major wildflowers[‡], % total basal cover	0.56^{a}	0.88^{ab}	1.35^{b}	0.283	0.03
Sericea lespedeza, % total basal cover	7.27^{a}	3.38^{b}	1.72^{b}	1.56	< 0.01
Baldwin’s ironweed, % total basal cover	0.71^{a}	0.22^{b}	0.38^{b}	0.156	0.01
Western ragweed, % total basal cover	3.29^{a}	0.93^{b}	0.73^{b}	0.534	< 0.01

[*] Mixed-model SEM associated with comparison of treatment main effect means.

[†] Treatment main effect.

[‡] Combined basal cover of catclaw sensitivebriar (*Mimosa nuttallii*), dotted gayfeather (*Liatris punctata*), heath aster (*Symphyotrichum ericoides*), prairie coneflower (*Ratibida columnifera*), purple poppymallow (*Callirhoe involucrata*), purple prairieclover (*Dalea purpurea*), roundhead prairieclover (*Dalea multiflora*), and white prairie clover (*Dalea candida*).

[a, b] Within row, means with unlike superscripts differ ($P \leq 0.05$).

Table 3.10 Effects of the timing of prescribed burning on basal cover of shrubs on native tallgrass rangeland

Item	Early spring (1 April)	Mid-summer (1 August)	Late summer (1 September)	SEM[*]	*P*-value[†]
Total shrub cover, % total basal cover	1.80	1.93	2.34	0.476	0.50
Increaser shrubs[‡], % total basal cover	0.98^a	0.46^b	0.85^a	0.204	0.04
Leadplant, % total basal cover	0.79	1.27	1.41	0.415	0.31
New Jersey tea, % total basal cover	0^a	0.19^b	0.01^a	0.063	< 0.01

[*] Mixed-model SEM associated with comparison of treatment main effect means.

[†] Treatment main effect.

[‡] Combined basal cover of roughleaf dogwood (*Cornus drummondii*), smooth sumac (*Rhus glabra*), and buckbrush (*Symphoricarpos orbiculatus*).

[a,b] Within row, means with unlike superscripts differ ($P \leq 0.05$).

Table 3.11 Effects of the timing of prescribed burning on plant species diversity on native tallgrass rangeland

Item	Early spring (01 April)	Mid-summer (1 August)	Late summer (1 September)	SEM[*]	P-value[†]
Overall species diversity[‡]					
Richness	22^{a}	27^{b}	27^{b}	1.6	< 0.01
Shannon diversity	2.28	2.32	2.28	0.088	0.90
Evenness	0.74	0.71	0.69	0.022	0.09
Simpson diversity	0.87	0.84	0.81	0.043	0.47
Simpson dominance	0.42	0.46	0.47	0.033	0.24
Native species diversity[§]					
Richness	21^{a}	25^{b}	26^{b}	1.6	< 0.01
Shannon diversity	2.20	2.25	2.23	0.087	0.85
Evenness	0.73	0.70	0.69	0.021	0.21
Simpson diversity	0.83	0.81	0.80	0.042	0.80
Simpson dominance	0.45	0.48	0.48	0.033	0.56

[*] Mixed-model SEM associated with comparison of treatment main effect means.

[†] Treatment main effect.

[‡] Diversity measures calculated from overall plant species composition.

[§] Diversity measures calculated from native plant species composition only.

[a, b] Within row, means with unlike superscripts differ ($P \leq 0.01$).

Table 3.12 Effects of the timing of prescribed burning on grass and forb diversity on native tallgrass rangeland

Item	Early spring (1 April)	Mid-summer (1 August)	Late summer (1 September)	SEM[*]	*P*-value[†]
Grass and grass-like species diversity[‡]					
Richness	10	11	11	0.6	0.46
Shannon diversity	1.89	1.94	1.95	0.075	0.72
Evenness	0.82	0.81	0.82	0.021	0.97
Simpson diversity	0.74	0.74	0.74	0.039	0.99
Simpson dominance	0.50	0.52	0.50	0.034	0.74
Forb species diversity[§]					
Richness	10^{a}	15^{b}	15^{b}	1.2	< 0.01
Shannon diversity	1.59^{a}	2.05^{b}	2.20^{b}	0.135	< 0.01
Evenness	0.70^{a}	0.76^{b}	0.81^{b}	0.039	0.02
Simpson diversity	0.57^{a}	0.73^{b}	0.83^{b}	0.066	< 0.01
Simpson dominance	0.65^{a}	0.52^{b}	0.45^{b}	0.057	< 0.01

[*] Mixed-model SEM associated with comparison of treatment main effect means.

[†] Treatment main effect.

[‡] Diversity measures calculated from grass and grass-like species composition only.

[§] Diversity measures calculated from forb species composition only.

[a, b] Within row, means with unlike superscripts differ ($P \leq 0.03$).

Literature Cited

AOAC International. 2000. Official Methods of Analysis, 17th ed. AOAC Int., Gaithersburg, MD.

AOAC International. 2005. Official Methods of Analysis, 18th ed. AOAC Int., Gaithersburg, MD.

Aubel, N. A., K. C. Olson, J. R. Jaeger, G. J. Eckerle, L. A. Pacheco, M. J. Macek, L. R. Mundell and L. W. Murray. 2011. Botanical composition of diets grazed by lactating cows with calves and non-lactating cows maintained on burned or unburned native tallgrass prairie. Proc. West. Sec. Amer. Soc. Anim. Sci. 62:222-227.

Auen, L. M., and C. E. Owensby. 1988. Effects of dormant-season herbage removal on Flint Hills rangeland. J. Range Manage. 41:481-482.

Beran, D. D., R. E. Gaussoin, and R. E. Masters. 1999. Native wildflower establishment with imidazolinone herbicide. Hort. Sci. 34:283-286.

Biondini, M. E., A. A. Steuter, and C. E. Grygiel. 1989. Seasonal fire effects on the diversity patterns, spatial distribution, and community structure of forbs in the northern mixed prairie, USA. Vegetation 85:21-31.

Blan, K. R. 1970. Evaluation of eastern red cedar (*Juniperus virginiana*) infestations in the northern Kansas Flint Hills. M.S. Thesis. Kansas State Univ., Manhattan.

Blocksome, C. B. 2006. Sericea lespedeza (*Lespedeza cuneata*): seed dispersal, monitoring, and effect on species richness. Ph.D. Diss. Kansas State Univ., Manhattan.

Cook, C. W. 1983. Forbs need proper ecological recognition. Rangelands 5:217-220.

Eddy, T., J. Davidson, and B. Obermeyer. 2003. Invasion dynamics and biological control prospects for sericea lespedeza in Kansas. Great Plains Res. 13:217–230.

Farney, J. K., C. B. Rensink, W. H. Fick, D. Shoup, and G. A. Milliken. 2017. Patch burning on tall-grass native prairie does not negatively affect stocker performance or pasture composition. Prof. Anim. Sci. 33:549-554.

Fuhlendorf, S. D., and D. M. Engle. 2004. Application of the fire – grazing interaction to restore a shifting mosaic on tallgrass prairie. J. Appl. Ecol. 41:604-614

Goering, H. K., and P. J. Van Soest. 1970. Forage Fiber Amylases (Apparatus, Reagents, Procedures, and some Applications). Agric. Handbook No. 379. USDA-ARS, Washington, DC.

Grime, J. P. 1998. Benefits of plant diversity to ecosystems: immediate, filter, and founder effects. J. Ecol. 86:902-910.

Haddock, M. J. 2005. Wildflowers and Grasses of Kansas. University Press of Kansas, Lawrence, KS.

Hickman, K. R., D. C. Hartnett, R. C. Cochran, and C. E. Owensby. 2004. Grazing management effects on plant species diversity in tallgrass prairie. J. Range Manage. 57:58-65.

Jackson, A. S. 1965. Wildfires in the great plains grasslands. Tall Timbers Fire Ecol. Conf. Proc. 4:241-259.

Koger, C. H., J. F. Stritzke, and C. D. Cummings. 2002. Control of sericea lespedeza (*Lespedeza cuneata*) with Triclopyr, Fluroxypyr, and Metsulfuron. Weed Sci. Soc. Amer. 16:893-900.

Kollmorgen, W. M., and D. S. Simonett. 1965. Grazing operations in the Flint Hills - bluestem pastures of Chase county, Kansas. Ann. Assoc. Amer. Geo. 55:260-290.

Kucera, C. L. 1960. Forest encroachment in native prairie. Iowa State J. of Sci. 34(4):635-639.

Magurran, A. E. 2004. Measuring Biological Diversity. Blackwell Science, Oxford.

McLachlan, S. M., and A. L. Knispel. 2005. Assessment of long-term tallgrass prairie restoration in Manitoba, Canada. Biol. Conservation 124:75-88.

Mills, H. A., and J. B. Jones Jr. 1996. Wet acid digestion procedure using nitric acid and 30% hydrogen peroxide. Page 122, Table 5–2, in Plant Analysis Handbook II. Micromacro Publ. Inc., Athens, GA.

Ogden, B. S. 2016. Grassland bird and butterfly response to sericea lespedeza control using fire and grazing. M.S. Thesis, Kansas State Univ., Manhattan.

Ohlenbusch, P. D., T. Bidwell, W. H. Fick, G. Kilgore, W. Scott, J. Davidson, S. Clubine, J. Mayo, and M. Coffin. 2007. Sericea lespedeza: history, characteristics, and identification. Kans. State Univ. Agric. Exp. Sta. MF-2408.

Owensby, C. E. 1973. Modified step-point system for botanical composition and basal cover estimates. J. Range Manage. 26:302-303.

Owensby, C. E., L. M. Auen, H. F. Berns, and K. C. Dhuyvetter. 2008. Grazing systems for yearling cattle on tallgrass prairie. Range. Ecol. Manage. 61:204-210.

Pielou, E. C. 1975. Ecological Diversity. John Wiley & Sons, New York.

Polley, H. W., J. D. Derner, and B. J. Wilsey. 2005. Patterns of plant species diversity in remnant and restored tallgrass prairies. Restore. Ecol. 13:480-487.

Randa, L. A., and J. A. Yunger. 2001. A comparision of management techniques on plant species composition and biomass in a tallgrass prairie restoration. Proc. N. Amer. Prairie Conf. 17:92-97.

Robel, R. J., J. N. Briggs, A. D. Dalton, and L. C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. J. Range Manage. 23:295-297.

Simpson, E. H. 1949. Measurement of diversity. Nature 163:688.

Sproul, N. A., L. W. Murray, J. R. Jaeger, D. A. Blasi, L. N. Edwards, G. J. Eckerle, L. A. Pacheco, and K. C. Olson. 2010. Forage selection preferences by multiparous and primiparous beef cows grazing native tallgrass range during winter. Proc. West. Sec. Amer. Soc. Anim. Sci. 61:15-20.

Stubbendieck, J., S. L. Hatch, and C. H. Butterfield. 1992. North American Range Plants, 4th ed. University of Nebraska Press, Lincoln, NE.

Towne, E. G., and J. M. Craine. 2014. Ecological consequences of shifting the timing of burning tallgrass prairie. PloS ONE 9(7): e103423.

Towne, E. G., and K. E. Kemp. 2008. Long-term response patterns of tallgrass prairie to frequent summer burning. Range. Ecol. Manage. 61:509-520.

Towne, G., and C. Owensby. 1984. Long-term effects of annual burning at different dates in ungrazed Kansas tallgrass prairie. J. Range Manage. 37:392-397.

USDA. 2010. New Jersey tea (*Ceanothus americanus* L.) plant fact sheet. https://plants.usda.gov/factsheet/pdf/fs_ceam.pdf. Accessed 6 December, 2017.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Vermeire, L. T., T. G. Bidwell, and J. Stritzke. 2007. Ecology and management of sericea lespedeza. Oklahoma Agric. Exp. Sta, PSS-2874.

Weir, J. R., and J. D. Scasta. 2017. Vegetation responses to season of fire in tallgrass prairie: a 13-year case study. Fire Ecol. 13:137-142.