Effects of prescribed fire timing on grazing performance of yearling beef cattle, forage biomass accumulation, and plant community characteristics on native tallgrass prairie in the Kansas Flint Hills

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ABSTRACT: Recent research demonstrated that mid- or late-summer prescribed fires can be employed to manage sericea lespedeza (*Lespedeza cuneata*) infestations in the Kansas Flint Hills. The effects of prescribed fire applied during the growing season (i.e., August to October) on grazing performance of yearling cattle have not been evaluated. Native pastures (n = 18; 22 ± 4.0 ha) were grouped by watershed and assigned randomly to one of three prescribed-fire treatments: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or autumn (2 October ± 9.9 d). Yearling beef cattle were grazed from May to August at a targeted stocking density of 280 kg live-weight/ha following prescribed-fire application. Forage biomass accumulations, soil cover, plant species composition, and root carbohydrate concentrations in four native plant species were evaluated. Total body weight (**BW**) gains and average daily gain were greater (P = 0.01) for cattle that grazed the spring and summer prescribed-fire treatments compared with those that grazed the autumn prescribed-fire treatment. As a result, final BW were greater (P = 0.04) in the spring and summer treatments than the autumn treatment. Conversely, forage biomass accumulations did not differ (P = 0.91) between fire regimes. Proportions of bare soil were greater (P < 0.01) in the spring treatment compared with the summer and autumn treatments, whereas proportions of litter on the soil surface were greater (P < 0.01) in summer- and autumn-burned pastures compared with spring-burned pastures. Total basal cover of graminoids and forbs did not differ (P ≤ 0.15) between prescribed fire treatments. Likewise, total basal cover of C3 or C4 perennial grasses did not differ (P ≥ 0.23) between prescribed-fire treatments. No treatment differences (P = 0.24) in root starch or root water-soluble carbohydrate concentrations in big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), or purple prairieclover (*Dalea purpurea*) were detected. These data were interpreted to suggest that summer or autumn prescribed fire can be applied without reducing forage biomass accumulations, root carbohydrate concentrations in key native plant species, or considerably altering native plant populations compared with conventional spring-season prescribed fire; however, summer prescribed fire could be favored over spring or autumn prescribed fire both to maintain stocker cattle growth performance and to achieve control over sericea lespedeza.

Key words: grazing, growth performance, *Lespedeza cuneata*, plant composition, prescribed fire, stocker cattle

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INTRODUCTION

Ranchers in the Kansas Flint Hills have applied annual spring-season prescribed fire to improve grazing-cattle performance since the late nineteenth century (Anderson, 1953). In part, the goal of frequent prescribed fire application was to mimic the historical fire regime of the region. Dendrochronological records at the Tallgrass Prairie Preserve in the central Flint Hills indicated that fire occurred in the region an average of every 2.04 yr between 1729 and 2005 (Allen and Palmer, 2011). When fire was withheld from the landscape, Bragg and Hulbert (1976) reported that trees and shrubs began to encroach upon the prairie, resulting in a loss of carrying capacity for livestock and habitat for native fauna.

Previous research reported late-spring (1 May) prescribed fire was associated with improved body weight (**BW**) gains by grazing yearling beef cattle, increased proportions of certain C4 forage grasses, increased forage biomass production, and more favorable soil moisture compared with early spring (20 March) prescribed fire (Aldous, 1934; McMurphy and Anderson, 1963; Anderson et al., 1970; Towne and Owensby, 1984). In addition, total BW gains, BW gains/ha, grazing distribution, and proportions of big bluestem (*Andropogon gerardii*) were improved when pastures were stocked with yearling beef cattle at 280 kg live-weight/ha and grazed from 1 May to 15 July—a practice known locally as intensive-early stocking—compared with season-long grazing (i.e., 1 May to 31 October) at 140 kg live weight/ha (Smith and Owensby, 1978).

An average of approximately 850,000 ha of native tallgrass rangeland are burned annually in the region from mid-March to early May (KDHE, 2020). In 2003, smoke produced from burning in the Flint Hills traveled to Kansas City, MO, where air quality monitors detected levels of ozone above the federally mandated maximum tolerable levels (KDHE, 2010). Since that time, concerns have developed regarding negative consequences to human health that may be caused by smoke produced from native-pasture burning in the Flint Hills. In addition, the noxious weed sericea lespedeza (*Lespedeza cuneata*) likely proliferates with exclusive use of annual spring-season prescribed fire (Alexander et al., 2021).

Sericea lespedeza was introduced into southeast Kansas in the early twentieth century as a soil-conservation measure; it has since invaded and degraded approximately 250,000 ha of Kansas prairie (Ohlenbusch et al., 2007; KDA, 2018). Consumption of sericea lespedeza by beef cows and yearling beef calves is limited due to extreme concentrations of condensed tannins (Preedy et al., 2013; Sowers et al., 2019). Pastoral production systems of the Kansas Flint Hills are overwhelmingly dominated by beef cattle (USDA, 2017); therefore, control of sericea lespedeza via grazing is unlikely. Current recommendations for sericea lespedeza control involve repeated herbicide applications; however, herbicides can be expensive to apply and are known to have negative impacts on nontarget, native forbs (Ohlenbusch et al., 2007; Gatson, 2018). In addition, herbicides have not proven useful for comprehensive sericea lespedeza control. Eddy et al. (2003) reported that acreage in Kansas affected by sericea lespedeza invasion increased 60-fold between 1988 and 2000, in spite of widespread control attempts via herbicide usage during that period.

Recent research indicated mid- or late-summer prescribed fire reduced sericea lespedeza and yellow bluestem (*Bothriochloa ischaemum*) basal frequencies, and subsequently increased native plant richness and forb diversity compared with spring prescribed fire or prescribed fire exclusion in nongrazed tallgrass prairie ecosystems (Reemts et al., 2019; Alexander et al., 2021). No differences in graminoid biomass were observed between nongrazed pastures burned in autumn (November), winter (February), or spring (April) over a 20-yr period (Towne and Craine, 2014). In addition, fire applied in September or October increased forb abundance and decreased woody plant cover compared with fire applied at any other time of year (Weir and Scasta, 2017).

Despite optimistic prospects for inexpensive and comprehensive sericea lespedeza control, ranchers across the region have voiced concerns that mid- or late-summer prescribed (i.e., August

or September) fire may reduce growth performance of grazing yearling stocker cattle, decrease forage biomass accumulation, negatively affect native C4 grass populations, or deplete root carbohydrate reserves in perennial forage plants. Therefore, the objectives of this experiment were to document the effects of prescribed-fire timing on growth performance of grazing yearling stocker cattle, forage biomass accumulations, plant composition, and root carbohydrate concentrations in key tallgrass plant species.

MATERIALS AND METHODS

The Kansas State University Institutional Animal Care and Use Committee reviewed and approved all animal handling and animal care practices used in our experiment. All animal procedures were conducted in accordance with the Guide for the Care and Use of Animals in Agricultural Research and Teaching (FASS, 2010).

Experimental Location and Design

Our experiment was conducted during the 2018, 2019, and 2020 growing seasons at the Kansas State University Beef Stocker Unit (39°13′48.80N, 96°38′35.56W). The Beef Stocker Unit is comprised of approximately 450 ha of native tallgrass rangeland and is fenced into 18 grazing units that range in size from 16 to 30 ha. Major soil types are of the Benfield-Florence complex with 5% to 30% slope (58% of total area), Clime-Sogn complex with 3% to 20% slope (13% of total area), and Dwight-Irwin complex with 1% to 3% slope (9% of total area; USDA-NRCS, 2018).

Historically, spring-season prescribed fire was applied and the site was grazed by yearling beef cattle for the late-spring and early-summer grazing season. Pretreatment plant species composition was determined in 2018. Big bluestem, Indiangrass (*Sorghastrum nutans*), and sideoats grama (*Bouteloua curtipendula*) were the predominant graminoid species and accounted for over 50% of pretreatment basal vegetation cover (Table 1).

Pastures (22 ± 4.0 ha) were grouped by watershed and each watershed was assigned randomly to one of three prescribed-fire timing treatments (n = 6 pastures per treatment): spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or autumn (2 October ± 9.9 d). Prescribed burns were applied on or near target dates for two consecutive years with permission from Riley Co. Emergency Management, Manhattan, KS (permit no. 1488). Burns were performed only under appropriate environmental conditions: 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 = 10 to 40 °C; and Haines index ≤ 4. All prescribed fire treatments were applied prior to grazing in 2019 and 2020; summer prescribed fires were conducted in August of 2018 and 2019, autumn prescribed fires were conducted in late September or early October of 2018 and 2019, and spring prescribed fires were conducted in April of 2019 and 2020.

Table 1. Pretreatment plant species composition of native tallgrass prairie located at the Kansas State Beef Stocker Unit (% of total basal plant cover)

Common name	Scientific name	%
Graminoids		92.6
Big bluestem	*Andropogon gerardii*	18.1
Indiangrass	*Sorghastrum nutans*	17.2
Sideoats grama	*Bouteloua curtipendula*	16.4
Sedges	*Carex* spp.	15.2
Little bluestem	*Schizachyrium scoparium*	13.9
Tall dropseed	*Sporobolus compositus*	6.0
Scribner's panicum	*Dichanthelium oligosanthes*	1.0
Hairy grama	*Bouteloua hirsuta*	1.9
Switchgrass	*Panicum virgatum*	0.9
Other graminoids	n = 14	1.9
Forbs		6.4
Western ragweed	*Ambrosia psilostachya*	1.1
Louisiana sagewort	*Artemisia ludoviciana*	0.9
Heath aster	*Symphyotrichum ericoides*	0.7
Violet lespedeza	*Lespedeza violacea*	0.6
Missouri goldenrod	*Solidago missouriensis*	0.4
Aromatic aster	*Symphyotrichum oblongifolium*	0.4
Viscid euthamia	*Euthamia gymnospermoides*	0.3
Baldwin's ironweed	*Vernonia baldwinii*	0.3
Tall goldenrod	*Solidago altissima*	0.2
False boneset	*Brickellia eupatorioides*	0.2
Pitcher sage	*Salvia azurea*	0.2
Fringeleaf ruellia	*Ruellia humilis*	0.2
Wavyleaf thistle	*Cirsium undulatum*	0.1
Other forbs	n = 35	0.9
Shrubs		1.0
Leadplant	*Amorpha canescens*	0.8
New Jersey tea	*Ceanothus americanus*	0.1
Other shrubs	n = 3	0.1

Animal Performance

A total of 675 yearling cattle were grazed over two consecutive growing seasons. Pastures were stocked at a targeted density of 280 kg live weight/

ha. Three-hundred-sixty heifers (initial BW = 282 ± 38.9 kg) were grazed from May 2 to July 31 in year 1, whereas 315 steers (initial BW = 335 ± 56.0 kg) were grazed from May 11 to August 10 in year 2. Grazing dates varied slightly from year to year due to fluctuation in arrival dates of cattle at our experimental site.

Steers and heifers were purchased in Texas and transported to the Kansas State Beef Stocker Unit. Upon arrival, calves were individually restrained using a hydraulic squeeze chute (Silencer, Moly Manufacturing Inc., Lorraine, KS), BW was recorded, and a visual identification tag was applied. Calves were then assigned randomly to pasture and treatment. Calves were held for 7 to 10 d in earth-floor pens and fed a growing diet at 2.0% of BW. On the day grazing began each year, each calf was again weighed individually following feeding to determine initial BW. Concurrently, calves were vaccinated for viral respiratory pathogens (Respivax 5, Huvepharma, Peachtree City, GA), treated for internal parasites (Agri-Mectin, Huvepharma, Peachtree City, GA), and then allocated to their assigned pastures. In addition, steers were given a growth-promoting implant (Ralgro, Merck Animal Health, Madison, NJ) in 2020. At the conclusion of the grazing season, calves were gathered and individual BW were immediately measured. Total BW gains and average daily gain (**ADG**) were calculated. Our livestock scale was validated once annually each April (Salina Scale, Inc., Salina, KS).

Forage Biomass

Abrams et al. (1986) indicated that aboveground biomass on Kansas tallgrass prairie peaked in mid- to late July, annually, during a 10-yr experiment; therefore, forage biomass accumulations were evaluated in mid-July of 2018 and 2020 using 50 × 50 cm clipping frames (i.e., quadrats). A single, permanent 100-m transect was established in each pasture. Transects were laid out exclusively on Benfield-Florence complex soils in areas with less than 2% slope. End points and the center of each transect were marked with orange survey stakes (Forestry Suppliers, Inc., Jackson, MS) and GPS coordinates were recorded (Garmin eTrex 20x, Olathe, KS). A total of 10 quadrats were clipped per transect. Beginning at the south or west end of each transect, quadrats were randomly placed alongside each transect at 10-m intervals. Quadrats were placed on alternating sides of transects beginning on the right. Litter was removed from each quadrat and all plant material was clipped 1 cm above the soil surface. Clipped material was weighed, dried in a forced-air oven (50 °C; 96 h), and reweighed to estimate standing forage DM/ha.

Botanical Composition and Soil Cover

Plant species composition and soil cover were evaluated annually using a modified step-point technique (Owensby, 1973; Farney et al., 2017), along the permanent transects described previously. At 1-m intervals along each transect, 100 points were independently and randomly selected using a step-point device (Owensby, 1973). Each point was first categorized as a hit on bare soil, litter, or basal plant matter. Second, the closest rooted plant and the closest forb in a 180° arc in front of the selected point were recorded. These observations were then used to calculate the abundance of individual plant species via the method described by Farney et al. (2017). A list of graminoids, forbs, and shrubs identified during our experiment are reported in Supplementary Appendices 1, 2, and 3, respectively. Common names and scientific names of plants were taken from the review by Haddock (2005).

To determine the effect of prescribed-fire timing on plant growth-form composition, plant species were grouped into growth-form categories as described by Hickman et al. (2004). Growth from categories included total C4 grasses, C4 perennial tall grasses, C4 perennial mid-grasses, C4 perennial short grasses, C3 perennial grasses and sedges, annual forbs, perennial forbs, and shrubs. Additional categories considered were native graminoids, introduced graminoids, native forbs, introduced forbs, leguminous forbs, nectar-producing forbs, increaser shrubs (i.e., shrubs that tend to proliferate in response to grazing; Vesk and Westoby, 2001), leguminous shrubs, and nectar-producing shrubs. Classifications of individual graminoid, forb, and shrub species are reported in Supplementary Appendices 1–3, respectively.

Root Carbohydrate Concentrations

Root starch and total water-soluble carbohydrate concentrations in three native C4 grasses (i.e., big bluestem, little bluestem, and Indiangrass) and one leguminous, native forb (i.e., purple prairie-clover; Dalea purpurea) were evaluated annually.

Individual roots and rhizomes were collected from each pasture (approximately 60 g of wet material per sample for each species) using a steel spading fork (Bully Tools, Steubenville, OH) to a depth of 30 cm. Roots were sorted by species, placed in individual plastic bags, and stored in coolers on ice until collection was complete. Following collection, roots samples were washed with tap water, separated from aerial portions of plants, and dried in a forced-air oven (50 °C; 96 h).

Following the drying period, samples were reweighed to determine root DM and then sent to a commercial laboratory (Dairy 1, Ithaca, NY) for root starch and water-soluble carbohydrate analysis. Total water-soluble carbohydrates concentrations were determined as described by Hall et al. (1999) using a Thermo Scientific Genesys 10s Vis Spectrophotometer. For root starch analyses, samples were incubated in a water bath at 40 °C and filtered through Whatman no. 41 filter paper. Subsequently, residues were autoclaved, incubated with a glucoamyalse enzyme, and analyzed using a YSI 2700 SELECT Biochemistry Analyzer (YSI Inc. Life Sciences, Yellow Springs, OH).

Statistical Analyses

Initial BW, total BW gain, ADG, final BW, forage biomass accumulations, soil cover, plant composition, root starch concentrations, and root water-soluble carbohydrate concentrations were analyzed as a completely random design using a mixed model (PROC MIXED; SAS 9.4, SAS Inst. Inc, Cary, NC). Class variables included treatment, year, and pasture. The initial model contained fixed effects for treatment, year, and treatment × year and a random effect for pasture within treatment. No treatment × year interactions were significant ($P > 0.10$); therefore, the final models contained a term for treatment only as a fixed effect and year and pasture within treatment as random effects.

When there were significant changes in major graminoid cover classes (e.g., C4 mid-grasses), individual plant species within those graminoid cover classes were analyzed using a mixed model. Class variables included treatment, year, and pasture. Models contained fixed effects for treatment, year, and treatment × year and a random effect for pasture within treatment. When *F*-tests associated with treatment × year were significant ($P \leq 0.05$), interaction means were reported.

When protected by a significant *F*-test ($P \leq 0.05$), treatment and treatment × year means were separated using the method of Least Significant Difference.

RESULTS AND DISCUSSION

Animal Performance

Total BW and ADG did not differ ($P = 0.43$; Table 2) between spring and summer prescribed-fire treatments; however, calves that grazed the autumn-fire treatment had reduced ($P = 0.01$) total BW and ADG compared with calves that grazed the spring- or summer-fire treatments. As a result, final BW were greater ($P = 0.04$) in the spring and summer fire treatments compared with the autumn fire treatment. Previous research in the Kansas Flint Hills indicated yearling steers that grazed spring-burned pastures exhibited greater ADG compared with those that grazed nonburned pastures (Woolfolk et al., 1975). Similarly, annual

Table 2. Effects of annual prescribed fire timing on yearling stocker cattle growth performance in 2019 and 2020 and on forage biomass accumulation from 2018 to 2020 on native tallgrass prairie

	Prescribed fire season				
Item	Spring	Summer	Autumn	SEM[1]	*P*-value[2]
Initial bodyweight, kg	308	310	307	5.1	0.82
Final bodyweight, kg	422[a]	420[a]	408[b]	5.0	0.04
Total bodyweight gain[3], kg	113[a]	110[a]	101[b]	3.4	0.01
Average daily gain[4], kg/d	1.26[a]	1.23[a]	1.13[b]	0.038	0.01
Forage biomass, kg/ha	2013	2095	2126	282.6	0.91

Eighteen pastures were grouped by watershed and assigned randomly to one of three prescribed-fire seasons: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or autumn (2 October ± 9.9 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight/ha following prescribed fire application.

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

[2]Treatment main effect.

[3]Calculated as final body weight − initial body weight.

[4]Calculated as total body weight gain ÷ total grazing days.

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

spring-season prescribed fire improved yearling stocker cattle performance in the tallgrass prairie of Oklahoma compared with nonburned controls (Svejcar, 1989; McCollum et al., 1992). Anderson et al. (1970) reported greater ADG when steers grazed pastures burned in mid-spring (10 April) and late spring (1 May) compared with those that grazed nonburned pastures; furthermore, steers grazing in the late spring prescribed-fire treatment outperformed those assigned to graze an early-spring (20 March) prescribed-fire treatment. After 14 grazing seasons, these researchers concluded that fire should be applied in mid- or late spring to achieve maximum ADG by stocker cattle.

Smith and Owensby (1978) evaluated the effects of intensive-early stocking (i.e., 0.69 ha/steer for 75 d) on cattle performance compared with season-long stocking (i.e., 1.38 ha/steer for 151 d) following late spring-season prescribed fire. For the first 75 d, steers in the intensive-early stocking system exhibited greater ADG and BW gains/ha compared with those in the season-long grazing system. Based on this model and current Flint Hills management practices, we determined that spring-season prescribed fire followed by a 90-d grazing season would serve as an appropriate control treatment that could be compared with the effects of summer (August) or autumn (October) prescribed fire on yearling beef cattle performance.

In our experiment, total BW gains were 113, 110, and 101 kg for calves that grazed spring, summer, and autumn treatments, respectively (Table 2). Previous research measuring the effects of annual spring-season prescribed fire on total BW gains by yearling cattle grazing in the Kansas Flint Hills were similar to those observed in our study. In a 9-yr study, Owensby et al. (2008) reported total BW gains of 87 kg/calf when steers were grazed from late April to mid-July at 0.81 ha/steer following late-spring prescribed fire. Similarly, Farney (2020) reported total BW gains of 109 and 122 kg for steers grazing pastures burned in early spring (19 March) or mid-spring (15 April), respectively, after an 87-d grazing season. We interpreted these data to suggest our performance results were representative of yearling beef cattle grazing in the Kansas Flint Hills.

Spring-season prescribed fire applied to only one-third of a grazing-management unit in a 3-yr rotation, otherwise known as patch burn-grazing, produced variable responses in beef cattle performance. Limb et al. (2011) reported no differences in stocker cattle BW gains, cow BCS change, or calf weaning BW when patch-burn grazing was compared with spring fire applied to entire grazing units at 3-yr intervals in the tallgrass prairie of Oklahoma. Conversely, stocker cattle performance did not differ between patch-burn grazing and a nonburned treatment for the first 4 yr in a mixed-grass prairie location; however, stocker cattle that grazed the patch-burn treatment outperformed those that grazed the nonburned treatment for the remaining 6 yr of the experiment (Limb et al., 2011).

In Kansas tallgrass prairie, Farney et al. (2017) did not observe any differences in stocker cattle growth performance when a patch-burn system was compared with annual spring-season prescribed fire; however, in growing seasons with abnormally low precipitation, patch burning increased total BW gains and ADG compared with annual spring-season prescribed fire, presumably because of greater forage availability in patch-burn units. These researchers concluded that land managers could use a patch-burn grazing system to minimize risk associated with summer drought. Similarly, the timing of prescribed fire application can be a part of a useful drought-management scheme. The Kansas Flint Hills receive the largest proportion of annual precipitation between April and October (Supplementary Appendix 4). When prescribed fire is shifted to later in the year (i.e., August to October), the decision to apply fire can be based on precipitation that has already occurred rather than what is expected historically.

To our knowledge, no direct comparisons of yearling stocker cattle growth performance while grazing native rangeland treated with spring, summer, or autumn prescribed fire have been documented. After two complete grazing seasons, stocker cattle growth performance did not differ between spring or summer prescribed-fire treatments. Furthermore, cattle that grazed autumn-burned pastures exhibited reduced total BW gains and ADG compared with those grazing spring- and summer-burned pastures.

The cause of the reduction in BW gain observed for cattle grazing the autumn-burn treatment was unclear. The impact of spring-season prescribed fire on forage quality has been evaluated. Forage obtained from pastures burned in the spring had increased carbohydrate availability and improved in vitro DM, crude fiber, and OM digestibilities when compared with forage obtained from nonburned pastures (Smith et al., 1960; Allen et al. 1976; Svejcar, 1989). Lack of differences in growth performance between the spring and summer prescribed-fire treatments in our experiment was

interpreted to suggest that forage quality on pastures burned in spring or summer was similar. Alternatively, diet selection by grazing livestock may be altered by prescribed fire (Svejcar, 1989). Aubel et al. (2011) documented that botanical composition of beef cow diets was altered by spring burning compared with not burning. Changes to diet selection driven by prescribed fire history may also be responsible for improvements in grazing livestock performance. Additional research is warranted to determine underlying reasons for the performance responses observed in our experiment.

Forage Biomass

Near the peak of the growing season, no differences in forage biomass ($P = 0.91$; Table 2) were detected between prescribed-fire regimes. Forage biomass was 2013, 2095, and 2126 kg/ha for the spring, summer, and autumn prescribed-fire treatments, respectively. Results from a 26-yr experiment indicated that nonburned plots produced significantly more biomass than burned plots; however, late-spring burning resulted in greater forage biomass accumulation than early-spring and late-autumn burning treatments (Aldous, 1934; McMurphy and Anderson, 1963). Forage biomass did not differ between plots burned in either mid- or late spring over that period of time.

Aldous (1934) as well as McMurphy and Anderson (1963) removed dead vegetation from nonburned plots at the beginning of each growing season to prevent litter accumulation. Hulbert (1969) later demonstrated that removing litter from nonburned plots resulted in greater forage yields when compared with plots where litter accumulated; therefore, the aforementioned work may be difficult to interpret. Towne and Owensby (1984) recognized the impact of litter accumulation on biomass yield and discontinued its removal from plots described by Aldous (1934) in 1968. Between 1968 and 1982, biomass production in the nonburned treatment was not different from that in mid- and late-spring burn treatments; however, nonburned plots and plots burned in mid-spring or late spring produced more biomass annually than plots burned in early spring or late autumn (Towne and Owensby, 1984). In a similar study, Owensby and Anderson (1967) reported that forage yields were greater in grazed pastures treated with late spring (1 May) or mid-spring (10 April) prescribed fire when compared with those treated with early-spring (20 March) prescribed fire.

In contrast, Towne and Craine (2014) did not observe any differences in graminoid biomass between nongrazed pastures burned in autumn (November), winter (February), or spring (April) over a 20-yr period; moreover, pastures burned in the autumn or winter were less susceptible to summer drought because they had more time to respond to April and May precipitation compared with those burned in the spring. Similarly, Alexander et al. (2021) reported no differences in forage biomass measured in July between pastures burned annually in the spring (April), mid-summer (August), or late summer (September).

Although early findings indicated that prescribed-fire timing was associated with changes in forage biomass accumulation, results from our experiment and other recent reports were interpreted to suggest that prescribed fire applied at different times during the year may not negatively affect forage biomass accumulation.

Soil Cover

Proportions of bare soil were greater ($P \leq 0.01$; Table 3) in the spring prescribed-fire treatment compared with the summer and autumn prescribed-fire treatments; however, proportions of litter on the

Table 3. Effects of annual prescribed fire timing on proportions of bare soil, litter, and basal vegetation cover on native tallgrass prairie from 2018 to 2020

	Prescribed fire season				
Item	Spring	Summer	Autumn	SEM[1]	*P*-value[2]
Bare soil, % of total area	62[a]	49[b]	48[b]	3.7	<0.01
Litter cover, % of total area	21[b]	36[a]	35[a]	4.8	<0.01
Basal vegetation cover, % of total area	17	15	17	1.6	0.22

Eighteen pastures were grouped by watershed and assigned randomly to one of three prescribed-fire seasons: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or autumn (2 October ± 9.9 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight/ha following prescribed fire application in 2019 and 2020.

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

[2]Treatment main effect.

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

soil surface were greater ($P \leq 0.01$) in summer- and autumn-burned pastures compared with spring-burned pastures. The difference in soil cover observed between our treatments may been related to the length of time between prescribed fire application and measurement time; however, Alexander et al. (2021) did not observe differences in bare soil, litter, or total basal plant cover between nongrazed pastures burned in April, August, or September. Soil cover in our experiment was evaluated each year in late June and early July, approximately 10, 8, and 2 mo post-fire for the summer, autumn, and spring prescribed-fire treatments, respectively. As time since prescribed fire decreased, the proportions of bare soil increased and litter cover on the soil surface increased. Total basal vegetation cover did not differ ($P = 0.22$) between prescribed-fire treatments.

Hanks and Anderson (1957) observed a reduction in water infiltration in burned plots compared with nonburned plots. Following several days of precipitation between 30 September and 14 October, 83% of total rainfall was absorbed into the soil in nonburned plots; however, only 37%, 39%, 46%, and 39% was absorbed into the soil of early-spring, mid-spring, late-spring, and late-autumn burned plots, respectively. These researchers attributed the reduction in infiltration rate to the removal of mulch on the soil surface. In the Kansas Flint Hills, much of the annual precipitation occurs between April and October (Supplementary Appendix 4). Results from our experiment were interpreted to suggest that pastures burned in the summer or autumn could have greater potential for water infiltration during periods of growing-season precipitation compared with pastures burned in the spring because of differences in litter accumulation.

Botanical Composition

Total graminoid basal cover did not differ ($P = 0.15$; Table 4) between prescribed-fire treatments. In addition, basal cover of introduced grasses, C4 grasses, and C3 grasses and sedges did not differ ($P \geq 0.23$) between fire regimes. In contrast, basal cover of native grasses was greater ($P = 0.05$) in the summer-burn treatment compared with the autumn-burn treatment, whereas spring-burn pastures were intermediate to and not different from either summer or autumn.

Although total basal cover of C4 grasses did not differ ($P = 0.23$; Table 4) between fire treatments, differences within C4 grass growth forms were detected. Perennial C4 tall grass basal cover tended to be greater ($P = 0.07$) in the summer-burn treatment compared with the spring-burn treatment, whereas basal cover of perennial C4 mid-grasses was greatest ($P = 0.05$) in the spring treatment, intermediate in the summer treatment, and least in the autumn treatment. Similarly, spring prescribed fire was associated with greater ($P = 0.01$) basal cover of perennial C4 short grasses compared with summer or autumn prescribed fire.

Trends in C4 tall grass basal cover grass cover between fire regimes may be explained by the impact of prescribed-fire timing on Indiangrass. Basal cover of Indiangrass did not change ($P < 0.27$; Table 5) from year to year in either the spring and

Table 4. Effects of annual prescribed fire timing on graminoid composition in native tallgrass prairie from 2018 to 2020

	Prescribed fire season				
Item, % basal plant cover	Spring	Summer	Autumn	SEM[1]	*P*-value[2]
Total graminoid cover	90	90	85	2.8	0.15
Native grasses	85^{ab}	87^{a}	79^{b}	3.2	0.05
Introduced grasses	4.3	3.0	6.2	1.92	0.28
C3 grasses and sedges	20.7	21.2	23.7	2.93	0.61
C4 grasses	68.9	69.1	61.4	4.90	0.23
C4 tall grasses	31.9^{y}	38.9^{z}	34.6^{yz}	2.87	0.07
C4 mid-grasses	33.0^{a}	29.0^{ab}	25.4^{b}	2.84	0.05
C4 short grasses	3.7^{a}	1.2^{b}	1.3^{b}	0.83	0.01

Eighteen pastures were grouped by watershed and assigned randomly to one of three prescribed-fire seasons: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or autumn (2 October ± 9.9 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight/ha following prescribed fire application in 2019 and 2020.

[1]Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[2]Treatment main effect.

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

[y, z]Within row, means with unlike superscripts tended to differ ($P \leq 0.10$).

Table 5. Effects of annual prescribed-fire timing on basal cover of Indiangrass (*Sorghastrum nutans*), sideoats grama (*Bouteloua curtipendula*), and hairy grama (*Bouteloua hirsute*) in native tallgrass prairie (% of total basal vegetation cover) from 2018 to 2020

	Year 1			Year 2			Year 3			
Item	Spring	Summer	Autumn	Spring	Summer	Autumn	Spring	Summer	Autumn	SEM[1]
Sorghastrum nutans	12.7^{cd}	16.7^{bc}	22.5^{a}	12.0^{cd}	15.7^{bcd}	6.0^{de}	11.8^{cd}	18.8^{b}	10.0^{de}	2.91
Bouteloua curtipendula	12.5^{bc}	21.5^{a}	15.3^{abc}	11.3^{bcde}	17.5^{ab}	5.7^{de}	14.8^{bc}	12.0^{bcd}	5.0^{e}	3.24
Bouteloua hirsuta	3.0^{ab}	1.0^{bcd}	1.7^{bc}	4.3^{a}	0.5^{cd}	0.8^{cd}	1.0^{cd}	1.2^{bcd}	0.2^{d}	1.07

Eighteen pastures were grouped by watershed and assigned randomly to one of three prescribed-fire seasons: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or autumn (2 October ± 9.9 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight/ha following prescribed fire application in 2019 and 2020.

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

summer prescribed-fire treatments. Conversely, basal cover of Indiangrass decreased ($P < 0.01$) over time in the autumn-fire regime. By year 3, basal cover of Indiangrass was greater ($P = 0.02$) in the summer-burn treatment compared with the spring- and autumn-burn treatments. Alexander et al. (2021) also reported reductions in basal cover of Indiangrass in nongrazed pastures burned in early September compared with those burned in early April or early August. Indiangrass produces biennial tillers that develop throughout the growing season, with the percentage of first-year tillers reaching an annual maximum immediately before senescence in the autumn (McKendrick et al., 1975). Fire applied in September and October could potentially damage first-year tillers and reduce the propagation potential of Indiangrass populations.

Treatment differences observed within C4 mid-grass and C4 short grass basal covers were also associated with fluctuations in individual plant species within those growth-form categories. Basal cover of sideoats grama (i.e., a C4 mid-grass) did not change ($P = 0.17$; Table 5) from year to year in the spring prescribed-fire treatment. Conversely, basal cover of sideoats grama decreased ($P < 0.01$) from year 1 to year 3 in the summer and autumn prescribed-fire treatments. When C4 short grasses were evaluated, basal cover of hairy grama tended to increase ($P = 0.07$; Table 5) from year 1 to year 2 in the spring fire treatment; however, it decreased ($P < 0.01$) from year 2 to year 3 in spring-burned pastures. Basal cover of hairy grama did not change ($P = 0.36$) in the summer prescribed fire treatment from year to year, whereas autumn prescribed fire was associated with decreased ($P = 0.05$) basal cover of hairy grama from year 1 to year 3. Reasons for changes in basal cover of sideoats grama and hairy grama over time are unclear. Additional research is warranted to define the phenology of these species and their seasonal responses to disturbance.

Table 6. Effects of annual prescribed fire timing on forb and shrub composition in native tallgrass prairie (% of total basal vegetation cover) from 2018 to 2020

	Prescribed fire season				
Item	Spring	Summer	Autumn	SEM[1]	*P*-value[2]
Total forb cover	9.9	8.4	13.4	2.74	0.21
Native forbs	9.7	8.3	13.4	2.62	0.17
Introduced forbs	0.15	0.12	0.02	0.134	0.61
Annual forbs	0.3^{b}	1.0^{ab}	1.7^{a}	0.49	0.03
Perennial forbs	9.6	7.4	11.7	2.57	0.28
Leguminous forbs	1.34	0.33	0.76	1.023	0.59
Nectar-producing forbs	1.8^{b}	1.9^{b}	3.8^{a}	0.68	0.02
Lespedeza cuneata	0.14	0.0	0.0	0.126	0.42
Total shrub cover	0.5^{y}	1.2^{yz}	1.5^{z}	0.43	0.08
Increaser shrubs[3]	0.02	0.12	0.25	0.103	0.11
Leguminous shrubs	0.46	0.89	1.23	0.371	0.13
Nectar-producing shrubs	0.48	1.11	1.23	0.756	0.14

Eighteen pastures were grouped by watershed and assigned randomly to one of three prescribed-fire seasons: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or autumn (2 October ± 9.9 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight/ha following prescribed fire application in 2019 and 2020.

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

[2]Treatment main effect.

[3]Shrubs that tend to proliferate in response to grazing (Vesk and Westoby, 2001).

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

[y, z]Within row, means with unlike superscripts tend to differ ($P \leq 0.10$).

Total forb, native forb, introduced forb, perennial forb, and leguminous forb basal covers did not differ ($P \geq 0.17$; Table 6) between prescribed-fire

treatments. Conversely, basal cover of annual forbs was greater ($P = 0.03$) in the autumn fire treatment than the spring fire treatment, whereas the summer fire treatment was intermediate to and not different ($P \geq 0.16$) from either autumn and spring. Basal cover of nectar-producing forbs was greater ($P = 0.02$) also in autumn-burned pastures compared with spring- or summer-burned pastures. These observations were interpreted to indicate that autumn-season prescribed fire may be of particular benefit to grassland-obligate invertebrates and the native birds that feed upon them (Ogden et al., 2019). Basal cover of sericea lespedeza was not different ($P = 0.42$) between prescribed fire regimes in our experiment; however, it was detected in small proportions in the spring-fire treatment and was not detected in the summer- or autumn-fire treatments (Table 6).

When total shrub basal cover was evaluated, spring prescribed fire tended ($P = 0.08$; Table 6) to be associated with lesser total shrub basal cover compared with autumn prescribed fire. Conversely, there were no treatment differences ($P = 0.11$) in basal cover of shrubs that tend to proliferate in response to grazing (i.e., increasers; Vesk and Westoby, 2001), whereas basal covers of leguminous shrubs and nectar-producing shrubs were numerically larger ($P \geq 0.13$) in summer- and autumn-burned pastures than in spring-burned pastures.

The effects of prescribed-fire timing on native plant composition have been extensively documented in the Kansas Flint Hills. Towne and Owensby (1984) indicated that late-spring (1 May) prescribed fire increased basal covers of big bluestem and Indiangrass, early-spring (20 March) or mid-spring (10 April) fire favored little bluestem, and early-spring or winter (1 December) fire increased basal cover of sedges and perennial forbs in nongrazed plots burned 48 times in 56 yr between 1928 and 1984. Based on these observations, researchers concluded mid- or late-spring prescribed fire should be applied to maximize production of the desirable C4 grasses, big bluestem, and Indiangrass. Similarly, Towne and Craine (2014) reported increased basal cover of Indiangrass and sideoats grama in nongrazed watersheds burned in the spring (21 April) compared with those burned in autumn (23 November) or winter (18 February).

Recent experiments have evaluated the effects of prescribed fire applied later in the year (i.e., August to November) on native-plant composition. Weir and Scasta (2017) indicated that C4 tall grass cover was greater in plots burned in September–October and November–December compared with plots burned at other times of the year (i.e., late winter, early spring, late spring, or early summer). In addition, prescribed fire applied in September or October was the only treatment that reduced woody plant cover when compared with fire applied at other times of year. Alexander et al. (2021) and Reemts et al. (2019) reported decreases in sericea lespedeza basal cover and yellow bluestem cover, respectively, when late summer (i.e., August or September) prescribed fire was applied compared with spring prescribed fire or nonburned treatments. In addition, Alexander and coworkers (2021) observed an increase in overall plant species richness and forb diversity in nongrazed plots when August or September prescribed fire was applied compared with April prescribed fire.

Root Carbohydrate Reserves

The impact of summer or autumn prescribed fire (i.e., August to October) on root carbohydrate concentrations of key native tall grass plant species has not previously been evaluated. Sowers et al. (2019) reported that grazing yearling steers in the Kansas Flint Hills consumed a diet consisting of 88 to 91% graminoids and 9 to 12% forb or forb-like species. Major dietary graminoid species included big bluestem, little bluestem, switchgrass (*Panicum virgatum*), and Indiangrass, whereas major forb species included purple prairieclover and dotted gayfeather (*Liatris punctata*). We selected big bluestem, little bluestem, Indiangrass, and purple prairieclover for root carbohydrate analyses because they comprised a large portion of yearling cattle diets according to Sowers et al. (2019) and they could be located and identified reliably throughout the growing season.

After the second year of prescribed fire application and grazing, root starch and root water-soluble carbohydrate concentrations in big bluestem, little bluestem, Indiangrass, and purple prairieclover did not differ ($P \geq 0.24$; Tables 7 and 8) between prescribed-fire treatments. Owensby et al. (1970) evaluated the effects of late-spring fire on total carbohydrate concentrations in big bluestem roots. In comparing nongrazed plots that were burned or not burned, total root carbohydrate concentrations did not differ at the beginning or end of the growing season. Conversely, differences between treatments were occasionally observed during the grazing season. In general, carbohydrate levels decreased rapidly when forage growth was vigorous and recovered subsequently when forage growth slowed. These researchers also measured carbohydrate concentrations in big bluestem root samples collected

Table 7. Effects of annual prescribed fire timing on root starch concentrations (% DM) in big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), and purple prairie clover (*Dalea purpurea*) from 2018 to 2020

	Prescribed fire season				
Item	Spring	Summer	Autumn	SEM[1]	*P*-value[2]
Andropogon gerardii	2.57	3.22	2.00	0.92	0.43
Schizachyrium scoparium	1.53	1.57	1.28	0.57	0.86
Sorghastrum nutans	3.19	2.09	1.81	1.22	0.49
Dalea purpurea	4.92	3.39	3.59	1.23	0.41

Eighteen pastures were grouped by watershed and assigned randomly to one of three prescribed-fire seasons: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or autumn (2 October ± 9.9 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight/ha following prescribed fire application in 2019 and 2020.

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

[2]Treatment main effect.

Table 8. Effects of prescribed fire timing on root water-soluble carbohydrate concentrations (% DM) in big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), and purple prairie clover (*Dalea purpurea*) from 2018 to 2020

	Prescribed fire season				
Item	Spring	Summer	Autumn	SEM[1]	*P*-value[2]
Andropogon gerardii	3.31	4.57	4.02	0.78	0.27
Schizachyrium scoparium	3.15	4.44	3.34	0.98	0.37
Sorghastrum nutans	5.11	3.47	3.95	1.29	0.42
Dalea purpurea	4.55	3.36	5.24	1.08	0.24

Eighteen pastures were grouped by watershed and assigned randomly to one of three prescribed-fire seasons: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or autumn (2 October ± 9.9 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight/ha following prescribed fire application in 2019 and 2020.

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

[2]Treatment main effect.

from burned or nonburned plots and plots clipped in June, July, August, or September. Roots from burned plots harvested in June, July, or August had lesser total carbohydrate concentrations than roots from nonburned plots that were harvested at the same times; however, root carbohydrate concentrations did not differ between nonburned and burned plots when roots were harvested in September.

In a similar experiment, Owensby et al. (1977) evaluated the impact of late-spring burning combined with intensive-early or season-long stocking on root nonstructural carbohydrate reserves in big bluestem. Over a 3-yr period, total nonstructural carbohydrate levels in big bluestem root samples were less in the intensive-early stocking treatment from 1 June until 15 August compared with those in the season-long treatment; however, nonstructural carbohydrate levels were not different between treatments after that period. Although intensive-early stocking decreased root nonstructural carbohydrates in big bluestem during the grazing season, resting the pasture for the remainder of the year allowed sufficient time for big bluestem carbohydrate reserves to recover. Auen and Owensby (1988) later determined that mowing during the dormant season did not reduce root nonstructural carbohydrates concentrations in big bluestem. We interpreted the lack of treatment differences in root starch and root water-soluble carbohydrate concentrations between treatments in our experiment to suggest that prescribed fire timing may not have strong short-term effects on root carbohydrate reserves in key native tallgrass species and, thus, limited influence on resilience of mature ramets of these species to disturbance by fire and grazing. Additional research is warranted to determine long-term effects of summer and fall burning on carbohydrate reserves in key tallgrass plant species.

Results following two cycles of prescribed-fire treatments and grazing were interpreted to suggest that summer or autumn prescribed fire could be applied without significant negative effects on the tallgrass prairie ecosystem. Shifting the timing of prescribed fire from spring to late summer or early autumn did not reduce forage biomass accumulation or root carbohydrate concentrations in key native tallgrass plants.

Summer-burned pastures had greater proportions of native graminoid plant species and tended to have greater proportions of C4 perennial tall grasses compared with autumn-burned pastures. In addition, total BW gains and ADG of grazing yearling cattle did not differ between spring and summer prescribed-fire treatments but were less in the autumn prescribed-fire treatment. In conclusion, land managers could use summer-season prescribed fire to manage sericea lespedeza infestations without reducing grazing performance of yearling cattle or damaging the vigor of native C4 plant populations. Industry adoption of the modified prescribed-fire described in our manuscript may have positive implications for spring-season air quality in metropolitan areas adjacent to the Kansas Flint Hills.

SUPPLEMENTARY DATA

Supplementary data are available at *Translational Animal Science* online.

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LITERATURE CITED

Abrams, M. D., A. K. Knapp, and L. C. Hulbert. 1986. A ten-year record of aboveground biomass in a Kansas tallgrass prairie: effects of fire and topographic position. Am. J. Bot. 73:1509–1515. doi:10.1002/j.1537-2197.1986.tb10897.x

Aldous, A. E. 1934. Effects of burning on Kansas bluestem pastures. Kansas Agricultural Experiment Station Bulletin 38. AAIDP14032. ETD collection for University of Nebraska–Lincoln. 65 p. [accessed 13 January 2021]. https://digitalcommons.unl.edu/dissertations/AAIDP14032.

Alexander, J. A., W. H. Fick, S. B. Ogden, D. A. Haukos, J. Lemmon, G. A. Gatson, and K. C. Olson. 2021. Effects of prescribed fire timing on vigor of the invasive forb sericea lespedeza (*Lespedeza cuneata*), total forage biomass accumulation, plant-community composition, and native fauna on tallgrass prairie in the Kansas Flint Hills. Transl. Anim. Sci. doi:10.1093/tas/txa079

Allen, L. J., L. H. Harbers, R. S. Schalles, C. E. Owensby, and E. F. Smith. 1976. Range burning and fertilizing related to nutritive value of bluestem grass. J. Range Manage. 29:306–308. doi:10.2307/3897089

Allen, M. S., and M. W. Palmer. 2011. Fire history of a prairie/forest boundary: more than 250 years of frequent fire in a North American tallgrass prairie. J. Veg. Sci. 22:436–444. doi:10.1111/j.1654-1103.2011.01278.x

Anderson, K. L. 1953. Utilization of grasslands in the Flint Hills of Kansas. J. Range Manage. 6:86–93. doi:10.2307/3893965

Anderson, K. L., E. F. Smith, and C. E. Owensby. 1970. Burning bluestem range. J. Range Manage. 23:81–92. doi:10.2307/3896105

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. Am. 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 Mange. 41:481–482. doi:10.2307/3899521

Bragg, T. B., and L. C. Hulbert. 1976. Woody plant invasion of unburned Kansas Bluestem prairie. J. Range Manage. 29:19–24. doi:10.2307/3897682

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

Farney, J. K. 2020. Evaluating stocker steer gains on tallgrass native range with two burn dates and species in mineral. Kansas Agric. Exp. Sta. Res. Rep. 6. doi:10.4148/2378–5977.7885

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. doi:10.15232/pas.2016-01574

Federation of Animal Science Societies (FASS). 2010. Guide for the care and use of animals in agricultural research and teaching. 3rd ed. Champaign (IL): Federation of Animal Science Societies.

Gatson, G. A. 2018. Restoration of tallgrass prairie degraded by the noxious weed sericea lespedeza [M.S. Thesis]. Manhattan (KS): Kansas State University.

Haddock, M. J. 2005. Wildflowers and grasses of Kansas. Lawrence (KS): University Press of Kansas.

Hall, M. B., W. H. Hoover, J. P. Jennings, and T. K. Miller-Webster. 1999. A method for partitioning neutral detergent soluble carbohydrates. J. Sci. Food Agric. 79:2079–2086. doi:10.1002/1097-0010

Hanks, R. J., and K. L. Anderson. 1957. Pasture burning and moisture conservation. J. Soil Water Conserv. 12:228–229.

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. doi:10.2011/1551-5028

Hulbert, L. C. 1969. Fire and litter in undisturbed bluestem prairie in Kansas. Ecology. 50:874–877. doi:10.2307/1933702

Kansas Department of Agriculture (KDA). 2018.. Noxious weed survey data. [accessed 13 January 2021]. https://agriculture.ks.gov/docs/default-source/pp-noxious-weed-control/2018-survey-data.pdf?sfvrsn=524190c1_0.

Kansas Department of Health and Environment (KDHE). 2010. Flint Hills smoke management plan. [accessed 13 January 2021]. https://www.ksfire.org/health/.

Kansas Department of Health and Environment (KDHE). 2020. Flint Hills prescribed fire update. [accessed 13 January 2021]. https://www.ksfire.org/new-media-archives/weeklyupdates/2020_Flint_Hills_ Summary _ May_15.pdf.

Limb, R. F., S. D. Fuhlendorf, D. M. Engle, J. R. Wier, R. D. Elmore, and T. G. Bidwell. 2011. Pyric-herbivory and cattle performance in grassland ecosystems. Rangeland Ecol. Manage. 69:659–663. doi:10.2011/REMD-10-00192.1

McCollum, F. T., D. M. Engle, and J. F. Stritzke. 1992. Cattle performance following prescribed burning of rangeland in north-central Oklahoma. Animal Science Research Report, Oklahoma Agricultural Experiment Station MP-136. Stillwater (OK): Oklahoma State University; p. 447–449. [accessed 13 January 2021]. http://dasnr54.dasnr.okstate.edu:8080/beefextension2018/research reports/1992rr/92-70.pdf.

McKendrick, J. D., C. E. Owensby, R. M. Hyde. 1975. Big bluestem and Indiangrass vegetative reproduction and annual reserve carbohydrate and nitrogen cycles. Agro-Ecosystems. 2:75–93. doi:10.1016/0304-3746

McMurphy, W. E., and K. L. Anderson. 1963. Burning bluestem range: forage yields. Trans. Kansas Acad. Sci. 66:49–51.

Ogden, S., D. A. Haukos, K. C. Olson, J. Lemmon, W. H. Fick, J. A. Alexander, and G. A. Gatson. 2019. Grassland bird and butterfly responses to sericea lespedeza control via late-season grazing pressure. Am. Midl. Nat. 181:147–169. doi:10.1674/0003-0031-181.2.147

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 Agricultural Experiment Station MF-2408. [accessed 13 January 2021]. https://www.bookstore.ksre.ksu.edu/pubs/mf2408.pdf.

Owensby, C. E. 1973. Modified step-point system for botanical composition and basal cover estimates. J. Range Manage. 26:302–303. doi:10.2307/3896585

Owensby, C. E., and K. L. Anderson. 1967. Yield response to time of burning in the Kansas Flint Hills. J. Range Manage. 20:12–16. doi:10.2307/3896282

Owensby, C. E., L. M. Auen, H. F. Berns, and K. C. Dhuyvetter. 2008. Grazing systems for yearling cattle on tallgrass prairie. Rangeland Ecol. Manage. 61:204–210. doi:10.2111/07-034.1

Owensby, C. E., G. M. Paulsen, and J. D. McKendrick. 1970. Effect of burning and clipping on big bluestem reserve carbohydrates. J. Range Manage. 23:358–362. doi:10.2307/3896167

Owensby, C. E., E. F. Smith, and J. R. Rains. 1977. Carbohydrate and nitrogen reserve cycles for continuous, season-long and intensive early stocked Flint Hills bluestem range. J. Range Manage. 30:258–260. doi:10.2307/3897299

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.

Reemts, C. M., W. M. McCaw, T. A. Greene, and M. T. Simmons. 2019. Short-term control of an invasive C4 grass with late-summer fire. Rangeland Ecol. Manage. 72: 182–188. doi:10.1016/j.rama.2018.07.009

Smith, E. F., and C. E. Owensby. 1978. Intensive-early stocking and season-long stocking of Kansas Flint Hills range. J. Range Manage. 31:14–17. doi:10.2307/3897624

Smith, E. F., V. A. Young, K. L. Anderson, W. S. Rulifson, and S. N. Rogers. 1960. The digestibility of forage on burned and non-burned bluestem pasture as determined with grazing animals. J. Anim. Sci. 19:388–391. doi:10.2527/jas1960.192388x

Sowers, C. A., G. A. Gatson, J. D. Wolf, W. H. Fick, and K. C. Olson. 2019. Botanical composition of yearling-steer and mature-ewe diets in the Kansas Flint Hills. Rangeland Ecol. Manage. 72:126–135. doi:10.1016/j.rama.2018.09.003

Svejcar, T. J. 1989. Animal performance and diet quality as influenced by burning on tallgrass prairie. J. Range Manage. 42:11–15. doi:10.2307/3899649

Towne, E. G., and J. M. Craine. 2014. Ecological consequences of shifting the timing of burning tallgrass prairie. PLoS One 9:e103423. doi:10.1371/journal.pone.0103423.

Towne, G., and C. E. Owensby. 1984. Long-term effects of annual burning at different dates in ungrazed Kansas tallgrass prairie. J. Range Manage. 35:392–397. doi:10.2307/3899622

United States Department of Agriculture (USDA). 2017. Census of agriculture – Kansas state profile. [accessed 28 January 2021]. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/ Volume_1, Chapter_1_State_Level/Kansas/.

United States Department of Agriculture – Natural Resources Conservation Service (USDA-NRCS). 2018. Web soil survey. [accessed 13 January 2021]. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

Vesk, P. A., and M. Westoby. 2001. Predicting plant species' response to grazing. J. Appl. Ecol. 38:897–909.

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. doi:10.4996/fireecology.130290241

Woolfolk, J. S., E. F. Smith, R. S. Schalles, B. E. Brent, L. H. Harbers, and C. E. Owensby. 1975. Effects of nitrogen fertilization and late-spring burning of bluestem range on diet and performance of steers. J. Range Manage. 28:190–193. doi:10.2307/3897523