Effects of prescribed fire timing on yearling stocker cattle performance, native plant composition, forage biomass accumulation, and root carbohydrate concentrations in key native tallgrass plant species

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Abstract

Recent research demonstrated that mid- or late-summer prescribed fire can be employed to manage sericea lespedeza infestations in the Kansas Flint Hills. Despite optimistic reports, ranchers have voiced concerns that mid- or late-summer prescribed fire may negatively affect stocker cattle growth performance, native warm-season plant populations, or forage biomass accumulation. Eighteen pastures were grouped by watershed and assigned to one of three prescribed-fire treatments: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or fall (2 October ± 9.9 d). All prescribed fire treatments were applied prior to grazing in 2019 and 2020. Yearling beef cattle were grazed from May to August at a targeted stocking density of 279 kg live-weight ⋅ ha^{-1}. Forage biomass accumulation was measured in July of 2018 and 2020 by clipping vegetation within 0.25^2-meter frames. Soil cover, botanical composition, and root carbohydrate concentrations of key native tallgrass species were evaluated during the growing seasons of 2018, 2019, and 2020. After 2 complete years of prescribed fire application and grazing, total body weight gains and average daily gains were greater ($P = 0.01$) for cattle that grazed the spring and summer prescribed-fire treatments compared with those that grazed the fall prescribed-fire treatment. As a result, final body weights were greater ($P = 0.04$) in the spring and summer fire treatments compared with the fall fire treatment. Conversely, forage biomass accumulation did not differ ($P = 0.91$) between fire regimes. When soil cover was evaluated, proportions of bare soil were greater ($P < 0.01$) in the spring treatment compared with the summer and fall treatments, whereas proportions of litter on the soil surface were greater ($P < 0.01$) in summer- and fall-burned pastures compared with spring-burned pastures. Basal cover of all graminoids and forbs did not differ ($P = 0.15$) between prescribed fire treatments; however, total shrub cover tended to be greater ($P = 0.08$) in the summer and fall prescribed-fire treatments compared with the spring prescribed-fire treatment. Total basal cover of C4 perennial grasses and C4 tallgrasses did not differ ($P \geq 0.07$) between prescribed fire treatments; however, C4 mid-grass cover was greatest ($P = 0.05$) in spring-burned pastures, intermediate in summer-burned pastures, and least in fall-burned pastures. Furthermore, C4 shortgrass cover was greater ($P = 0.01$) in the spring fire treatment compared with the summer and fall fire treatments. Conversely, basal cover of native grasses was greater ($P = 0.02$) in the summer fire treatment compared with the fall fire treatment, while pastures burned in the spring were intermediate to and not different from the summer and fall fire treatments. Basal cover of nectar-producing forbs was greater ($P = 0.02$) in the summer and fall fire regimes compared with the spring fire regime. No differences ($P = 0.24$) in root starch or total root water-soluble carbohydrate concentrations in big bluestem, little bluestem, Indiangrass, or purple prairieclover were observed between prescribed fire treatments. These data were interpreted to suggest that summer or fall prescribed fire can be applied without reducing forage biomass accumulation, root carbohydrate concentrations of key tallgrass species, or considerably altering native plant populations; however, summer prescribed fire could be favored over fall prescribed fire to maintain stocker cattle growth performance.

Key words: grazing, prescribed fire, sericea lespedeza

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Chapter 1 - Review of Literature

Introduction

The tallgrass prairie historically included 170 million acres of native grassland that extended from Indiana in the east, Kansas in the west, Canada in the north, and Texas in the south (Middendorf et al., 2009). Euro-American settlement and agricultural advancements led to the conversion of millions of acres of native grasslands into farmland, to the extent that less than 4% of the original tallgrass prairie remains (Samson and Knopf, 1994). Today, the Kansas Flint Hills, an area with shallow, rocky soils not suitable for cultivation, represent the largest contiguous portion of the remaining tallgrass prairie (Samson and Knopf, 1994). Traditionally, ranchers apply annual spring-season prescribed fire to limit encroachment of woody and invasive plant species that threaten the tallgrass prairie ecosystem. Over the last 20-years, an average of 2.1 million acres throughout the Flint Hills were burned annually from mid-March to early May (KDHE, 2020). Benefits of spring prescribed fire include increased warm-season (C4) grass production, suppression of trees and shrubs, and improved stocker-cattle growth performance (Anderson et al., 1970).

Although annual spring-season prescribed fire has been established as a standard management practice for ranchers across the Flint Hills, there are challenges associated with burning during this time of year. When fire is restricted to late-spring, there are a limited number of days in which weather conditions are favorable to safely conduct a prescribed burn before cattle turnout. Strong, unpredictable winds and low relative humidity are typical throughout mid-March to early May in the Flint Hills. When combined with elevated fuel loads, these conditions increase the risk of uncontrolled fire. Furthermore, many of the stocker cattle sent to the Flint Hills for the summer grazing season are of southeastern U.S. origin. High-risk calves like these generally require additional care and supervision from a health standpoint; thus, time available for burning is reduced.

Another challenge associated with burning millions of acres in a short period of time is the volume and concentration of smoke produced, which can reduce air quality considerably. Smoke produced from prescribed fire contains fine particulate matter and precursors for ozone. These compounds can remain in the air and travel to urban areas downwind of the Flint Hills. Large amounts of ozone and particulate matter in the air can have negative impacts on the human cardiovascular or respiratory system (KDHE, 2010). Smoke management initially became a concern in the spring of 2003 when air quality monitors in Kansas City detected levels of ozone above federally-mandated maximum tolerable levels (KDHE, 2010); this change in air quality was attributed to burning in the Flint Hills in that season. Many such exceedances in ozone and particulate matter have been registered since that time.

In addition to smoke management, a large portion of the Kansas Flint Hills has been degraded by the noxious weed, sericea lespedeza (*Lespedeza cuneata*). Sericea lespedeza was originally introduced in southeastern Kansas in the 1930s because of its perceived soil conservation properties (Ohlenbusch et al., 2007). Since that time, the highly prolific plant has moved westward and invaded approximately 2,500 km^2 of Kansas prairie (KDA, 2018). While late-spring fires decrease invasive cool-season (C3) grasses (e.g., Kentucky Bluegrass), it does not reduce sericea lespedeza growth or proliferation. In contrast, recent research by Alexander (2018) demonstrated fire applied in mid- or late summer can achieve comprehensive control of sericea lespedeza at an affordable cost.

As new challenges continue to develop, it is becoming more imperative that ranchers and grassland managers in the Kansas Flint Hills begin to consider alternatives to annual spring-season prescribed fire. Establishing potential dates outside of the traditional spring-season burn window that do not negatively affect native plant species composition or growth could be beneficial. Additional burn dates could give land managers more flexibility and opportunities to apply fire when weather conditions are favorable to safely conduct a burn. Smoke traditionally produced from burning large amounts of land from mid-March to early May could be distributed throughout the year; thus, improving air quality in areas downwind of the Flint Hills. Furthermore, naturalization of noxious weeds such as sericea lespedeza could potentially be achieved if prescribed fire was applied later in the year.

History of Fire

Fire has played an essential role in the formation and preservation of the tallgrass prairie (Sauer, 1950; Buell and Facey, 1960). Historically, fires across the Great Plains were ignited from lightning strikes and traveled west to east until a natural fire break was reached (Gleason, 1913; Higgins, 1986). The arrival of the Kaw, Greater Osage, and Lesser Osage tribes to the region was coincident with increased fire frequency in the Flint Hills, as they applied annual fires to attract bison to recently burned areas (Middendorf et al., 2009). Higgins (1986) indicated that aboriginal peoples of the Northern Great Plains prescriptively burned grasslands in every month except January, with a majority of fires occurring in April and October. Although fires set by aboriginal peoples occurred throughout the year, 73% of fires initiated by lightning strikes took place in July and August (Higgins, 1986).

The degree to which fire impacted the development of the prairie has been deliberated. Gleason (1913) indicated that fires were responsible for the distribution of prairie and forests throughout the central and western portions of the United States. Whenever fire was eliminated from the landscape, trees and shrubs begin to encroach upon the prairie (Bragg and Hulbert, 1976). Buell and Facey (1960) suggested that if the combination of fire and man had not been present, grasslands would have been limited to areas not suitable for the establishment of woody-stemmed plant species. Borchet (1950) recognized the impact that fire had in expanding the prairie eastward but argued that fire was one of many contributing factors in the maintenance of the prairie. He indicated that climate created favorable burning conditions and, thus, fire likely had a stronger influence in maintaining grassland ecosystems with the rainfall and soil types to support adequate fuel accumulations. In contrast, Sauer (1950) noted that grasslands occurred in different types of climates and that the frequent use of fire by aboriginal peoples caused significant changes in grassland species composition.

Allen and Palmer (2011) used dendrochronological methods to reconstruct the burn history of the Tallgrass Prairie Preserve in the southern Flint Hills. Results indicated that fire occurred, on average, every 2.04 years between 1729 and 2005; however, variations in fire return interval as a result of human activity were observed. The mean fire return interval before European settlement (i.e., 1770-1871) was 3.36 years while the mean fire return interval following European settlement (i.e., 1871-2005) was 1.33 years. This trend may be explained by the increase in use of annual prescribed fire. Kansas became a territory in 1854 and the establishment of the stocker industry began shortly thereafter (Hoy, 1989). Within 8 years of Kansas becoming a territory, annual prescribed fire was a common practice in the Flint Hills and remains so today (Hoy, 1989).

Soil Characteristics

Throughout the early part of the 19th century, the perception of prescribed fire and its impact on the tallgrass prairie varied among the scientific and ranching communities (Hensel, 1923). To develop a better understanding, Hensel (1923) measured soil temperatures of burned and non-burned plots in the Kansas Flint Hills. Average maximum soil temperatures at one- and three-inch depths were greater in burned plots compared with non-burned plots. Aldous (1934) reported similar results when evaluating the impact of multiple years of fire on soil temperature. Average mean maximum temperatures were 10.5, 4.5, and 2.2 °F greater in burned plots at 1-, 3-, and 7-inch depths below the soil surface, respectively, compared to non-burned plots. The increase in soil temperature that results from burning has been associated with greater plant growth early in the growing season (Hensel, 1923; Aldous, 1934).

In addition to elevated soil temperatures, prescribed fire also influences soil moisture. Aldous (1934) evaluated the effects of prescribed fire at different times of the year on soil moisture in the Kansas Flint Hills. Treatments included non-grazed plots that were burned in early spring (20 March), mid-spring (10 April), late spring (5 May), or late fall (1 December); non-burned plots served as negative controls. Non-burned plots had numerically greater soil moisture than burned plots in both sampling years. Subsequently, Hanks and Anderson (1957) assessed the impact of prescribed-fire timing on water infiltration rates after a 11.4 cm rainfall. Eighty-three percent of the total rainfall was absorbed into the soil of the non-burned plot, whereas only 37, 39, 46, and 39% was absorbed into the soil of early-spring, mid-spring, late-spring, and late-fall burned plots, respectively.

Anderson (1965) reevaluated the interaction between prescribed fire timing and soil moisture levels at multiple depths. Results from 1960 to 1963 indicated that non-burned plots had greater overall soil moisture levels than non-grazed plots burned in early spring, mid-spring, late spring, or late fall. Burning early in the year resulted in greater soil moisture loss compared with burning in late spring. Furthermore, plots that were burned in late fall had lesser soil moisture levels at greater soil depths. Decreases in moisture reserves deep in the soil could lead to decreased forage production in years of drought. Anderson et al. (1970) observed similar results in pastures where cattle were grazed over a 5-year period. Soil moisture was greater when burning was applied in late spring (1 May) as opposed to early spring (20 March); however, non-burned pastures had the least overall soil moisture. Lesser soil moisture in non-burned plots was attributed to increased plant growth as opposed to greater runoff, as observed in burned pastures.

In order to understand the impact of fire on soil moisture and temperature, Wyrill (1970) evaluated the effects of prescribed fire timing on chemical composition of the soil. Non-grazed plots were either not burned or burned annually in early spring (20 March), mid-spring (10 April), late spring (1 May), or late fall (1 December). In addition, one pasture was grazed and burned annually on 1 May, whereas one pasture was grazed and not burned annually. Burning non-grazed plots in late spring decreased soil nitrogen concentrations; moreover, the combination of burning and grazing resulted in losses of soil organic matter, nitrogen, potassium, and phosphorus (Wyrill, 1970). In contrast, burning plots in the late fall increased soil organic matter, calcium, magnesium, and potassium; however, though the combination of late fall burning and grazing was not evaluated (Wyrill, 1970). Changes in soil temperature, moisture, or chemical composition have the potential to negatively or positively impact herbage production in the tallgrass prairie.

Biomass Production

A considerable amount of research has been conducted to determine the impact of prescribed fire on total biomass production in the tallgrass prairie. Hensel (1923) compared herbage production from non-grazed plots either burned or not burned at the end of the growing season. Non-burned plots produced almost twice as much forage biomass as burned plots one year after treatment; however, over the next 3 years, non-burned plots only produced 2 to 6%

more forage biomass relative to burned plots. Aldous (1934) evaluated the impact of annual prescribed fire in late fall (1 December), early spring (20 March), mid-spring (10 April), and late spring (May 5) on non-grazed plots. Plots that were burned annually produced less biomass than non-burned plots. Within burned treatments, forage yields increased as fire timing was delayed; thus, late-spring burning produced the most forage, followed by mid-spring, early spring, and then late fall treatments, respectively (Aldous, 1934).

McMurphy and Anderson (1963) continued work by Aldous (1934) to determine the long-term effects of prescribed fire on herbage production. Similar results were obtained over a 26-year period and indicated that non-burned plots produced significantly more biomass compared with burned plots. Furthermore, late-spring burning resulted in greater forage biomass accumulation than early-spring and late-fall treatments; however, forage biomass did not differ between mid- and late-spring burned plots.

In both the Aldous (1934) and McMurphy and Anderson (1963) studies, dead vegetation was removed from non-burned plots at the beginning of each growing season to prevent litter accumulation. Hulbert (1969) later demonstrated that removing litter from non-burned plots resulted in greater forage yield when compared to plots where litter accumulated; therefore, the aforementioned work could potentially be misleading. 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 non-burned treatment was not different between mid- and late-spring burn treatments; however, non-burned plots and plots burned in mid spring or late spring produced more biomass annually than plots burned in early spring or late fall.

Owensby and Anderson (1967) evaluated the combination of spring prescribed fire and grazing on biomass production. Treatments included pastures burned in early spring (20 March), mid-spring (10 April), or late spring (1 May). These were compared with one another and with non-burned pastures. Pastures that were not burned and pastures that were burned in late spring had greater forage yields than pastures burned in early spring. Furthermore, mid- and late-spring burns resulted in a greater forage yield compared with the early-spring burn treatment.

In a similar study, Towne and Craine (2014) evaluated the effects of prescribed fire at different times throughout the year on total forb and grass biomass. Measurements were collected on ordinary uplands and lowlands on pastures burned in fall (November), winter (February), and spring (April) in non-grazed watersheds. Over the 20-year period of the experiment, total grass biomass did not differ between burn treatments on upland and lowland sites. Forb biomass was greater following fall or winter fire compared to that following spring fire on uplands; however, forb biomass was not different between treatments on lowlands.

Alexander (2018) evaluated the effects of growing-season prescribed fire on total forage biomass. Non-grazed pastures were burned annually for 4 years in the spring (1 April), mid-summer (1 August), or late summer (1 September). Total forage biomass did not differ between treatments on the 17 July sampling date; however, forage biomass was greater in the spring treatment compared to the mid- and late summer treatments by 10 October. The difference in forage biomass at the end of the grazing season resulted from burning that took place during the interval between 17 July and 10 October. In conclusion, early findings indicated burning reduced forage biomass; however, more recent research has been interpreted to suggest that prescribed fires conducted at any time throughout the year do not negatively influence forage biomass accumulation.

Botanical Composition

Hensel (1923) demonstrated that annual prescribed fire in the Kansas Flint Hills can cause shifts in native plant composition. Subsequently, several studies investigated the impact of prescribed fire and its timing on plant population dynamics in the tallgrass prairie. Early research focused on spring prescribed fire timing for the purpose of identifying an optimal burn date that promoted both native C4 grass growth and stocker cattle performance. More recent research has evaluated the effect of alternative burn dates on key tallgrass plant species in hopes of mitigating smoke production and controlling invasive species. The major graminoid species that make up the Kansas tallgrass prairie include big bluestem (*Andropogon gerardi*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), sideoats grama (*Bouteloua curtipendula*), and switchgrass (*Panicum virgatum*; Anderson et al, 1970). The following information reviews the effects of prescribed fire and its timing on key tallgrass plant species in the Kansas Flint Hills.

Early-Spring Prescribed Fire

Anderson et al. (1970) determined that early-spring burning (20 March) in grazed pastures decreased basal cover of little bluestem and Kentucky bluegrass compared with not burning; however, basal cover of big bluestem, sideoats grama, and buffalograss (*Bouteloua dactyloides*) was greater in early-spring burn treatments than in non-burned treatments. Furthermore, basal perennial forb and shrub cover was greater in the early-spring burn treatment compared with mid-spring, late-spring, and non-burned treatments. Over a 56-year period, Towne and Owensby (1984) reported that non-grazed plots burned in early spring (20 March) had increased basal cover of big bluestem, little bluestem, and prairie junegrass (*Koleleria macrantha*) compared with non-burned plots. These effects were coincident with reduced basal cover of Indiangrass and Kentucky Bluegrass (*Poa pratensis*) compared with non-burned plots. Both sedges and perennial forbs were also favored by early-spring burn treatments compared with mid- and late-spring burn treatments.

Mid-Spring Prescribed Fire

Anderson et al. (1970) demonstrated that mid-spring (10 April) burning increased basal cover of big bluestem, little bluestem, and Indiangrass, and reduced basal cover of Kentucky bluegrass compared with not burning. In a similar study, Towne and Owensby (1984) reported that non-grazed plots burned in mid-spring (10 April) contained greater concentrations of little bluestem compared with non-grazed plots burned in early spring, late spring, or late fall, as well as in non-burned control plots. Mid-spring burning also increased big bluestem basal cover and decreased basal cover of Kentucky bluegrass, prairie junegrass, and perennial forbs compared with not burning. Towne and Craine (2014) indicated that basal cover of Indiangrass and sideoats grama was greater in watersheds burned annually in mid-spring (21 April) compared with watersheds burned annually in late fall (23 November) or winter (18 February) over a 20-year period. In the Oklahoma tallgrass prairie, Collins (1987) determined that basal cover of big bluestem was greater on pastures burned in mid-spring compared with non-burned pastures.

Late-Spring Prescribed Fire

Anderson et al. (1970) indicated that basal cover of big bluestem was greater in grazed pastures that were burned in late spring compared with grazed pastures that were not burned or burned in early spring or mid-spring. Compared with non-burned pastures, basal cover of Indiangrass and switchgrass increased, whereas basal cover of Kentucky bluegrass decreased in pastures burned in late spring; however, basal cover of little bluestem, sideoats grama, and buffalograss did not differ between late spring-burned and non-burned treatments. Similarly, Towne and Owensby (1984) reported that non-grazed plots burned in late spring (1 May) had greater abundance of big bluestem and Indiangrass and fewer sedges and perennial forbs than non-burned plots or plots burned in early spring, mid-spring, or late fall. Late-spring burning was also associated with lesser concentrations of Kentucky bluegrass and prairie junegrass than non-burned treatments. Owensby et al. (1973) evaluated the use of late-spring (24 April) prescribed fire as a control mechanism for Eastern redcedar (*Juniperus virginiana*) in the Kansas Flint Hills. Burning resulted in 89% reduction of redcedar trees less than 0.61 m tall and 83% reduction of redcedar trees less than 1.8 m tall; however, the effectiveness of prescribed fire as a control mechanism decreased as redcedar height increased above 1.8 m.

Mid-Summer Prescribed Fire

Alexander (2018) evaluated the use of mid-summer (1 August) prescribed fire as a control mechanism for the noxious weed, sericea lespedeza. Mid-summer fire successfully reduced biomass, stem length, seed production, aerial frequency, and basal cover of sericea lespedeza, and subsequently increased basal cover of certain habitat-critical forbs relative to early-spring (1 April) fire. Consequently, overall species richness, native-species richness, forb richness and forb diversity were greater in the mid-summer treatment compared to the early-spring treatment. Basal cover of big bluestem, Indiangrass, switchgrass, little bluestem, and sideoats grama did not differ between early-spring and mid-summer treatments.

Late-Summer Prescribed Fire

Weir and Scasta (2017) evaluated the impact of burning in two month increments throughout the year on basal plant cover; C4 tallgrass cover was greater in plots burned in September-October and November-December than in plots burned at other times of the year. Furthermore, September-October fire had the greatest forb abundance and was the only treatment that reduced woody plant cover. Alexander (2018) evaluated the effects of late-summer (1 September) prescribed fire on native plant composition and sericea lespedeza control. Compared with the early-spring burn treatment (1 April), the late-summer burn treatment reduced biomass, stem length, seed production, aerial frequency and basal cover of sericea lespedeza, and subsequently increased basal cover of major wildflowers. As a result, late-summer fire increased overall species richness, native-species richness, forb richness, forb evenness, and forb diversity compared with early-spring fire. Additionally, basal cover of switchgrass and sideoats grama did not differ between late-summer and early-spring burning treatments; however, basal cover of big bluestem was less and basal cover of little bluestem was greater in the late-summer treatment compared to the early-spring treatment. In a similar study, Reemts et al. (2019) evaluated the impact of late-summer (September) prescribed fire on yellow bluestem (*Bothriochloa ischaemum*) frequency at 2 separate field sites. Plots that were treated with late-summer prescribed fire had lesser yellow bluestem frequencies at both sites 3 years after treatment compared with plots that were not burned; however, while remaining less than the non-burned treatment, yellow bluestem populations recovered to pretreatment frequency at one location in year 3.

Late-Fall Prescribed Fire

Towne and Owensby (1984) determined that non-grazed plots burned in late fall (1 December) had greater prairie junegrass cover and lesser Indiangrass cover than plots that were either not burned or burned in early spring, mid-spring, or late spring. The late fall treatment also contained more sedges and perennial forbs compared with the non-burned treatment and mid-spring or late-spring burning treatments. Late fall burning was associated with more big bluestem cover and less Indiangrass, little bluestem, and Kentucky bluegrass cover relative to non-burned plots. Similarly, Towne and Craine (2014) reported that late-fall (23 November) and winter (18 February) prescribed fire increased cover of aromatic aster (*Symphyotrichum oblongifolius*), heath aster (*Symphyotrichum ericoides*), prairie junegrass, sedges (*Carex spp.*), and white prairieclover (*Dalea candida*) compared with mid-spring (21 April) prescribed fire.

Conclusions

Early research indicated that late spring prescribed fire promoted native C4 grass growth and subsequently reduced forb abundance. (Anderson et al., 1970; Towne and Owensby, 1984). Furthermore, plots burned in late fall or early spring had a greater abundance of sedges and perennial forbs (Towne and Owensby 1984). These results lead to the nearly-exclusive recommendation of late-spring burning and the belief that prescribed fire at any other time could potentially damage native plant species. More recent work has demonstrated that prescribed fire later in the year (i.e., August-October) can be used to promote native plant diversity and potentially achieve control of non-woody invasive plants (Weir and Scasta, 2017; Alexander, 2018; Reemts et al., 2019).

Cattle Performance

The Kansas Flint Hills have historically represented the largest segment of the stocker-cattle industry in the United States (Malin, 1942). Each year, yearling cattle from across the U.S. are brought to the Flint Hills for the summer grazing season. This long-standing tradition dates to the mid-1800s, when ranchers from the southwestern United States and Texas drove cattle through the Flint Hills on the way to eastern markets (Anderson, 1953). Ranchers soon realized cattle could achieve gains of 200 to 300 pounds in a single grazing season (Anderson, 1953; Middendorf et al., 2009). The development of barbed wire in the late 1880s led to the transition from cattle drives to custom grazing (Kollmorgen and Simonett, 1965; Middendorf et al., 2009).

Contracts were established that allowed southern ranchers to lease pastureland in the Flint Hills (Anderson, 1953; Kollmorgen and Simonett, 1965). Most contracts involved Kansas ranchers caring for the cattle and required that prescribed fire be applied before each grazing season to improve cattle bodyweight gains (Kollmorgen and Simonett, 1965).

Although prescribed fire was initially applied to improve stocker cattle performance, the timing of fire application needed to maximize bodyweight gain was unknown. Woolfolk et al. (1975) noted that steers grazing pastures burned in late spring had greater average daily gains compared with steers grazing non-burned pastures. Anderson et al. (1970) looked at the effects of spring prescribed fire timing on stocker cattle performance. Steers were grazed for 151 days on non-burned pastures or pastures burned in the early spring (20 March), mid-spring (10 April), or late spring (1 May). Results over 14 grazing seasons indicated that steers grazing pastures burned in mid- and late spring had greater average daily gains than steers grazing non-burned pastures. Steers grazing the late-spring treatment outperformed steers grazing the early-spring treatment, whereas non-burned and early-spring burn treatments produced similar average daily gains.

In addition to average daily gains, Anderson et al. (1970) measured total bodyweight gain at the end of each month. Bodyweight gains in the mid- and late-spring burn treatments were greater than the non-burned treatment in May and June; however, no differences in monthly bodyweight gain were observed thereafter. Consequently, Smith and Owensby (1978) evaluated the combination of late-spring prescribed fire with intensive-early stocking as opposed to season-long stocking. Steers were stocked at a rate of 1.7 or 3.4 acres per steer and grazed for 75 or 151 days beginning 1 May in the intensive-early and season-long stocking models, respectively. Intensive-early stocking resulted in a greater average daily gains and gains per acre than season-long stocking for the first 75 days; however, total bodyweight gain per steer was greater under season-long stocking compared with intensive-early stocking, due to the longer grazing season.

In a recent study, Farney (2020) reevaluated the effects of spring-season prescribed fire timing on yearling stocker cattle performance during a double-stocked, 90-day grazing season. Yearling steers that grazed pastures burned on 15 April had greater average daily gains and total body weight gains compared with those that grazed pastures burned on 19 March. In a similar study, Farney et al. (2017) measured the impact of burning one third of a pasture each year, otherwise known as patch burning, on stocker cattle growth performance during a 6-year experiment. Over the course of the entire experiment, average daily gains and total bodyweight gains of steers did not differ between patch-burning or annual-burning treatments after a 114-day grazing season; however, patch burning produced greater average daily gains and total bodyweight gains than annual burning in dry years.

The use of prescribed fire to improve stocker cattle bodyweight gain has also been well documented in the tallgrass prairie of Oklahoma. Svejcar (1989) measured the impact of prescribed fire on animal performance over a 3-year period. Results indicated that annual spring prescribed fire increased total bodyweight gains per head and total weight gains per hectare by 15.2 and 11.2 kg, respectively, compared with no prescribed fire. In a similar experiment, McCollum et al. (1992) evaluated the impact of late March / early April prescribed fire and season-long grazing on stocker cattle performance. Over a 4-year period, total body weight gains averaged 15.4 kg more per head for stocker cattle grazing burned pastures compared with those grazing non-burned pastures. Subsequently, these researchers discovered 10.2 kg of the 15.4 kg of increased weight gains achieved by burning occurred in the first 80 days of the grazing season.

Limb et al. (2011) later evaluated the impact of patch-burn grazing on stocker cattle and cow-calf performance in both tallgrass and mixed-grass prairie settings. Over a 4-year period, stocker cattle bodyweight gains, cow body-condition scores, and calf weaning weights did not differ between cattle grazing the patch-burn treatment or those grazing pastures burned at three year intervals in the tallgrass prairie. When stocker cattle performance was evaluated in the mixed-grass prairie location, no differences in stocker cattle bodyweight gains were observed between treatments for the first 4 years of the experiment; however, stocker cattle bodyweight gains were greater for the patch-burn treatment compared with the non-burned treatment for the remaining 6 years of the study.

Although the use of prescribed fire is most often associated with the tallgrass prairie of Kansas and Oklahoma, its usefulness has been documented in other ecosystems. Greene (1935) studied the effects of annual winter (February) prescribed fire on animal performance in the longleaf pine belt of Mississippi. The 11-year trial indicated that cattle grazing burned pastures gained an average of 14.5 kg more per head than cattle grazing non-burned pastures during a 217-day grazing season. In the wiregrass region of Georgia, Hilmon and Hughs (1965) noted that cows grazing winter-burned pastures gained 39.5 kg more and their calves gained 16.8 kg more than cows and calves grazing non-burned pastures. Kirk and Hodges (1970) assessed the impact of prescribed fire on performance of cow-calf pairs in the wiregrass region of Florida. Weaned calf crop increased from 53% on non-burned pastures to 69% on pastures treated with prescribed fire. In the Edwards Plateau of Texas, average daily gains were greater for heifers grazing pastures burned in spring (1 March) compared with those grazing non-burned pastures (McGinty et al, 1983). Additionally, Angell et al. (1986) evaluated the effects of late-October / early-November prescribed fire on yearling cattle performance in the Texas coastal prairie. Cattle that grazed burned pastures had greater average daily gains in 2 out of the 3 grazing seasons evaluated compared with cattle grazing non-burned pastures. Furthermore, cattle that grazed burned pastures tended to retain condition throughout the winter and outperform those cattle that grazed non-burned pastures the following spring.

Research from the Kansas and Oklahoma tallgrass prairie has indicated that prescribed fire increases stocker cattle performance. Cattle that grazed pastures burned in the spring had improved average daily gains and total bodyweight gains compared with cattle that grazed non-burned pastures. In addition, burning late in the spring promoted additional weight gains compared with burning early in the spring. Although dormant-season fire in the Flint Hills has been extensively evaluated, limited research on growing-season prescribed fire and its impact on stocker cattle growth performance is available.

Forage Quality

Smith and Young (1959) were among the first to investigate the impact of burning on the chemical composition of little bluestem. Mid-spring burning (10 April) increased concentrations of crude protein and decreased organic matter and ether extract concentrations in little bluestem compared with not burning. Anderson et al. (1970) subsequently attributed the increase in stocker cattle weight gain following spring prescribed fire to improved forage quality. Allen et al. (1976) later evaluated the impact of late-spring (28 April) prescribed fire on forage quality. Grass samples were clipped at the beginning of each month and chemical composition was averaged throughout the growing season. These data were interpreted to suggest that late-spring burning increased concentrations of crude protein, ether extract, ash, and nitrogen-free extract compared with other treatments. Furthermore, post-fire samples contained lesser concentrations of dry matter, crude fiber, lignin, and cellulose than non-burned samples. Crude protein concentrations in big bluestem and little bluestem did not differ between burned and non-burned treatments.

Alexander (2018) evaluated the impact of prescribed fire timing on fall forage quality in the tallgrass prairie. Chemical composition of treatments burned in early spring (1 April), mid-summer (1 August) and late summer (1 September) were measured in October. Crude protein levels were 2.3% and 2.9% greater in mid-summer and late summer treatments compared with the early-spring treatment, respectively. Furthermore, mid- and late-summer prescribed fire samples had less neutral detergent fiber and acid detergent fiber than early-spring prescribed fire samples during the fall of the year.

Smith et al. (1960) evaluated the impact of mid-spring prescribed fire on apparent total-tract forage digestibility. Burning increased both dry matter and crude fiber digestibility consistently over 4 experiments compared with not burning; however, crude protein digestibility was improved by burning in only 1 of 4 experiments compared with not burning. Woolfolk et al. (1975) indicated that steers grazing pastures burned in late spring had more crude protein and hemicellulose and less acid detergent fiber in their diets compared with steers grazing non-burned pastures.

In a similar study, Svejcar (1989) looked at effects of spring prescribed fire on dietary protein and *in vitro* organic matter digestibility. Early in the grazing season, esophageal masticate collected from steers grazing burned pastures tended to have greater *in vitro* organic matter digestibility than masticate collected from steers grazing non-burned pastures; however, *in vitro* digestibility of masticate was similar between treatments the remainder of the grazing season. Additionally, masticate from cattle grazing spring-burned pastures tended to have lesser dietary crude protein concentrations than masticate from cattle grazing non-burned pastures.

Spring prescribed fire consistently decreased levels of crude fiber and cell wall constituents compared with not burning, thus increasing the relative amount of highly-digestible carbohydrates (Allen et al. 1976). Shifts in chemical composition led to improved dry matter, crude fiber, and organic matter digestibilities (Smith et al., 1960; Svejcar, 1989). These results may indicate that prescribed fire improves forage quality and is the mechanism that drives improvements in stocker cattle bodyweight gains. In addition, burning in mid- to late summer may improve fall forage quality. Alternatively, diet selection by grazing livestock may be altered by prescribed fire (Svejcar, 1989). Although not widely evaluated, changes to diet selection caused by prescribed fire history may also be responsible for improvements in grazing livestock performance. Aubel et al. (2011) documented that botanical composition of beef cow diets was altered by spring burning compared with not burning.

Root Carbohydrate Reserves

An additional concern associated with frequent or poorly-timed prescribed fire is the impact burning can have on root carbohydrate reserves of native plant species. Owensby et al. (1970) evaluated the effects of late-spring fire on total carbohydrate concentrations in big bluestem. In comparing non-grazed 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 subsequently recovered when forage growth slowed. These researchers also measured carbohydrate concentrations in big bluestem samples collected from burned or non-burned plots clipped in June, July, August, and September. Roots from plots burned and clipped in June, July, or August had lesser total carbohydrate concentrations than roots from non-burned plots clipped at the same times; however, root carbohydrate concentrations did not differ between non-burned and burned plots clipped 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-year period, total nonstructural carbohydrate levels in big bluestem root samples were lesser in the intensive-early stocking treatment from June 1 until 15 August compared to 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 throughout the grazing season, resting the pasture for the remainder of the year allowed sufficient time for big bluestem carbohydrate reserves to recover. Furthermore, Auen and Owensby (1988) determined that mowing during the dormant season did not reduce root nonstructural carbohydrates in big bluestem, thus pastures could be utilized for grazing from October to April with minimal stress on big bluestem.

Conclusions

The use of late spring prescribed fire to limit encroachment of trees and shrubs, to promote growth of native C4 grasses, and to boost stocker cattle performance is a long-standing tradition in the Kansas Flint Hills. Early research that evaluated the impact of prescribed fire in the tallgrass prairie largely focused on a narrow time window (approximately between 20 March and 1 May) and concluded that late spring (approximately 15 April to 1 May) was the optimal burn time. This recommendation was derived from data that indicated burning in late spring resulted in minimal soil moisture loss, greater forage biomass production, general increases in C4 grass cover, and maximal stocker-cattle bodyweight gain (Hanks and Anderson, 1957;

McMurphy and Anderson, 1963; Anderson et al., 1970) From that time on, the application of late-spring prescribed fire became the standard for the ranching community of the region.

Air quality issues, labor availability, and non-woody invasive species have created a demand for research evaluating the impacts of alternative timings for prescribed fire. Towne and Craine (2014) indicated that total grass biomass did not differ between treatments burned in February, April, or November over a 20-year period. Towne and Craine (2014), Weir and Scasta (2017), and Alexander (2018) also demonstrated that native plant composition was not negatively influenced by shifting prescribed fire timing from spring to later in the year. Furthermore, Alexander (2018) and Reemts et al. (2019) documented potential for control of non-woody invasive species by using late-summer prescribed fire.

Although the impact of prescribed fire timing on the tallgrass-prairie plant communities have been evaluated, no direct comparisons of stocker cattle performance are available for these prescribed fire regimes; therefore, the objective of our experiment was to document the effects of prescribed-fire timing on stocker cattle growth performance, plant composition, forage biomass accumulation, and root carbohydrate concentrations in key native plants annually during a 7-year experiment. This thesis reports the first 3 years of data related to plant composition, forage biomass, and root carbohydrate concentrations and the first 2 years of stocker cattle growth performance associated with spring, summer, and fall prescribed fires.

Literature Cited

Aldous, A. E. 1934. Effects of burning on Kansas bluestem pastures. Kansas Agric. Exper. Stat. Bull. 38, 65 pp. ETD collection for University of Nebraska - Lincoln. AAIDP14032. https://digitalcommons.unl.edu/dissertations/AAIDP14032 (Accessed 30 January, 2020).

Alexander, J. A. 2018. Effects of prescribed fire timing on vigor of sericea lespedeza in the Kansas Flint Hills. M.S. Thesis. Kansas State University, Manhattan, KS, USA.

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.

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.

Anderson, K. L. 1953. Utilization of grasslands in the Flint Hills of Kansas. J. Range Manage. 6:86-93.

Anderson, K. L. 1965. Time of burning as it affects soil moisture in an ordinary upland bluestem prairie in the Flint Hills. J. Range Manage. 18:311:316.

Anderson K. L., E. F. Smith, and C. E. Owensby. 1970. Burning bluestem range. J. Range Manage. 23:81-92.

Angell, F. R., J. W. Stuth, and D. L. Drawe. 1986. Diets and liveweight changes of cattle grazing fall-burned Gulf cordgrass. J. Range Manage. 39:233-236.

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 Mange. 41:481-482.

Borchert, J. R. 1950. The climate of the central North American grassland. Ann. Assoc. Am. Geogr. 40:1-29.

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

Buell, M. F. and V. Facey. 1960. Forest-prairie transition west of Itasca Park, Minnesota. Bull. Torrey Bot. Club. 87(1):46-58.

Collins, S.L. 1987. Interaction of Disturbances in Tallgrass Prairie: A Field Experiment. Ecol. 68(5):1243-1250.

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.

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. Vol. 6: Iss. 2. https://doi.org/10.4148/2378-5977.7885.

Gleason, H. A. 1913. The relation of forest distribution and prairie fires in the middle west. J. Torrey Bot. Soc. 13(8):173-181.

Greene, S. W. 1935. Relation between winter grass fires and cattle grazing in the longleaf pine belt. J. For. 33(3):338-341.

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

Hensel, R. L. 1923. Recent studies on the effect of burning on grassland vegetation. Ecol. 4:183-188.

Higgins, K. F. 1986. Interpretation and compendium of historical fire accounts in the Northern Great Plains. Washington, D.C.: U.S. Dept. of the Interior, Fish and Wildlife Service. 39 pp.

Hilmon, J. B. and R. H. Hughes. 1965. Fire and forage in the wiregrass type. J. Range Manage. 18:251-254.

Hoy, J. 1989. Controlled pasture burning in the Folklife of the Kansas Flint Hills. Great Plains Q. 9:231-238.

Hulbert, L. C. 1969. Fire and litter in undisturbed bluestem prairie in Kansas. Ecol. 50:874-877.

[KDA] Kansas Department of Agriculture, 2018. 2018 Noxious weed survey data. https://agriculture.ks.gov/docs/default-source/pp-noxious-weed-control/copy-of-survey-datad293eb002e6262e1aa5bff0000620720.xlsx?sfvrsn=1df189c1. (Accessed 6 December 2019).

[KDHE] Kansas Department of Health and Environment. 2010. Flint Hills smoke management plan. https://www.ksfire.org/health/ (Accessed 3 February 2020).

[KDHE] Kansas Department of Health and Environment. 2020. Flint Hills prescribed fire update. https://www.ksfire.org/new-media-archives/weeklyupdates/2020_Flint_Hills_Summary_May_15.pdf (Accessed 7 September 2020).

Kirk, W. G. and F. M. Hodges. 1970. Effect of controlled burning on production of cows on native range. Proc. Soil and Crop Sci. of Florida 30:341-343.

Kollmorgen, W. M., and D. S. Simonett. 1965. Grazing operations in the Flint Hills-bluestem pastures of Chase County, Kansas. Annals Assoc. Am. Geogr. 55(2):260–290. www.jstor.org/stable/2561757 (Accessed 3 Feb. 2020).

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.

Malin, J. C. 1942. An introduction to the history of the bluestem pasture region of Kansas. Kansas Hist. Q. 11:3-28.

McCollum F. T., D. M. Engle, and J. F. Stritzke. 1992. Cattle performance following prescribed burning of rangeland in north-central Oklahoma. pp. 447-449 in Anim. Sci. Res. Rep., Oklahoma Agric. Exp. Sta. MP-136. http://dasnr54.dasnr.okstate.edu:8080/beefextension2018/research_reports/1992rr/92-70.pdf (Accessed 3 February 2020).

McGinty, A., F. E. Smeins, and L. B. Merrill. 1983. Influence of spring burning on cattle diets and performance on the Edwards Plateau. J. Range Manage. 32:175-178.

McMurphy, W. E. and K. L. Anderson. 1963. Burning bluestem range: forage yields. Trans. Kansas Acad. Sci. 66(1):49-51.

Middendorf, G., T. A, Becerra, and D. Cline. 2009. Transition and resilience in the Kansas Flint Hills. Online J. Rural Res. Policy. 4(3):1-28.

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. https://www.bookstore.ksre.ksu.edu/pubs/mf2408.pdf (Accessed 4 September 2020).

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.

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.

Owensby, C. E., K. R. Blan, F. J. Eaton, and O. G. Russ. 1973. Evaluation of Eastern Redcedar infestation in the northern Kansas Flint Hills. J. Range Manage. 26:256-260.

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.

Reemts, C. M., W. M. McCaw, T. A. Greene, and M. T. Simmons. 2019. Short-term control of an invasive C_4 grass with late-summer fire. Rangeland Ecol. Manage. 72: 182-188.

Samson, F. and Knopf, F. 1994. Prairie conservation in North American. Biosci. 44:418-421.

Sauer, C.O. 1950. Grassland climax, fire, and man. J. Range. Manage. 3:16-21.

Smith, E. F. and V. A. Young. 1959. The effect of burning on the chemical composition of little bluestem. J. Range Manage. 12:139-140.

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. Animal Sci. 19:388-391.

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.

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. E. Owensby. 1984. Long-term effects of annual burning at different dates in ungrazed Kansas tallgrass prairie. J. Range Manage. 35:392-397.

Towne, E. G., and J. M. Craine. 2014. Ecological consequences of shifting the timing of burning tallgrass prairie. Plos One. 9(7):e103423. https://doi.org/10.1371/journal.pone.0103423 (Accessed 3 February 2020).

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.

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.

Wyrill, J. B. 1970. Effect of burning on soil chemical and physical properties of loamy upland bluestem range. M.S. Thesis. Kansas State University, Manhattan, KS, USA.

Chapter 2 - Effects of prescribed fire timing on yearling cattle grazing performance and forage biomass accumulation in the Kansas Flint Hills

Abstract

In the Kansas Flint Hills, ranchers traditionally apply annual spring-season prescribed fire to improve bodyweight gains by yearling stocker cattle. Recent research demonstrated that mid- or late-summer prescribed fires can be used to manage sericea lespedeza infestations. The effect of prescribed fire applied during the growing season (i.e., August-October) on yearling grazing cattle performance has not been evaluated. The objectives of our experiment were to document the effects of prescribed fire timing on grazing performance of yearling cattle and forage biomass accumulation in the Kansas Flint Hills over a 7-year period. This manuscript addresses the first 3 years of that experiment. Eighteen pastures were grouped by watershed and assigned to 1 of 3 prescribed-fire treatments: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or fall (2 October ± 9.9 d). Yearling cattle were grazed from May to August at a targeted stocking density of 279 kg live-weight $\cdot$ ha^{-1}. Forage biomass was estimated in 2018 and 2020 by clipping vegetation 1-cm above the soil surface within ten 0.25^2-meter frames in each pasture. All prescribed-fire treatments were applied prior to grazing in 2019 and 2020. Following the second full year of fire application, initial bodyweights did not differ ($P = 0.82$) between prescribed-fire treatments. Cattle that grazed the spring- and summer-burn treatments had greater ($P = 0.01$) total bodyweight gains and average daily gains compared with those that grazed the fall-burn treatment. As a result, final body weights were greater ($P = 0.04$) in the spring and summer prescribed-fire treatments compared with the fall prescribed-fire treatment. Furthermore, forage

biomass accumulation in July did not differ (P = 0.91) between spring-, summer-, or fall-burn treatments. These data were interpreted to indicate that summer prescribed fire could be used to manage sericea lespedeza populations without negatively affecting growth performance of grazing yearling cattle or forage biomass accumulations in the Kansas Flint Hills.

Key Words: grazing, prescribed fire, sericea lespedeza

Introduction

Annual spring-season prescribed fire has been used in Kansas Flint Hills to improve grazing-cattle performance since the 1880s (Anderson, 1953). Early work by Anderson et al. (1970) demonstrated that pastures burned in late spring (1 May) resulted in greater total bodyweight gains and average daily gains compared to pastures burned in early spring (20 March). When evaluating different grazing systems, Smith and Owensby (1978) discovered total bodyweight gains per hectare were improved when cattle were doubled-stocked 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 half of the aforementioned stocking density. Based on these data, researchers concluded that annual spring-season prescribed fire followed by intensive-early stocking was a suitable grazing model for the Flint Hills. Today, an average of 2.1 million acres throughout the Flint Hills are burned annually from mid-March to early May (KDHE, 2020). Unfortunately, smoke produced from burning large areas of prairie during a short period of time have led to numerous air quality issues in downwind municipalities (KDHE, 2010).

In addition to concerns associated with smoke management, a large portion of the Kansas Flint Hills have been degraded by the noxious weed, sericea lespedeza (*Lespedeza cuneata*). Sericea lespedeza was originally cultivated in North Carolina in the late 19th century for erosion prevention, livestock feed, and wildlife habitat (Ohlenbusch et al., 2007). In the 1930s, sericea lespedeza was introduced in southeast Kansas to revegetate strip-mined lands (Ohlenbusch et al., 2007). Since that time, the highly-competitive and invasive forb has moved westward into the Great Plains and degraded approximately 2,500 km^2 of native prairie in Kansas (KDA, 2018). Current recommendations for sericea lespedeza control involve a combination of spring-season prescribed fire, grazing, and routine herbicide application; however, herbicides can be expensive to apply and have negative impacts on non-target native plant species (Ohlenbusch et al., 2007; Gatson, 2018).

Alexander (2018) observed reductions in sericea lespedeza frequency, vigor, and seed production in pastures where prescribed fire applied relatively late in the year (i.e., August-September) compared with those where fire was applied in the spring. Gatson (2018) reported similar reductions in sericea lespedeza frequency and vigor when late summer (i.e., September) prescribed fire was applied in moderately-degraded rangeland. Despite optimistic reports from Alexander (2018) and Gatson (2018), Flint Hills ranchers have expressed reluctance to use mid- or late-summer prescribed fire for sericea lespedeza control out of concerns over reducing stocker cattle performance. At this time, no direct comparisons of yearling cattle grazing these prescribed fire regimes are available. Therefore, the objectives of this experiment were to document the effects of prescribed-fire timing on yearling stocker cattle performance and forage biomass accumulation in the Kansas Flint Hills over a 6-year period. This manuscript reports observations after collection of 3 years of vegetation data and 2 years of cattle performance data.

Materials and Methods

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 rangeland and is fenced into 18 grazing units that range in size from 12 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, 2020).

Historically, spring-season prescribed fire was applied and the site was stocked with yearling beef cattle for the late-spring and early-summer grazing season. Pre-treatment plant species composition was determined in 2018 and is presented in Table 2.1. Big bluestem, Indiangrass, and sideoats grama were the predominant graminoid species and accounted for over 50% of pre-treatment basal vegetation cover (Table 2.1). Common names, scientific names, and taxonomic authorities were taken from Haddock (2005).

Using a completely randomized design, pastures were grouped by watershed and each watershed was assigned randomly to 1 of 3 prescribed-fire treatments (n = 6 pastures per treatment): spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or fall (2 October ± 9.9 d). Prescribed burns were applied on or near target dates for 2 consecutive years with permission from Riley Co. Emergency Management, Manhattan, KS (permit no. 1488). Burns were performed under appropriate environmental conditions: surface wind speed = 8 to 20 $km \cdot h^{-1}$; surface wind direction = steady and away from urban areas; mixing height ≥ 550 m; transport wind speed = 13 to 33 $km \cdot h^{-1}$; 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.

Animal Performance

Animal care and handling practices were reviewed and approved by the Kansas State University Institutional Animal Care and Use Committee (protocol no. 3858). A total of 675 yearling cattle were grazed over 2 consecutive growing seasons. Pastures were stocked at a targeted stocking density of 279 kg live-weight ⋅ ha^{-1}. Three-hundred-sixty heifers (initial BW = 282 ± 38.9 kg) were grazed from May 2 to July 31 in year 1 while 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 the timing of cattle arrival 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), bodyweight was recorded, and a visual identification tag was applied. Calves were then assigned randomly to pasture and treatment. On the day grazing began, each calf was again weighed individually to determine initial bodyweight. Concurrently, calves were vaccinated for viral respiratory pathogens, treated for internal parasites, and then allocated to their respective pastures. In addition, steers were given a growth-promoting implant in 2020. At the conclusion of the grazing season calves were gathered and individual bodyweights were measured. Total bodyweight gains and average daily gains were calculated.

Forage Biomass

Forage biomass accumulation was evaluated in 2018 and 2020 using 50 × 50-cm quadrats. A single, permanent 100-m transect was established in each pasture. Transects were laid out on Benfield-Florence complex soils in areas with less than 2% slope. Endpoints and the center of each transect were marked with orange survey stakes (Forestry Suppliers, Inc., Jackson, MS) and GPS coordinates were recorded (Garmin, 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 side. Litter was removed from each quadrat and all plant material was clipped at a height of 1 cm above the soil surface. Clipped material was weighed, dried in a forced-air oven (50ºC; 96 h), and reweighed to estimate standing forage DM $\cdot$ ha^{-1}.

Statistical Analyses

Initial body weight, total bodyweight gain, average daily gain, final bodyweight, and forage biomass accumulation 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 of treatment and year and a random effect of pasture within treatment. Year × treatment interactions were not significant; therefore, the final model contained a term for treatment only as a fixed effect and year and pasture within treatment as random effects. When protected by a significant F-test ($P \leq 0.05$), treatment means were separated using the method of Least Significant Difference.

Results

Initial bodyweights did not differ ($P = 0.82$; Table 2.2) between prescribed-fire treatments. When total bodyweight gains were evaluated, no differences ($P = 0.43$; Table 2.2) between spring and summer prescribed-fire treatments were detected; however, calves that grazed the fall-fire treatment had lesser ($P = 0.01$; Table 2.2) total bodyweight gains compared with calves grazing the spring- or summer-fire treatments. Total bodyweight gains were 113, 110, and 101 kg for the spring, summer, and fall prescribed-fire treatments, respectively. Calves that grazed spring- and summer-burned pastures gained 12 and 10 kilograms more bodyweight, respectively, than calves that grazed fall-burned pastures.

Similarly, average daily gains did not differ ($P = 0.46$; Table 2.2) between spring and summer prescribed-fire treatments; however, calves that grazed the fall-burn treatment had lesser ($P = 0.01$; Table 2.2) average daily gains compared with calves that grazed the spring- and summer-burn treatments. Average daily gains were 1.26, 1.23, and 1.13 kg $\cdot$ $d^{-1}$for the spring, summer, and fall prescribed-fire treatments, respectively. As a result, final bodyweights were greater ($P = 0.04$; Table 2.2) in the spring and summer treatments compared with the fall treatment. When total forage biomass was evaluated, no differences ($P = 0.91$; Figure 2.1) were detected between prescribed-fire regimes. Forage biomass was 2013, 2095, and 2126 kg $\cdot$ ha^{-1} for the spring, summer, and fall prescribed-fire treatments, respectively.

Discussion

Animal Performance

In our experiment, summer prescribed fire did not reduce total bodyweight gains or average daily gains when compared to spring prescribed fire; however, stocker cattle growth performance was reduced when pastures were treated with fall prescribed fire. As a result, final bodyweights were greater for calves that grazed spring- and summer-burned pastures when compared with those that grazed fall-burned pastures. Previous research in the Flint Hills indicated that yearling steers that grazed spring-burned pastures exhibited greater average daily gains compared with those that grazed non-burned pastures (Woolfolk et al., 1975). Similarly, annual spring-season prescribed fire improved yearling stocker cattle performance in the tallgrass prairie of Oklahoma (Svejcar, 1989; McCollum et al, 1992). When evaluating spring-season prescribed fire timing, Anderson et al. (1970) reported greater average daily gains when steers grazed pastures burned in mid-spring (10 April) and late spring (1 May) compared with those that grazed non-burned pastures; furthermore, steers in the late spring prescribed-fire treatment outperformed those assigned to the early-spring prescribed-fire treatment. After 14 grazing seasons, researchers concluded that fire should be applied in mid- or late spring to achieve maximum stocker cattle bodyweight gains (Anderson et al., 1970).

Smith and Owensby (1978) evaluated the effects of intensive-early stocking (i.e., 0.69 ha $\cdot$ steer^{-1}for 75 d) on cattle performance compared with season-long stocking (i.e., 1.38 ha $\cdot$ steer^{-1}for 151 d) following late spring-season prescribed fire. For the first 75 days, steers in the intensive-early stocking system exhibited greater average daily gains and gains $\cdot$ ha^{-} compared to 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-day grazing season would serve as an appropriate control treatment that could be compared with the effects of summer (August) or fall (October) prescribed fire on yearling beef cattle performance.

Previous research measuring the effects of annual spring-season prescribed fire on total bodyweight gains for yearling cattle grazing in the Kansas Flint Hills were similar to those observed in our study. In a 9-year study, Owensby et al. (2008) reported total bodyweight gains of 87 kg $\cdot$ calf^{-1}when steers were grazed from late-April to mid-July at 0.81 ha $\cdot$ steer^{-1}following late-spring prescribed fire. Similarly, Farney (2020) reported total bodyweight gains of 109 kg and 122 kg for steers grazing pastures burned in early spring (19 March) or mid-spring (15 April), respectively, after an 87-day grazing season. In our experiment, total bodyweight gains were 113, 110, and 101 kg for calves that grazed spring, summer, and fall treatments, respectively. 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-year rotation, otherwise known as patch burn-grazing, has produced variable responses in beef cattle performance. Limb et al. (2011) reported no differences in stocker cattle weight gains, cow body-condition scores, or calf weaning weights when patch-burn grazing was compared to spring fire applied to entire grazing units at 3-year intervals in the tallgrass prairie of Oklahoma. Conversely, stocker cattle performance did not differ between patch-burn grazing and a non-burned treatment for the first 4 years in a mixed-grass prairie location; however, stocker cattle that grazed the patch-burn treatment outperformed those that grazed the non-burned treatment for the remaining 6 years of the study (Limb et al., 2011).

In Kansas tallgrass prairie, Farney et al. (2017) did not observe any differences in stocker cattle performance when a patch-burn system was compared with annual spring-season prescribed fire; however, in years with low precipitation, patch burning increased total bodyweight gains and average daily gains 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 useful drought-management scheme. The Kansas Flint Hills receive the largest portion of annual precipitation between April and October (Figure 2.2). When prescribed fire is shifted to later in the year (i.e., August-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 performance while grazing native rangeland treated with spring, summer, or fall prescribed fire have been documented. After 2 complete grazing seasons, stocker cattle performance did not differ between spring or mid-summer prescribed-fire treatments. Furthermore, cattle that grazed fall-burned pastures exhibited lesser total bodyweight gains and average daily gains compared with those grazing spring- and summer-burned pastures. The reason behind the reduction in weight gain observed for cattle grazing the fall-burn treatment is currently 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 forage dry matter, crude fiber, and organic matter digestibilities when compared to non-burned forage (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.

Pastures within the experimental site contained light infestations of sericea lespedeza and yellow bluestem (*Bothriochloa ischaemum*). Alexander (2018) reported reductions in sericea lespedeza aerial frequency, basal frequency, biomass, and seed production in native prairies where mid-summer (August) or late summer (September) prescribed fire was applied compared with spring (April) prescribed fire. In moderately degraded tallgrass prairie, Gatson (2018) observed similar reductions in basal cover and aerial frequency of sericea lespedeza when plots were treated with late summer (September) prescribed fire. Furthermore, Reemts et al. (2019) reported reductions in yellow bluestem frequency when late summer (September) prescribed fire was applied; however, yellow bluestem populations were judged by these authors to have recovered at one of three sites evaluated in that experiment by year 3 post-fire.

When considering methods for sericea lespedeza control, beef producers are encouraged to compare revenue changes that may result from fall prescribed fire application (i.e., decreased weight gains) with the costs of herbicides to determine a least-cost control program. Herbicide application can be expensive and usually has negative impacts on non-target native forbs (Ohlenbusch et al., 2007; Gatson, 2018).

Forage Biomass

Prescribed-fire timing did not influence forage biomass accumulation under the conditions of our experiment. In non-grazed plots, Towne and Owensby (1984) observed greater forage biomass accumulations in non-burned, mid-spring (10 April), or late-spring (1 May) burned plots compared with those burned in early spring (20 March) or late fall (1 December). 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 non-grazed pastures burned in fall (November), winter (February), or spring (April) over a 20-year period; moreover, pastures burned in the fall 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 (2018) reported no differences in forage biomass measured in July between pastures burned annually in the spring (April), mid-summer (August 1), 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 throughout the year may not negatively affect forage biomass accumulation.

Implications

Following 2 full cycles of prescribed fire application, total bodyweight gains and average daily gains of grazing yearling cattle did not differ between spring and summer prescribed-fire treatments. In addition, prescribed fire timing was not associated with negative effects on forage biomass accumulation. These data were interpreted to suggest that beef producers could employ summer prescribed fire to manage sericea lespedeza populations without reducing grazing performance of yearling grazing cattle or pasture carrying capacity. The long-term impacts of prescribed fire timing on stocker cattle performance and forage biomass accumulation will continue to be evaluated over the next 4 years.

Literature Cited

Alexander, J. A. 2018. Effects of prescribed fire timing on vigor of sericea lespedeza in the Kansas Flint Hills. M.S. Thesis. Kansas State University, Manhattan, KS, USA.

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.

Anderson, K. L. 1953. Utilization of grasslands in the Flint Hills of Kansas. J. Range Manage. 6:86-93.

Anderson K. L., E. F. Smith, and C. E. Owensby. 1970. Burning bluestem range. J. Range Manage. 23: 81-92.

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.

Farney, J. K. 2020. Evaluating stocker steer gains on tallgrass native range with two burn dates and spices in mineral. Kansas Agric. Exp. Sta. Res. Rep. Vol. 6: Iss. 2. https://doi.org/10.4148/2378-5977.7885

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

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

[KDHE] Kansas Department of Health and Environment. 2010. Flint Hills smoke management plan. https://www.ksfire.org/health/ (Accessed 3 February 2020).

[KDHE] Kansas Department of Health and Environment. 2020. Flint Hills prescribed fire update. https://www.ksfire.org/new-media-archives/weeklyupdates/2020_Flint_Hills_Summary_May_15.pdf (Accessed 7 September 2020).

[KDA] Kansas Department of Agriculture, 2018. 2018 Noxious weed survey data. https://agriculture.ks.gov/docs/default-source/pp-noxious-weed-control/copy-of-survey-datad293eb002e6262e1aa5bff0000620720.xlsx?sfvrsn=1df189c1 (Accessed 4 September 2020).

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.

McCollum F. T., D. M. Engle, and J. F. Stritzke. 1992. Cattle performance following prescribed burning of rangeland in north-central Oklahoma. pp. 447-449 in Anim. Sci. Res. Rep., Oklahoma Agric. Exp. Sta. MP-136. http://dasnr54.dasnr.okstate.edu:8080/beefextension2018/research_reports/1992rr/92-70.pdf (Accessed 16 September 2020)

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. https://www.bookstore.ksre.ksu.edu/pubs/mf2408.pdf (Accessed 4 September 2020).

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.

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

Reemts, C. M., W. M. McCaw, T. A. Greene, and M. T. Simmons. 2019. Short-term control of an invasive C_4 grass with late-summer fire. Rangeland Ecol. Manage. 72:182-188.

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. Animal Sci. 19:388-391.

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.

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. E. Owensby. 1984. Long-term effects of annual burning at different dates in ungrazed Kansas tallgrass prairie. J. Range Manage. 35:392-397.

Towne, E. G., and J. M. Craine. 2014. Ecological consequences of shifting the timing of burning tallgrass prairie. Plos One. 9(7):e103423. https://doi.org/10.1371/journal.pone.0103423 (Accessed 3 February 2020).

[USDA-NRCS] US Department of Agriculture Natural Resources Conservation Service, 2020. Web soil survey. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (Accessed 14 July 2020).

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.

Figures

Figure 2.1. Effects of prescribed-fire timing on forage biomass accumulation in the Kansas Flint Hills during the summer growing season. Eighteen pastures were grouped by watershed and assigned to 1 of 3 prescribed-fire treatments: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or fall (2 October ± 9.9 d). Treatments were applied on or near target dates for two consecutive years. No differences (*P* = 0.91; SEM = 282.6) in forage biomass accumulation were detected between prescribed-fire treatments.

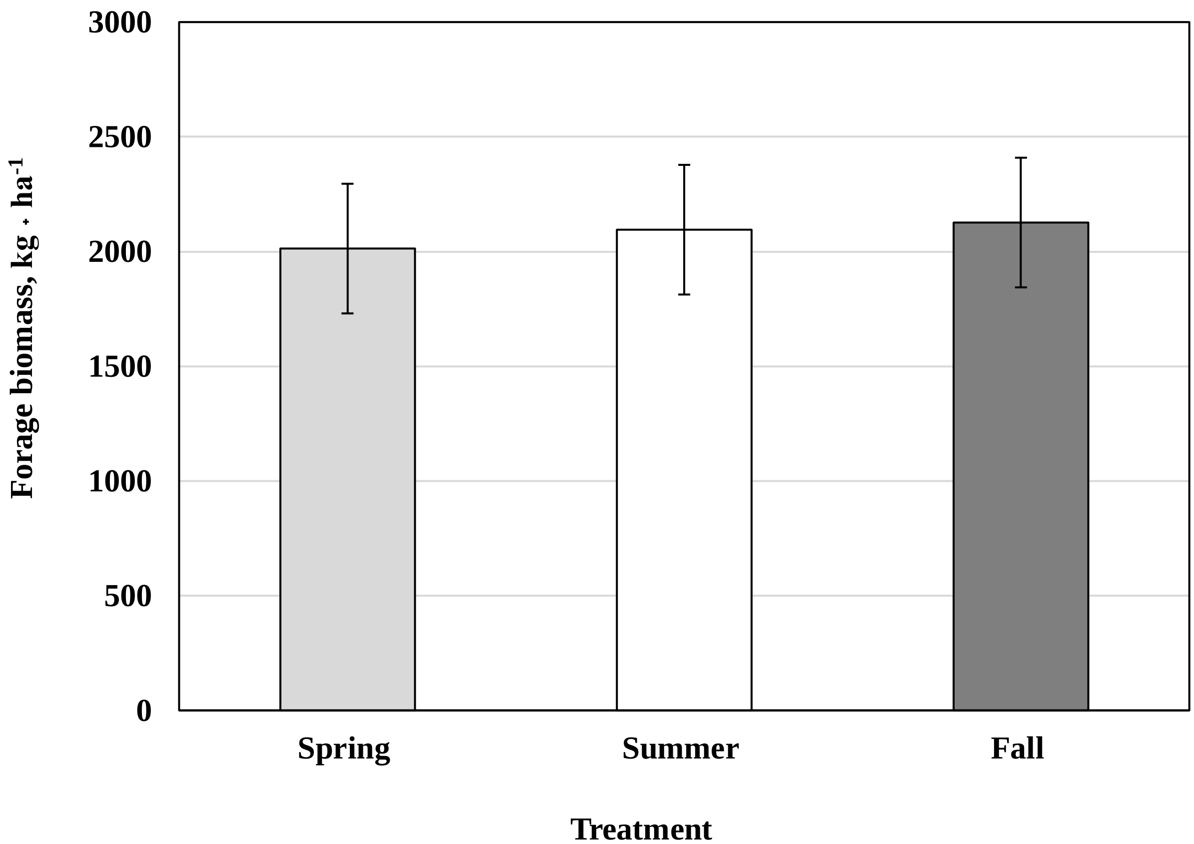
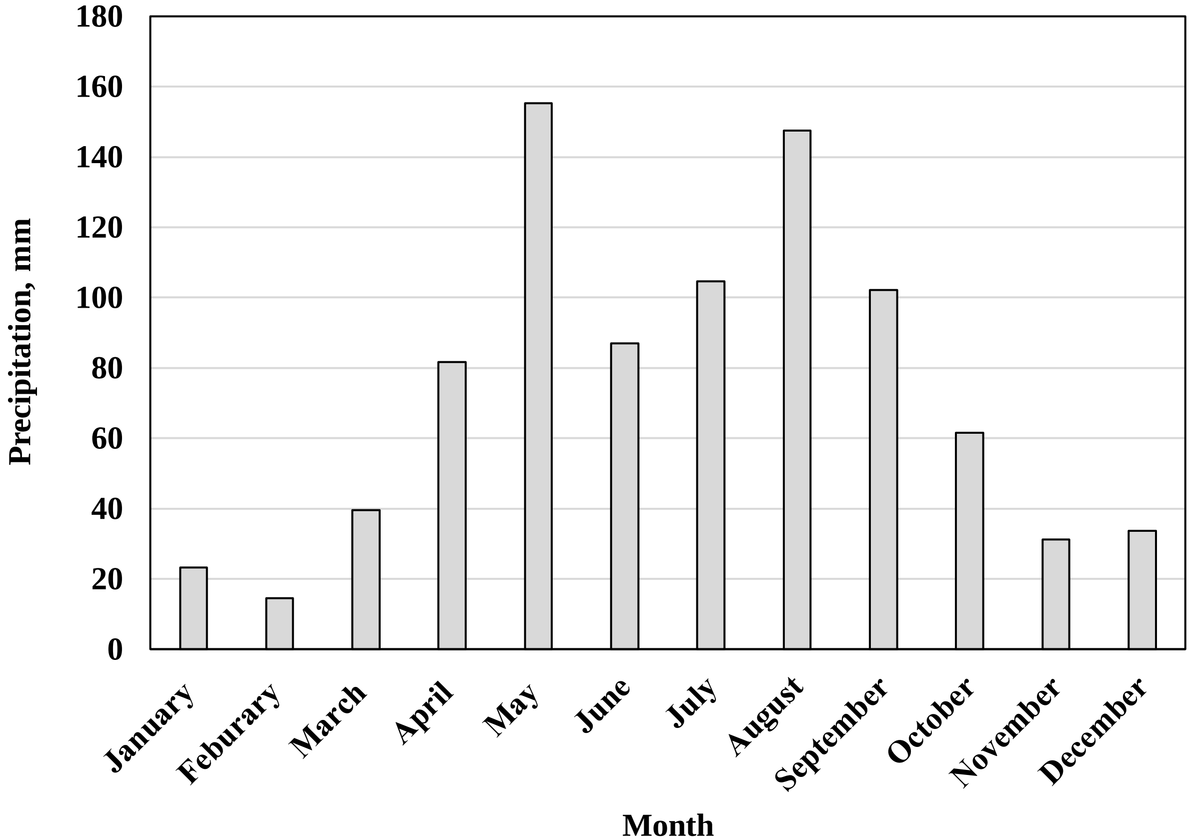


Figure 2.2. Mean annual precipitation received near the Kansas State University Beef Stocker Unit between January 2015 and August 2020. Historical records were obtained from the Kansas Mesonet database using the Rocky Ford weather station, located approximately 5 km east of the experimental site.



Tables

Table 2.1. Pre-treatment plant species composition of native tallgrass prairie located at the Kansas State Beef Stocker Unit (% of total basal plant cover)

Item		Percent
Graminoids		**92.61**
Big bluestem	*Andropogon gerardii*	18.11
Indiangrass	*Sorghastrum nutans*	17.17
Sideoats grama	*Bouteloua curtipendula*	16.44
Sedges	*Carex spp.*	15.22
Little bluestem	*Schizachyrium scoparium*	13.94
Tall dropseed	*Sporobolus compositus*	6.00
Scribner's panicum	*Dichanthelium oligosanthes*	1.00
Hairy grama	*Bouteloua hirsuta*	1.89
Switchgrass	*Panicum virgatum*	0.94
Other graminoids	n = 14	1.89
Forbs		**6.37**
Western ragweed	*Ambrosia psilostachya*	1.12
Louisiana sagewort	*Artemisia ludoviciana*	0.89
Heath aster	*Symphyotrichum ericoides*	0.69
Violet lespedeza	*Lespedeza violacea*	0.57
Missouri goldenrod	*Solidago missouriensis*	0.42
Aromatic aster	*Symphyotrichum oblongifolium*	0.36
Viscid euthamia	*Euthamia gymnospermoides*	0.28
Baldwin's ironweed	*Vernonia baldwinii*	0.27
Tall goldenrod	*Solidago altissima*	0.21
False boneset	*Brickellia eupatorioides*	0.20
Pitcher sage	*Salvia azurea*	0.19
Fringeleaf ruellia	*Ruellia humilis*	0.16
Wavyleaf thistle	*Cirsium undulatum*	0.10
Other forbs	n = 35	0.92
Shrubs		**1.02**
Leadplant	*Amorpha canescens*	0.83
New Jersey tea	*Ceanothus americanus*	0.10
Other Shrubs	n= 3	0.09

Table 2.2. Effects of prescribed fire timing on yearling stocker cattle growth performance in the Kansas Flint Hills

	Prescribed fire season				
Item	Spring (7 April)	Summer (21 August)	Fall (2 October)	SEM*	*P*-value†
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, kg‡	113[a]	110[a]	101[b]	3.4	0.01
Average daily gain, $kg \cdot d^{-1}$ §	1.26[a]	1.23[a]	1.13[b]	0.038	0.01

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

† Treatment main effect.

‡ Calculated as final body weight – initial body weight

§ Calculated as total body weight gain ÷ total grazing days

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

Chapter 3 - Effects of prescribed fire timing on native plant composition, soil cover, and root carbohydrate concentrations of key tallgrass plant species

Abstract

Annual spring prescribed fire followed by intensive early stocking is commonly practiced throughout the Kansas Flint Hills. Recent research demonstrated that fire applied later in the year (i.e., August-September) can achieve control over sericea lespedeza (*Lespedeza cuneata*) infestations at an affordable rate. Although mid-summer or early-fall prescribed fire can be applied to manage sericea lespedeza, ranchers have voiced concerns that fire applied later in the year may negatively affect native C4 grass populations. Therefore, the objectives of our experiment were to determine the effect of prescribed-fire timing on soil cover, native plant composition, and root carbohydrate concentrations in key native tallgrass species. This manuscript addresses the first 3 years of a 7-year experiment. Eighteen pastures were grouped by watershed and assigned to 1 of 3 prescribed-fire treatments: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or fall (2 October ± 9.9 d). Soil cover, plant composition, and root carbohydrate concentrations were measured during the growing seasons of 2018, 2019, and 2020. All prescribed fire treatments were applied prior to grazing in 2019 and 2020. Total grass and forb basal cover did not differ (P = 0.15) between prescribed fire treatments. Total shrub basal cover tended to be greater (P = 0.08) in summer- and fall-burned pastures compared with spring-burned pastures but was generally small (i.e., ≤ 1.5%) across treatments. No treatment differences (P = 0.23) were observed in basal cover of C3 or C4 graminoids; however, differences within C4 growth forms were detected. Basal cover of perennial C4 mid-grasses was greatest ($P = 0.05$) in the spring fire treatment, intermediate in the summer fire treatment, and least in the fall fire treatment. In addition, basal cover of perennial C4 shortgrasses was greater ($P < 0.01$) in the spring treatment compared with the summer and fall treatments. When forb growth forms were evaluated, basal cover of annual forbs was greater ($P = 0.01$) in the fall fire regime compared with the spring fire regime, whereas the summer fire regime was intermediate to and not different from the fall and spring fire regimes. Furthermore, basal cover of nectar-producing forbs was greater ($P = 0.02$) in the summer and fall fire treatments compared with the spring fire treatment. In contrast, no differences ($P = 0.24$) in root starch or root water-soluble carbohydrate concentrations of big bluestem, little bluestem, Indiangrass, or purple prairieclover were observed between prescribed-fire treatments. These data were interpreted to suggest that changes to prescribed-fire timing were associated with small changes in rangeland plant composition but did not negatively affect root carbohydrate concentrations in key native tallgrass plant species.

Key words: grazing, prescribed fire, sericea lespedeza

Introduction

Recurring fire throughout the central United States played an important role in the formation and preservation of the tallgrass prairie. Gleason (1913) suggested that the modern distribution of forests and prairies could be explained by historical fire patterns. When fire was withheld from the landscape for an extended period, trees and shrubs began to encroach upon the prairie (Bragg and Hulbert, 1976). Historically, the tallgrass prairie included 170 million acres of native rangeland; however, Euro-American settlement and agricultural advancements were concomitant with a shift from native grasslands to farmland (Middendorf et al., 2009). Today, less than 4% of the original tallgrass prairie remains, much of which is located in the Kansas

Flint Hills (Samson and Knopf, 1994). The preservation of this dynamic ecosystem is essential for the conservation of native grassland plants and animals.

Traditionally, ranchers in the Flint Hills apply annual spring-season prescribed fire and graze yearling beef cattle through the summer growing season. Early research focused on spring-season prescribed fire to determine a burn date where yearling stocker cattle growth performance and native C4 grass production could be optimized. Anderson et al. (1970) reported greater levels of decreaser plant species (i.e., big bluestem, little bluestem, Indiangrass, and switchgrass) and increased weight gains of yearling stocker cattle when pastures were burned in late spring (1 May) compared with non-burned pastures or pastures burned in early spring (20 March). When evaluating the effects of intensive-early stocking and season-long stocking, Smith and Owensby (1978) indicated intensive-early stocking systems increased the proportion of big bluestem, maximized performance of cattle grazing early in the growing season, and improved grazing distribution compared with season-long stocking systems. These data led to the recommendation that annual spring-season prescribed fire followed by intensive-early stocking be used to maximize financial margins in yearling cattle grazing systems in the tallgrass prairie; both of these practices are used commonly by ranchers across the Flint Hills today.

Today, an average of 2.1 million acres of native Flint Hills rangeland are burned each year from mid-March to early May (KDHE, 2020). In 2003, smoke produced from burning in the Flint Hills traveled to Kansas City 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 burning in the Flint Hills. In addition, sericea lespedeza likely proliferates with exclusive use of annual spring-season prescribed fire (Alexander, 2018). Sericea lespedeza was initially introduced into southeast Kansas in the 1930s for its soil conservation properties; however, the highly prolific and invasive forb has since degraded approximately 2,500 km^2 of Kansas prairie (Ohlenbusch et al., 2007; KDA, 2018).

When evaluating alternative methods for sericea lespedeza control, Alexander (2018) observed a reduction in sericea lespedeza basal frequency, seed production, and vigor in pastures burned later in the year (i.e., August-September) compared with those burned in the spring. Furthermore, summer-season prescribed fire increased overall species richness and forb diversity compared with spring prescribed fire (Alexander, 2018). Similarly, Weir and Scasta (2017) indicated fire applied in September or October increased forb abundance and decreased woody plant cover compared with fire applied at any other time of year. Despite optimistic reports from Alexander (2018) and Weir and Scasta (2017), ranchers have voiced concerns that mid- or late-summer prescribed fire may negatively affect native C4 grass populations or root carbohydrate reserves in key native tallgrass plant species. Therefore, the objective of this experiment was to document the effects of prescribed-fire timing on native plant composition and root carbohydrate concentrations of key tallgrass plant species over a 7-year period. This manuscript reports observations after 3 complete years of plant data collection.

Materials and Methods

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 rangeland and is fenced into 18 grazing units that range in size from 12 to 30 ha.

Major soil types at the Beef Stocker Unit were 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, 2020). Historically, spring-season prescribed fire was applied and the site was stocked with yearling beef cattle for the late-spring and early-summer grazing season. Big bluestem, Indiangrass, and sideoats grama were the predominant grasses and accounted for over 50% of the pre-treatment basal vegetation cover.

Using a completely randomized design, pastures were grouped by watershed and each watershed was assigned to 1 of 3 prescribed-fire treatments (n = 6 pastures per treatment): spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or fall (2 October ± 9.9 d). Prescribed burns were applied on or near target dates for 2 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 $km \cdot h^{-1}$; surface wind direction = steady and away from urban areas; mixing height ≥ 550 m; transport wind speed = 13 to 33 $km \cdot h^{-1}$; 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. Pastures were grazed for 90 days from early May to early August by yearling beef cattle at a targeted stocking density of 279 kg live-weight $\cdot$ ha^{-1}.

Botanical Composition and Soil Cover

Plant species composition and soil cover were evaluated annually utilizing a modified step-point technique (Owensby, 1973; Farney et al., 2017). A permanent 100-m transect was established in each pasture. Transects were laid out on Benfield-Florence complex soils in areas with less than 2% slope. Endpoints and the center of each transect were marked with orange survey stakes (Forestry Suppliers Inc., Jackson, MS) and GPS coordinates were recorded (Garmin, Olathe, KS). Along each transect, 100 points were independently and randomly selected using a step-point device. Each point was first categorized as a hit on bare soil, litter, or basal plant matter. Secondly, 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 tables 3.1, 3.2, and 3.3, respectively. Common names, scientific names, and taxonomic authorities were taken from 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 tallgrasses, C4 perennial mid-grasses, C4 perennial shortgrasses, 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, leguminous shrubs, and nectar-producing shrubs.

Sericea Lespedeza and Yellow Bluestem Aerial Frequency

Aerial frequencies of sericea lespedeza and yellow bluestem (*Bothriochloa ischaemum*) were evaluated annually. A 30 × 30-cm quadrat was placed parallel to the eastern or southern side of each transect and read at 1-m intervals (i.e., 100 observations per transect). Within each quadrat the presence of sericea lespedeza or yellow bluestem was recorded (i.e., yes or no). Aerial frequency (%) was then calculated by dividing the total number of quadrats within each transect that contained sericea lespedeza or yellow bluestem by total observations recorded and then multiplied by 100 (i.e., [{(total quadrats containing sericea lespedeza or yellow bluestem) ÷ 100 observations} x 100]).

Root Carbohydrate Concentrations

Root starch and total water-soluble carbohydrate concentrations in 3 native C4 grasses (i.e., big bluestem, little bluestem, and Indiangrass), and one leguminous, native forb (i.e., purple prairieclover) were evaluated annually. Individual roots and rhizomes were collected from each pasture (approximately 60 grams of wet material per species) using a steel spading fork (Bully Tools, Steubenville, Ohio) 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 (50ºC; 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 ºC 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, Ohio).

Statistical Analyses

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 models contained fixed effects for treatment and year and a random effect for pasture within treatment. All year × treatment interactions were not significant; 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 terms for treatment, year, and treatment × year. When the *F*-test 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

Soil Cover

Following the second full year of prescribed fire application, proportions of bare soil were greater ($P \leq 0.01$; Table 3.4) in the spring prescribed-fire treatment compared to the summer and fall prescribed-fire treatments; however, proportions of litter on the soil surface were greater ($P \leq 0.01$) in summer- and fall-burned pastures compared with spring-burned pastures. The difference in soil cover observed between treatments can likely be attributed to the length of time since prescribed fire application. Soil cover was evaluated each year in late June and early July. As time since prescribed fire decreased, the proportions of bare soil increased while litter cover on the soil surface increased. Total basal vegetation cover did not differ (P = 0.22) between prescribed-fire treatments.

In a similar study, Alexander (2018) did not observe differences in bare soil, litter, or total basal plant cover between pastures burned in April, August, and September. Similarly, Gatson (2018) reported no differences in soil cover between non-burned plots and those burned in September. In both studies, soil cover was evaluated in October. Measuring soil cover after August and September prescribed fires were applied is likely why no differences in the proportions of bare soil and litter on the soil surface were detected.

Hanks and Anderson (1957) observed a reduction in water infiltration in burned plots compared with non-burned plots. Following several days of precipitation between 30 September and 14 October, 83% of total rainfall was absorbed into the soil in non-burned plots; however, only 37, 39, 46, and 39% was absorbed into the soil of early-spring, mid-spring, late-spring, and late-fall burned plots, respectively

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. Results from our experiment were interpreted to suggest that pastures burned in the summer or fall could have greater potential for water absorption during periods of high precipitation compared to those pastures burned in the spring because of differences in litter accumulation on the soil surface.

Botanical Composition

When plant-species composition was evaluated, total graminoid cover did not differ (P = 0.15; Table 3.5) 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 fall-burn treatment, whereas spring-burn pastures were intermediate to and not different from summer and fall. Differences in native grass cover between fire regimes could potentially be explained by the impact of prescribed fire timing on Indiangrass. Basal cover of

Indiangrass did not change ($P < 0.27$; Figure 3.1) from year to year in the spring and summer prescribed fire treatments. Conversely, basal cover of Indiangrass was greater ($P < 0.01$) in the fall-fire regime in year 1 compared with the spring and summer fire regimes; however, fall prescribed fire was associated with decreased ($P < 0.01$) basal cover of Indiangrass from year 1 to year 3, to the degree that summer-burned pastures had greater ($P < 0.01$) proportions of Indiangrass in year 3 than fall-burned pastures.

Although total basal cover of C4 grasses did not differ ($P = 0.23$; Table 3.5) between fire treatments, differences within C4 grass growth forms were detected. Perennial C4 tallgrass basal cover tended to be greater ($P = 0.07$; Table 3.5) in the summer-burn treatment compared with the spring-burn treatment. 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 fall treatment. Furthermore, spring prescribed fire was associated with increased ($P = 0.01$) basal cover of perennial C4 shortgrasses compared with summer or fall prescribed fire.

To explain the differences observed within C4 growth forms, we considered the effects of prescribed fire timing on basal cover of individual plant species. Basal cover of sideoats grama (i.e., a C4 mid-grass) did not change ($P = 0.17$; Figure 3.2) 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 fall prescribed-fire treatments. By year 3, basal cover of sideoats grama was greater ($P = 0.04$; Figure 3.2) in the spring and summer prescribed-fire treatments than the fall prescribed-fire treatment. When C4 shortgrasses were evaluated, basal cover of hairy grama tended to increase ($P = 0.07$; Figure 3.3) 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 fall prescribed fire was associated with decreased (*P* = 0.05; Figure 3.3) basal cover of hairy grama from year 1 to year 3. Furthermore, basal cover of hairy grama was more than 4 times greater (*P* < 0.01) in the spring prescribed fire treatment in year 2 compared with the summer and fall prescribed fire treatments. The decrease over time in sideoats grama basal cover observed in fall-burned pastures and the increased cover of hairy grama observed in spring-burned pastures in year 2 likely contributed to the overall treatment differences in C4 mid-grass and shortgrass cover (Table 3.5).

Total forb, native forb, introduced forb, perennial forb, leguminous forb, and sericea lespedeza basal covers did not differ ($P \geq 0.17$; Table 3.6) between prescribed fire treatments. Conversely, basal cover of annual forbs was greater (*P* = 0.03) in the fall fire treatment compared with the spring fire treatment, whereas the summer fire treatment was intermediate to and not different from fall and spring. Basal cover of nectar-producing forbs was greater (*P* = 0.02) also in fall-burned pastures compared with spring- or summer-burned pastures. These observations were interpreted to indicate that fall-season prescribed fire may be of particular benefit to grassland-obligate invertebrates and the native birds that feed upon them (Ogden et al., 2019).

When total shrub basal cover was evaluated, spring prescribed fire tended (*P* = 0.08; Table 3.7) to be associated with lesser total shrub basal cover compared with fall prescribed fire; however, no differences (*P* = 0.11) in increaser shrub basal cover was detected between treatments. Basal covers of leguminous shrubs and nectar-producing shrubs were numerically larger ($P \geq 0.13$) in summer- and fall-burned pastures than 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 cover 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 non-grazed plots burned 48 times in 56 years 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 non-grazed 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-November). Weir and Scasta (2017) indicated that C4 tallgrass 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-October was the only treatment that reduced woody plant cover when compared with fire applied at other times of year. Alexander (2018) and Reemets et al. (2019) reported decreases in sericea lespedeza basal cover and yellow bluestem cover, respectively, when late summer (i.e., August-September) prescribed fire was applied compared with spring prescribed fire or non-burned treatments. In addition, Alexander (2018) observed in increase in overall plant species richness and forb diversity in non-grazed plots when August or September prescribed fire was applied compared with spring prescribed fire.

Alexander (2018) also indicated that late summer (1 September) prescribed fire decreased basal cover of big bluestem and increased basal cover of little bluestem compared with spring (1 April) or summer (1 August) prescribed fire. In our experiment, basal cover of big bluestem did not differ (P = 0.80) between prescribed fire treatments; whereas basal cover of little bluestem was greatest (P = 0.03) in spring-burn pastures, intermediate in fall-burn pastures, and least in summer-burn pastures (data not shown). These data were interpreted to suggest that the addition of grazing to native pastures burned in summer and fall may have influenced basal covers of big bluestem and little bluestem. Alexander (2018) reported also that basal cover of Indiangrass was greater in non-grazed native pastures burned in August than in non-grazed pastures burned in early September. We observed similar trends in our experiment where basal cover of Indiangrass decreased over time in the fall prescribed-fire treatment. We interpreted these data to suggest that fall prescribed fire may be associated with negative impacts on Indiangrass populations.

Sericea Lespedeza and Yellow Bluestem Frequency

The total number of 30 × 30-cm quadrats (n = 100 per transect) that contained sericea lespedeza or yellow bluestem did not differ (P = 0.13; Table 3.8) between prescribed fire treatments. When evaluating alternative methods for sericea lespedeza control, Alexander (2018) reported a reduction in the proportion of 30 × 30-cm quadrats that contained sericea lespedeza in pastures that were burned in mid- or late-summer compared with those burned in the spring. Similarly, sericea lespedeza frequency and vigor were reduced when mid- or late-summer prescribed fire was applied in moderately-degraded tallgrass prairie (Gatson, 2018). In year 1 of our experiment, sericea lespedeza was recorded along transects in the spring prescribed-fire treatment. Yellow bluestem was detected within pastures assigned to all prescribed-fire treatments but not present along all transects. After 2 years of prescribed fire application, both sericea lespedeza and yellow bluestem were recorded along transects in the spring treatment; however, neither species was present along transects assigned to summer or fall prescribed-fire treatments.

Root Carbohydrate Reserves

The impact of summer or fall prescribed fire (i.e., August-October) on root carbohydrate concentrations of key native tallgrass 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, and Indiangrass, whereas major forb species included purple prairieclover and dotted gayfeather. 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 easily throughout our sampling period.

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 ($P \geq 0.24$; Table 3.9 and Table 3.10) between prescribed-fire treatments. Owensby et al. (1970) evaluated the effects of late-spring fire on total carbohydrate concentrations in big bluestem. In comparing non-grazed 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 from burned or non-burned plots and plots clipped in June, July, August, or September. Roots from plots burned and clipped in June, July, or August had lesser total carbohydrate concentrations than roots from non-burned plots clipped at the same times; however, root carbohydrate concentrations did not differ between non-burned and burned plots clipped 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-year period, total nonstructural carbohydrate levels in big bluestem root samples were less in the intensive-early stocking treatment from June 1 until August 15 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 effects on root carbohydrate reserves in key native tallgrass species.

Implications

Results following 2 cycles of prescribed-fire treatments and grazing were interpreted to suggest that summer or fall prescribed fire can be applied without significant negative effects on the tallgrass prairie ecosystem. Shifting the timing of prescribed fire from spring to late summer or early fall did not reduce root carbohydrate concentrations in key native tallgrass plants. In addition, only small changes in rangeland plant composition were observed between prescribed fire treatments. Summer-burned pastures had greater proportions of native graminoid plant species and tended to have greater proportions of C4 perennial grasses compared with fall-burned pastures. These data were interpreted to suggest that land managers could use summer-season prescribed fire to manage sericea lespedeza infestations without damaging growth potential of native C4 plant populations. The long-term impacts of prescribed fire timing on botanical composition and root carbohydrate reserves of key tallgrass species will continue to be evaluated over the next 4 years. In addition, 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.

Literature Cited

Alexander, J. A. 2018. Effects of prescribed fire timing on vigor of sericea lespedeza in the Kansas Flint Hills. M.S. Thesis. Kansas State University, Manhattan, KS, USA.

Anderson K. L., E. F. Smith, and C. E. Owensby. 1970. Burning bluestem range. J. Range Manage. 23: 81-92.

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

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

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.

Gleason, H. A. 1913. The relation of forest distribution and prairie fires in the middle west. J. Torrey Bot. Soc. 13(8):173-181.

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

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.

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

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.

[KDHE] Kansas Department of Health and Environment. 2010. Flint Hills smoke management plan. https://www.ksfire.org/health/ (Accessed 7 September 2020).

[KDHE] Kansas Department of Health and Environment. 2020. Flint Hills prescribed fire update. https://www.ksfire.org/new-media-archives/weeklyupdates/2020_Flint_Hills_Summary_May_15.pdf (Accessed 7 September 2020).

[KDA] Kansas Department of Agriculture, 2018. 2018 Noxious weed survey data. https://agriculture.ks.gov/docs/default-source/pp-noxious-weed-control/copy-of-surveydatad293eb002e6262e1aa5bff0000620720.xlsx?sfvrsn=1df189c1 (Accessed 4 September 2020).

Middendorf, G., T. A, Becerra, and D. Cline. 2009. Transition and resilience in the Kansas Flint Hills. Online J. Rural Res. Policy. 4(3):1-28.

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. https://doi.org/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 Agric. Exp. Sta. MF-2408. https://www.bookstore.ksre.ksu.edu/pubs/mf2408.pdf (Accessed 4 September 2020).

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.

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

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.

Reemts, C. M., W. M. McCaw, T. A. Greene, and M. T. Simmons. 2019. Short-term control of an invasive C_4 grass with late-summer fire. Rangeland Ecol. Manage. 72:182-188.

Samson, F. and Knopf, F. 1994. Prairie conservation in North American. Biosci. 44:418-421.

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.

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. Range. Ecol. Manage. 72:126-135.

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.

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

[USDA-NRCS] US Department of Agriculture - Natural Resources Conservation Service, 2020. Web soil survey. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (Accessed 14 July 2020).

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.

Figures

Figure 3.1. Effects of prescribed fire timing on basal cover of Indiangrass in the Kansas Flint Hills. Eighteen pastures were grouped by watershed and assigned to 1 of 3 prescribed-fire treatments: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or fall (2 October ± 9.9 d). Treatments were applied on or near target dates for 2 consecutive years. Basal cover of Indiangrass did not change ($P < 0.27$) from year to year in the spring and summer prescribed treatments. Basal cover of Indiangrass was initially greater ($P < 0.01$) in the fall fire regime compared with the spring and summer fire regimes; however, Indiangrass sharply declined ($P < 0.01$) from year 1 to year 3 in the fall prescribed-fire treatment. By year 3, basal cover of Indiangrass was greater ($P < 0.01$) in the summer fire treatment compared with the fall fire treatment. Means with unlike superscripts differ ($P \leq 0.05$).

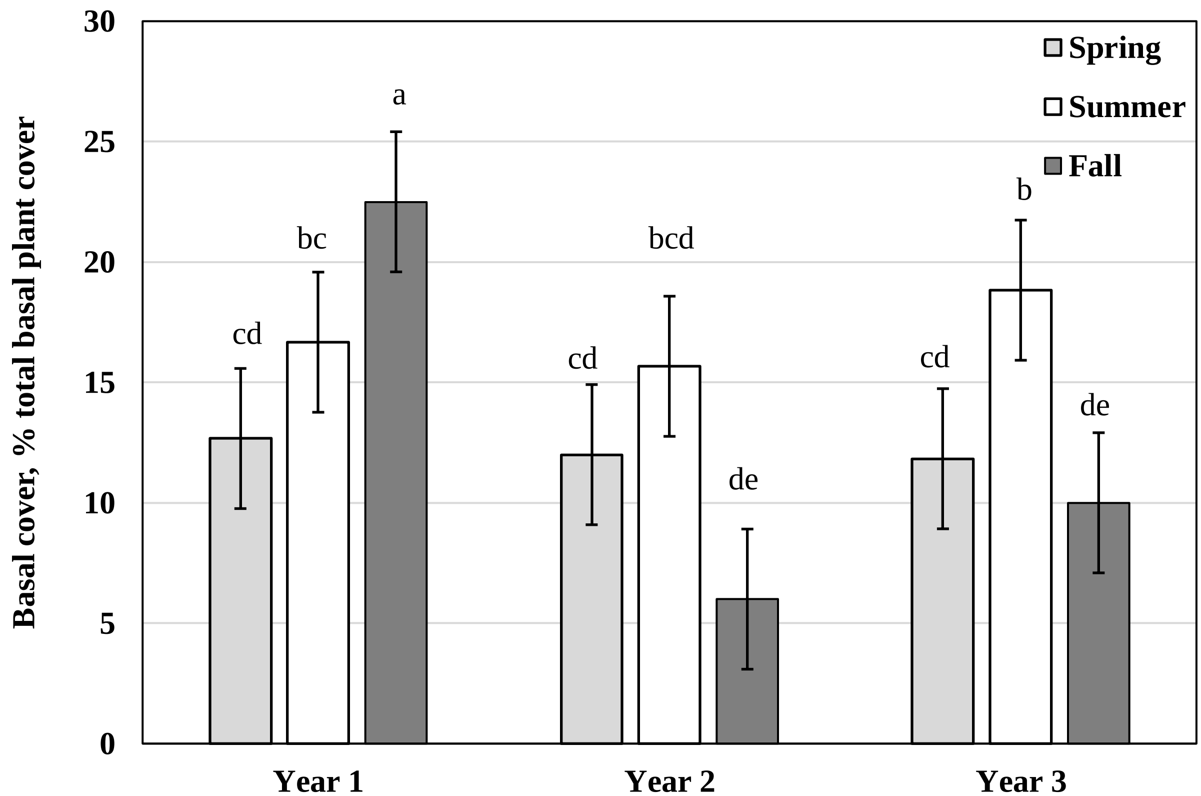


Figure 3.2. Effects of prescribed fire timing on basal cover of sideoats grama in the Kansas Flint Hills. Eighteen pastures were grouped by watershed and assigned to 1 of 3 prescribed-fire treatments: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or fall (2 October ± 9.9 d). Treatments were applied on or near target dates for 2 consecutive years. Basal cover of sideoats grama did not change ($P = 0.17$) in the spring fire treatment from year to year. In contrast, basal cover of sideoats grama decreased ($P < 0.01$) from year 1 to year 3 in both the summer and fall prescribed-fire treatments. In year 3, basal cover of sideoats grama was greater ($P = 0.04$) in spring- and summer-burned pastures compared with fall-burned pastures. Means with unlike superscripts differ ($P \leq 0.05$).

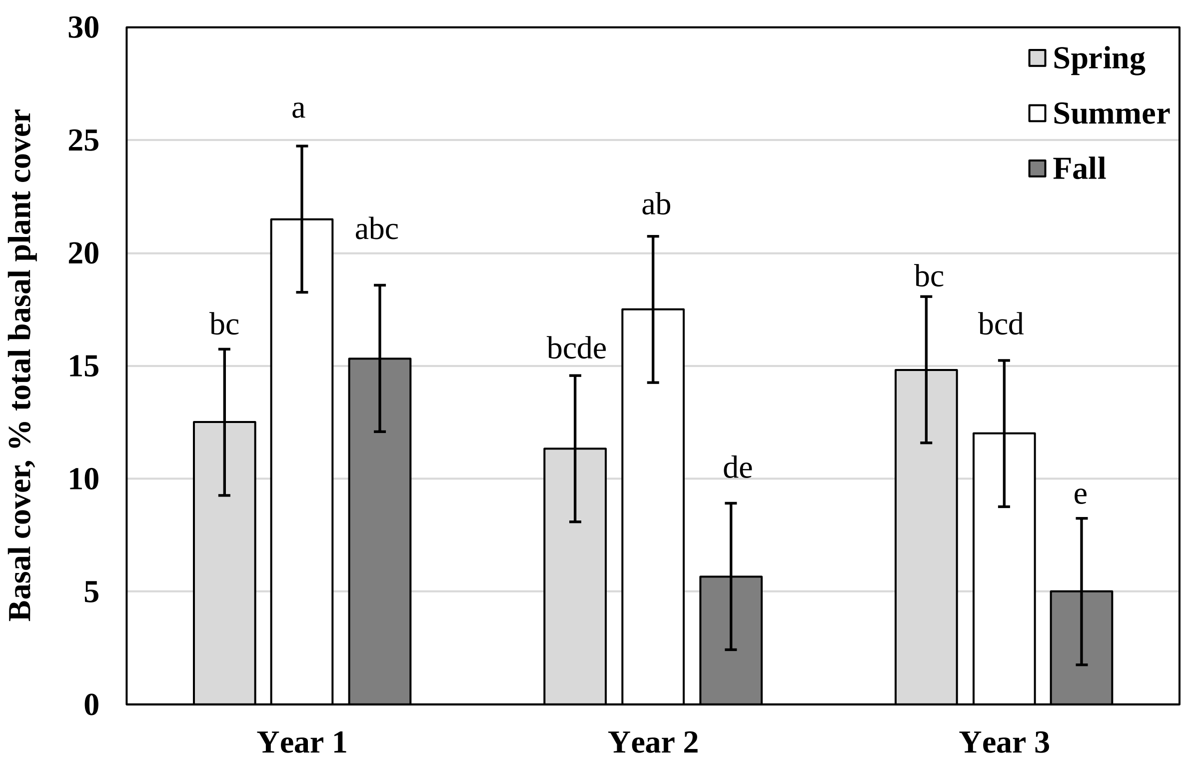
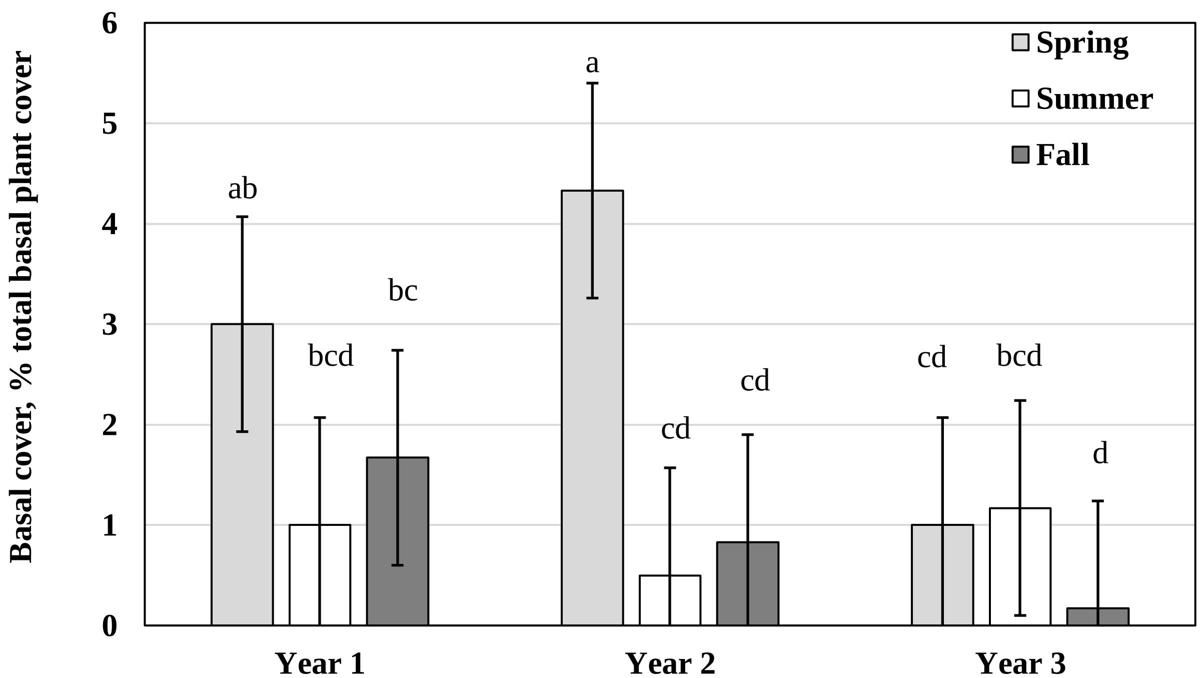


Figure 3.3. Effects of prescribed fire timing on basal cover of hairy grama in the Kansas Flint Hills. Eighteen pastures were grouped by watershed and assigned to 1 of 3 prescribed-fire treatments: spring (7 April ± 2.1 d), summer (21 August ± 5.7 d), or fall (2 October ± 9.9 d). Treatments were applied on or near target dates for 2 consecutive years. Basal cover of hairy grama tended to increase ($P = 0.07$) from year 1 to year 2 in the spring prescribed fire treatment; however, spring prescribed fire deceased ($P < 0.01$) basal cover from year 2 to year 3. In the summer-fire treatment, basal cover of hairy grama did not change ($P = 0.36$) from year to year. In contrast, basal cover of hairy grama decreased ($P = 0.05$) from year 1 to year 3 in fall-burned pastures. In year 2, basal cover of hairy grama was greater ($P < 0.01$) in the spring-fire treatment compared with the summer- and fall-fire treatments. Means with unlike superscripts differ ($P \leq 0.05$).



Tables

Table 3.1. Graminoid species encountered at the Kansas State Beef Stocker Unit during the 2018, 2019, and 2020 summer growing seasons

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	n.a.
Hairy dichanthelium	*Dichanthelium acuminatum*	Perennial	Native	C3	n.a.
Hairy grama	*Bouteloua hirsuta*	Perennial	Native	C4	Short
Indiangrass	*Sorghastrum nutans*	Perennial	Native	C4	Tall
Kentucky bluegrass	*Poa pratensis*	Perennial	Introduced	C3	n.a.
Little bluestem	*Schizachyrium scoparium*	Perennial	Native	C4	Mid
Plains muhly	*Muhlenbergia cuspidata*	Perennial	Native	C4	Mid
Prairie dropseed	*Sporobolus heterolepis*	Perennial	Native	C4	Mid
Prairie junegrass	*Koeleria macrantha*	Perennial	Native	C3	n.a.
Purple lovegrass	*Eragrostis spectabilis*	Perennial	Native	C4	n.a.
Purpletop	*Tridens flavus*	Perennial	Native	C4	Tall
Sand dropseed	*Sporobolus cryptandrus*	Perennial	Native	C4	Tall
Scribner panicum	*Dichanthelium oligosanthes*	Perennial	Native	C3	n.a.
Sedges	*Carex spp.*	Perennial	Native	C3	n.a.
Sideoats grama	*Bouteloua curtipendula*	Perennial	Native	C4	Mid
Smooth bromegrass	*Bromus inermis*	Perennial	Introduced	C3	n.a.
Switchgrass	*Panicum virgatum*	Perennial	Native	C4	Tall
Tall dropseed	*Sporobolus compositus*	Perennial	Native	C4	Mid
Tall fescue	*Schedonorus arundinaceus*	Perennial	Introduced	C3	n.a.
Tumblegrass	*Schedonnardus paniculatus*	Perennial	Native	C4	n.a.
Western wheatgrass	*Pascopyrum smithii*	Perennial	Native	C3	n.a.
Windmill grass	*Chloris verticillata*	Perennial	Native	C4	Short
Witchgrass	*Panicum capillare*	Annual	Native	C4	n.a.
Yellow bluestem	*Bothriochloa ischaemum*	Perennial	Introduced	C4	Mid

Table 3.2. Forb species encountered at the Kansas State Beef Stocker Unit during the 2018, 2019, and 2020 summer growing seasons

Common Name	Scientific Name	Growth	Status
American germander	*Teucrium canadense*	Perennial	Native
Annual fleabane	*Erigeron annuus*	Annual	Native
Aromatic aster	*Symphyotrichum oblongifolium*	Perennial	Native
Baldwin's ironweed	*Vernonia baldwinii*	Perennial	Native
Betony noseburn	*Tragia betonicifolia*	Perennial	Native
Blackeyed susan	*Rudbeckia hirta*	Perennial	Native
Black medic	*Medicago lupulina*	Annual	Introduced
Blacksamson echinacea	*Echinacea angustifolia*	Perennial	Native
Blue wildindigo	*Baptisia australis*	Perennial	Native
Breadroot scurf-pea	*Pediomelum esculentum*	Perennial	Native
Butterfly milkweed	*Asclepias tuberosa*	Perennial	Native
Carolina cranesbill	*Geranium carolinianum*	Annual	Native
Carolina horsenettle	*Solanum carolinense*	Perennial	Native
Catclaw sensitivebriar	*Mimosa nuttallii*	Perennial	Native
Catnip noseburn	*Tragia ramosa*	Perennial	Native
Clammy groundcherry	*Physalis heterophylla*	Perennial	Native
Common chickweed	*Stellaria media*	Annual	Introduced
Common groundcherry	*Physalis longifolia*	Perennial	Native
Common ragweed	*Ambrosia artemisiifolia*	Annual	Native
Daisy fleabane	*Erigeron strigosus*	Annual	Native
David’s toothed spurge	*Euphorbia dentata*	Annual	Native
Deptford pink	*Dianthus armeria*	Annual	Introduced
Dotted gayfeather	*Liatris punctata*	Perennial	Native
False boneset	*Brickellia eupatorioides*	Perennial	Native
Field pussytoes	*Antennaria neglecta*	Perennial	Native
Fringed puccoon	*Lithospermum incisum*	Perennial	Native
Fringeleaf ruellia	*Ruellia humilis*	Perennial	Native
Goat’s beard	*Tragopogon dubius*	Biennial	Native
Green milkweed	*Asclepias viridis*	Perennial	Native
Grey-green wood sorrel	*Oxalis dillenii*	Perennial	Native
Grooved flax	*Linum sulcatum*	Annual	Native
Ground-plum milk-vetch	*Astragalus crassicarpus*	Perennial	Native
Hairy aster	*Symphyotrichum pilosum*	Perennial	Native
Heath aster	*Symphyotrichum ericoides*	Perennial	Native
Johnny-jump-up	*Viola bicolor*	Annual	Native
Long-bearded hawkweed	*Hieracium longipilum*	Perennial	Native
Louisiana sagewort	*Artemisia ludoviciana*	Perennial	Native
Low milkvetch	*Astragalus lotiflorus*	Perennial	Native
Marestail	*Conyza canadensis*	Annual	Native
Mint-leaf beebalm	*Monarda fistulosa*	Perennial	Native
Missouri evening primrose	*Oenothera macrocarpa*	Perennial	Native
Missouri goldenrod	*Solidago missouriensis*	Perennial	Native
Narrowleaf tickclover	*Desmodium sessilifolium*	Perennial	Native
Nodding green violet	*Hybanthus verticillatus*	Perennial	Native
Old plainsman	*Hymenopappus scabiosaeus*	Perennial	Native
Oneseed croton	*Croton monanthogynus*	Annual	Native
Pale comandra	*Comandra umbellata*	Perennial	Native
Pigweed spp.	*Amaranthus spp.*	Annual	Native
Pitcher sage	*Salvia azurea*	Perennial	Native
Plains wildindigo	*Baptisia australis*	Perennial	Native
Plain-seeded plantain	*Plantago virginica*	Annual	Native
Prairie groundcherry	*Physalis pumila*	Perennial	Native

Table 3.2 continued

Common name	Scientific name	Growth	Status
Prairie groundsel	*Senecio plattensis*	Perennial	Native
Prairie pepper-grass	*Lepidium virginicum*	Annual	Native
Purple poppymallow	*Callirhoe involucrata*	Perennial	Native
Purple prairieclover	*Dalea purpurea*	Perennial	Native
Red river scaleseed	*Spermolepis inermis*	Annual	Native
Rough false pennyroyal	*Hedeoma hispida*	Annual	Native
Roundhead lespedeza	*Lespedeza capitate*	Perennial	Native
Roundhead prairieclover	*Dalea multiflora*	Perennial	Native
Sericea lespedeza	*Lespedeza cuneata*	Perennial	Introduced
Silky aster	*Symphyotrichum sericeum*	Perennial	Native
Silverleaf scurfpea	*Pediomelum argophyllum*	Perennial	Native
Sleepy catchfly	*Silene antirrhina*	Annual	Native
Snow-on-the-mountain	*Euphorbia marginata*	Annual	Native
Spider milkweed	*Asclepias viridis*	Perennial	Native
Spotted spurge	*Chamaesyce maculata*	Annual	Native
Stiff goldenrod	*Solidago rigida*	Perennial	Native
Stiff sunflower	*Helianthus pauciflorus*	Perennial	Native
Tall goldenrod	*Solidago altissima*	Perennial	Native
Tall thistle	*Cirsium altissimum*	Annual	Native
Venus looking glass	*Triodanis perfoliata*	Annual	Native
Violet lespedeza	*Lespedeza violacea*	Perennial	Native
Violet wood sorrel	*Oxalis violacea*	Perennial	Native
Virginia copperleaf	*Acalypha virginica*	Annual	Native
Virginia groundcherry	*Physalis virginiana*	Perennial	Native
Viscid euthamia	*Euthamia gymnospermoides*	Perennial	Native
Warty spurge	*Euphorbia spathulata*	Annual	Native
Wavyleaf thistle	*Cirsium undulatum*	Perennial	Native
Western ragweed	*Ambrosia psilostachya*	Perennial	Native
Western yarrow	*Achillea millefolium*	Perennial	Native
White prairieclover	*Dalea candida*	Perennial	Native
Whorled milkweed	*Asclepias verticillata*	Perennial	Native
Whorled polygala	*Polygala verticillata*	Annual	Native
Wild alfalfa	*Psoralidium tenuiflorum*	Perennial	Native
Wild licorice	*Glycyrrhiza lepidota*	Perennial	Native
Wild strawberry	*Fragaria virginiana*	Perennial	Native
Wooly verbena	*Verbena stricta*	Perennial	Native

Table 3.3. Shrub species encountered at the Kansas State Beef Stocker Unit during the 2018, 2019, and 2020 summer growing seasons

Common Name	Scientific Name	Growth	Status
Arkansas rose	*Rosa arkansana*	Perennial	Native
Buckbrush	*Symphoricarpos orbirculatus*	Perennial	Native
Elm	*Ulmus spp.*	Perennial	Native
Leadplant	*Amorpha canescens*	Perennial	Native
New Jersey tea	*Ceanothus americanus*	Perennial	Native
Roughleaf dogwood	*Cornus drummondii*	Perennial	Native
Smooth sumac	*Rhus glabra*	Perennial	Native

Table 3.4. Effects of prescribed fire timing on bare soil, litter, and basal vegetation cover in the Kansas Flint Hills

	Prescribed fire season				
Item	Spring (7 April)	Summer (21 August)	Fall (2 October)	SEM*	*P*-value†
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

* Mixed-model standard error of the mean (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 3.5. Effects of prescribed fire timing on graminoid composition in native tallgrass prairie

Item	Prescribed fire season				
	Spring (7 April)	Summer (21 August)	Fall (2 October)	SEM*	*P*-value†
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 tallgrasses	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 shortgrasses	3.7[a]	1.2[b]	1.3[b]	0.83	0.01

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

† Treatment main effect.

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

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

Table 3.6. Effects of prescribed fire timing on forb composition in native tallgrass prairie

Item	Prescribed fire season: Spring (7 April)	Summer (21 August)	Fall (2 October)	SEM*	*P*-value†
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
Sericea lespedeza	0.14	0.0	0.0	0.126	0.42

* Mixed-model standard error of the mean (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 3.7. Effects of prescribed fire timing on shrub species composition in the native tallgrass prairie

Item	Prescribed fire season			SEM[*]	*P*-value[†]
	Spring (7 April)	Summer (21 August)	Fall (2 October)		
Total shrub cover	0.5[y]	1.2[yz]	1.5[z]	0.43	0.08
Increaser shrubs	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

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

[†] Treatment main effect.

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

Table 3.8. Effects of prescribed fire timing on aerial frequency of sericea lespedeza (*Lespedeza cuneata*) and yellow bluestem (*Bothriochloa ischaemum*) during the summer growing season

	Prescribed fire season				
Item*	Spring (7 April)	Summer (21 August)	Fall (2 October)	SEM†	*P*-value‡
Sericea lespedeza, %	1.85	0.00	0.00	0.995	0.13
Yellow bluestem, %	3.51	0.00	0.00	2.833	0.37

* Aerial frequency calculated as [{(total quadrats containing sericea lespedeza or yellow bluestem) ÷ 100 observations} x 100].

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

‡ Treatment main effect.

Table 3.9. Effects of prescribed fire timing on root starch concentrations in key native tallgrass species during the summer growing season

Item	Prescribed fire season: Spring (7 April)	Summer (21 August)	Fall (2 October)	SEM*	*P*-value†
Big bluestem, % DM	2.57	3.22	2.00	0.92	0.43
Little bluestem, % DM	1.53	1.57	1.28	0.57	0.86
Indian grass, % DM	3.19	2.09	1.81	1.22	0.49
Purple prairieclover, % DM	4.92	3.39	3.59	1.23	0.41

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

† Treatment main effect.

Table 3.10. Effects of prescribed fire timing on root water-soluble carbohydrate concentrations in key native tallgrass species during the summer growing season

	Prescribed fire season				
Item	Spring (7 April)	Summer (21 August)	Fall (2 October)	SEM*	*P*-Value†
Big bluestem, % DM	3.31	4.57	4.02	0.78	0.27
Little bluestem, % DM	3.15	4.44	3.34	0.98	0.37
Indiangrass, % DM	5.11	3.47	3.95	1.29	0.42
Purple prairieclover, % DM	4.55	3.36	5.24	1.08	0.24

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

†Treatment main effect.